UNIVERSITY OF TRENTO

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KHANITIN JORNKOKGOUD

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF
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IN RESEARCH AND STATISTICS IN COGNITIVE SCIENCE
AT BURAPHA UNIVERSITY
AND FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN COGNITIVE SCIENCE
AT THE UNIVERSITY OF TRENTO
UNDER A BI-NATIONALLY SUPERVISED DOCTORAL AGREEMENT
(CO-TUTELLE DE THÈSE)
BETWEEN BURAPHA UNIVERSITY AND THE UNIVERSITY OF TRENTO
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This study evaluates the effectiveness of a Computerized Multicomponent Cognitive Stimulation (CMCS) program, adapted from Cognitive Stimulation Therapy (CST), in improving cognitive functions, emotions, and quality of life in older adults with mild cognitive impairment (MCI). Ninety-three participants (mean age = 67.68 years) were randomly assigned to three groups: (1) the CMCS or computerized CST integrated with multisensory stimulation (MCST), (2) computerized CST (CST), and (3) a control group. Over ten weeks, participants in the intervention groups attended weekly 45-minute sessions. Cognitive functions were assessed using paired-associated learning tasks, verbal fluency tasks, Corsi-block tapping and mental rotation tasks, the Wisconsin Card Sorting Test, simple and choice reaction time tasks, and the sound-induced flash illusion task. EEG data were analyzed for band frequencies, and ERP components such as N1, P2, P3, N4, and P6 were explored. Additionally, depression, anxiety, and quality of life were measured. Data were analyzed primarily using analysis of covariance, with posttest scores as the dependent variable and pretest scores as the covariate.

Results showed significant improvements in learning and memory, language, visuospatial skills, psychomotor performance, and multisensory integration in the MCST group compared to the CST and control groups. Both intervention groups experienced notable reductions in depression and anxiety, with the MCST group showing greater efficacy. However, no significant changes were

observed in the quality of life post-intervention. EEG analyses indicated increased theta power in the occipital region during the resting state and enhanced P3 amplitude and latency changes during cognitive tasks, particularly in the frontal and central regions.

The findings suggest that CMCS, especially with integrated multisensory stimulation, effectively enhances cognitive functions and emotions in older adults with MCI. These results support the potential of computerized cognitive interventions to mitigate cognitive decline and emotional distress, contributing to dementia prevention. Further research is warranted to explore the long-term impacts and underlying mechanisms of these improvements.

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CHAPTER 1
INTRODUCTION

Statement and significance of the problem

Mild Cognitive Impairment (MCI) is the stage between normal aging and probable Alzheimer's disease (AD) (Petersen et al., 1997). AD is the most prevalent kind of dementia. It is a degenerative disease, which means it becomes worse with time (Alzheimer's Association, 2019) and is one of society's most expensive long-term illnesses in other countries across the world, with 60 % of costs related to family or social care (Gauthier et al., 2021; Kongpakwattana et al., 2019). Estimated $8,014 annual costs of AD care per Thai patient (Kongpakwattana et al., 2019). MCI is an emerging health concern in Thailand, reflecting global trends as the population ages. The prevalence of MCI in the Thai elderly is significantly revealed that approximately 15% of the elderly population in Thailand suffer from MCI, especially in a rural area is very high (up to 71%), with an annual progression rate of dementia estimated at around 12-18% (Griffiths et al., 2020; Senanarong et al., 2013; Thaipisuttikul et al., 2022). There is strong evidence of slowing disease progression for adults with MCI aged 65 and older, with a 7.5 % probability of getting dementia in the first year after diagnosis. Further, the risk of acquiring dementia increases to roughly 15 % in the second year and 20 % in the third year (Tangalos & Petersen, 2018). As per potential risk factors for mortality, MCI increases the probability of death. Specifically, MCI was responsible for 10.7% of deaths in 65–74, 16.0 % in people aged 75–84, and 24.2 % in those aged 85. Moreover, mortality risks from cerebrovascular disease, respiratory disease, and external causes were higher in the older adults with MCI than in the cognitively normal elderly (Bae et al., 2018).

MCI increases depression symptoms and decreases quality of life and avoidant coping strategies such as downplaying the severity of one's diagnosis and retreating from leisure activities (Anderson, 2019). Further, having trouble navigating to an unfamiliar location, receiving collateral information about worsening work performance, finding words or names, not retaining information after reading a short text, having difficulty learning the names of new acquaintances, misplacing valuable

items, and having concentration issues have been mentioned in several studies (Qarni & Salardini, 2019). To be concerning depression and anxiety are widespread in MCI patients. They are significant predictors of dementia progression, highlighting the necessity of evaluating depressive symptoms, as well as anxiety, in the early stages of cognitive impairment (Ma, 2020b).

Likewise**,** learning and memory, attention, language, visuospatial, executive, and psychomotor may be impaired in elderly persons with MCI (Knopman & Petersen, 2014; Petersen, 2004). The most prevalent subtype of MCI is amnestic MCI (aMCI), with a ratio of 2:1 compared with non-aMCI. In particular, Single domain aMCI refers to those individuals with significantly impaired memory who do not meet the criteria for dementia. Multiple domains of MCI complain only of memory loss; however, they may have additional subtle impairments in other cognitive domains. (Tangalos & Petersen, 2018). The subtype of MCI had a borderline statistically significant association with progression to dementia. Those with single nonmemory MCI or with multiple domains MCI were less likely to progress to dementia compared to patients with aMCI (Yaffe et al., 2006)

Sensory, perceptual, emotional, higher-order, and memory-related are all affected negatively by age-related changes (Humes & Young, 2016). When compared to younger individuals, healthy older persons generally exhibit an increase in the gain resulting from multisensory integration of redundant cross-sensory information (Murray et al., 2018). Multisensory integration is linked to structural changes in the aging brain. Gray matter volume in the right angular gyrus is identified as a potential “cross-modal hub” linked to age-related changes in multisensory perception (Hirst et al., 2021). Furthermore, Cognitive function varies with age, and numerous studies have linked sensorimotor impairments to this. Reduced visual or auditory processing is one of them (Niederstrasser et al., 2016). The functional cognitive deficits of patients with MCI contribute to the differences in performance enhancements of audiovisual integration compared with normal aging. When they are performing more than one sensory activity, hearing, and vision, at the same time, this will affect the selected attention and the deviled attention (Wu et al., 2012).

The functioning of the nervous system in the cerebral cortex acts on visualization of the temporal lobe associated with hearing and the parietal lobe. It is

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responsible for transmitting and assisting the functioning of the posterior and temporal lobes. There is a response to the image; the sound lasts longer and decreases sensory accuracy (Wu et al., 2012). Moreover, information from numerous sensory systems is processed in the superior colliculus region, mainly auditory and somatosensory and visual. Multisensory processing is interestingly standard among the principal goals of intercollicular regions' output routes. Parts of the auditory thalamus and the cochlear nucleus are also capable of multisensory processing. Cholinergic projections to the intercollicular areas are thought to play a significant role in modulating multisensory integration (Noftz et al., 2021). Cholinergic modulation is an essential mechanism behind complex actions because acetylcholine can coordinate the response of neural networks in numerous brain locations (Picciotto et al., 2012). Acetylcholine (ACh) has been linked to a variety of cognitive functions, including attention and sensory processing (Solari & Hangya, 2018). Therefore, cholinergic degeneration is associated with healthy aging and the cholinergic disruption that characterizes neurodegenerative diseases such as MCI and AD (Robbins, 2002).

Neuropathologies identified in MCI include atrophy of the medial temporal lobe, particularly the hippocampus and entorhinal cortex, the posterior cingulate cortex, and hypometabolism in the temporoparietal posterior cingulate cortices, and hypoperfusion of the parietal cortices and the hippocampus (Anderson, 2019). Currently, no approved pharmacologic treatments for MCI are available. Several studies have been conducted in the MCI spectrum, but none has successfully demonstrated effectiveness in reducing the progression from MCI to AD dementia (Petersen, 2016). However, numerous studies have found improvements in objective memory and other cognitive functions, as well as improvements in subjective memory (Anderson, 2019). These treatments usually teach people practical, everyday memory strategies and cognitive and social engagement in memory, facilitate the adoption of healthier lifestyles, and address coping strategies such as relaxation and preparing for the future (Anderson, 2019; Spector et al., 2001; Spector et al., 2003). Exercise and dietary treatments tend to be beneficial in boosting reserve in MCI patients, as do group psychoeducational programs that teach practical memory techniques (Anderson, 2019; Jiang et al., 2019). In particular, systematic reviews and meta-

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analyses show that cognitive intervention can increase their general cognitive function and specific cognitive functions such as memory, executive functioning, visuospatial capacity, attention, and processing speed (Sanjuán et al., 2020). Many observational studies have linked more cognitive stimulation to a lower risk of cognitive decline or older age at the start of dementia that cognitive stimulation programs improve cognition in patients with mild to severe dementia, independent of medication effects (Spector et al., 2001; Spector et al., 2003; Woods et al., 2006; Yamanaka et al., 2013). However, the trials were of varying quality, with tiny sample numbers in some cases and only a few elements of the randomization method apparent in others (Kelley, 2015).

Specifically, Cognitive stimulation intervention using reality orientation techniques and cognitive exercises employing an applied cognitive strategy, the primary target of memory stimulation, were found to benefit the memory abilities of elders with MCI (Wenisch et al., 2007). Moreover, Cognitive stimulation therapy (CST) showed significant improvements in cognition (Spector et al., 2003). The belief that continuous participation in a variety of mental activities improves cognitive and social functioning underpins CST treatments. According to empirical data, individuals who remain actively engaged in tasks that involve the use of cognitive abilities may have a decreased chance of acquiring dementia and a slower progression of cognitive impairment (Eckroth-Bucher & Siberski, 2009). CST has been found to enhance cognitive function and quality of life (QOL) in persons with mild-to-moderate dementia in the United Kingdom and cognition, mood, and elements of QOL in people with dementia in Japan (Yamanaka et al., 2013). However, it is necessary to adapt CST to different cultures by following the guidelines (Aguirre et al., 2014). Essential characteristics of cognitive stimulation aim for general cognitive improvement, using several techniques such as reality orientation, reminiscence, semantic associations, and usually group sessions. Nevertheless, the intervention may not be accessible to certain individuals who prefer to attend individual CST (iCST) sessions (Yates et al., 2017). Silva and colleagues discovered that in MCI or mild dementia, a home-based individual cognitive stimulation program could explain the improved cognition response. These data reveal that the lower the cognitive damage, the better the neuroplastic capacity and ability to learn and the potential to induce

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neurogenesis. Cognitive interventions should be implemented at the earliest stages of cognitive impairment (Silva et al., 2021).

According to deficits of older adults with MCI in audiovisual integration, multisensory stimulation has been applied as a non-pharmacological therapy that can be applied in older adults with any stage of dementia (Silva et al., 2016). Previous studies showed that after a multisensory group intervention, the effects on the cognitive status of older adults in the early stages of dementia showed a significant improvement. (Sánchez et al., 2013). In addition, multisensory integration can be reduced by temporal order judgment training that shows plasticity in older adults' temporal multisensory processing (Setti et al., 2014). Multisensory therapies are intended to provide patients with dementia with a wide range of sensory stimulation. It also includes therapies that integrate two distinct sensory stimuli, such as music and visual stimulation (Hayden et al., 2022). In a previous audiovisual study, the Taiko video game was used for audiovisual (AV) integrative training. The participants learned to play a Taiko drum (Japanese percussion instrument) to songs chosen through the Playstation 4 rhythm game "Taiko no Tatsujin." The MCI participants improved their attentional control ability (L. P. Lee et al., 2020). Furthermore, previous research showed that the presentation of sensory stimuli across four different sensory modalities could evoke increased ACh release in the hippocampus and frontal cortex (Acquas et al., 1996; Inglis & Fibiger, 1995). In particular, ACh, produced during behavioral activities, can influence the excitability of auditory cortex neurons. ACh discharge from the basal forebrain has been demonstrated to affect the consistency of spike firing and synchronization among neurons in the visual cortex, which might affect how cortical neurons multiplex sensory data. The temporal characteristics of multisensory integration may thus be changeable via attention and arousal processes (King & Walker, 2012).

The increased computerization of intervention programs is a step toward treatment uniformity. Computer-based intervention methods are cost-effective, non-invasive, and simple to execute, requiring little human and financial resources (Niederstrasser et al., 2016). In a systematic review and meta-analysis, the previous study on the effect of computerized cognitive training on cognitive outcomes in MCI was based on results from 18 randomized control trials and reported an average Mini-

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Mental State Examination (MMSE) score that showed improving cognition. There were effects on a particular performance outcome on a neuropsychological test that showed a small to moderate effect size in all domains but a large effect size in working memory and memory (Zhang et al., 2019). Cognitive intervention programs as a way of improving cognitive ability and emotional states and reducing subjective memory complaints in MCI (Faucounau et al., 2010).

Djabelkhir and colleagues studied the feasibility and acceptability of the computerized cognitive stimulation program (CCS) and computerized cognitive engagement programs. Both treatments were efficient and acceptable, allowing MCI patients to improve in several aspects of cognitive and psychosocial functioning. However, the effect sizes on free recall and Trail Making Test part A (TMT-A) were both moderate, favoring the CCS group (Djabelkhir-Jemmi et al., 2017). The further study explored whether a CCS induced differential effects in older adults with MCI according to the degree of white matter hyperintensities (WMH). Following the session, both groups improved on numerous cognitive tests. On psychological metrics, neither group improved, with the exception of motivation, which was initially intense but improved for both groups following the intervention (Djabelkhir-Jemmi et al., 2018). CCS is becoming more widely utilized as a standard approach for delivering non-pharmacological interventions to older adults with MCI (Sobral & Sobral, 2021).

Previous research shows the benefits of computerized cognitive stimulation applications in improving several cognitive functions. However, determining the effectiveness of non-pharmacological therapies can be challenging (Sobral & Sobral, 2021). They lack appraisal in brain activities and neuropsychological evaluation that correlates with specific cognitive functions in people with MCI.

From the biomarkers' point of view, the accumulation of beta-amyloid protein and the formation of neurofibrillary tangles are the two markers of AD (Djabelkhir-Jemmi et al., 2018). Biomarkers for AD and MCI pathology have been identified using magnetic resonance imaging (MRI) modalities. These can then be utilized to increase diagnosis accuracy (Chandra et al., 2019). According to growing evidence, white matter hyperintensities (WMH) appear to have a role in developing MCI and AD. WMH is visualized as an increased signal on T2-weighted fluid-attenuated

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inversion recovery MRI sequences (Djabelkhir-Jemmi et al., 2018). Furthermore, using fMRI in MCI patients, the fact that it is one of the few pathologies to exhibit brain changes at a structural level, which generally happens in neurodegenerative disorders, determines survival research on functional brain connections (Farràs-Permanyer et al., 2015). Comparatively low-cost electroencephalography (EEG) is also being investigated to detect MCI (Höller, 2021). Also, this technique has shown great potential in clinical practice to monitor and assess the intervention effects because it showed fair to excellent reliability (Ip et al., 2018). Moreover, The EEG-based Achetycoline index offers a physiological way to track cholinergic activity in the brain in real time. This offers much potential for diagnosing and stratifying patients and monitoring illness progression and therapy response (Johannsson et al., 2015).

The EEG is a non-harmful neuroscientific tool that can be utilized in sensitive populations (Höller, 2021). In comparison to typical healthy aging, the EEG features of the MCI group indicated an increase in beta two power across the right anterior area (Fauzan & Amran, 2015). Moreover, cortical thinning and poorer perfusion in the temporoparietal regions were linked to a high EEG upper/low power ratio. An increase in the EEG upper/low-frequency power ratio might be beneficial in identifying those who are at risk of developing AD (Moretti, 2015). Furthermore, theta is more prevalent in the parietal and temporal areas, showing symptoms of cognitive decline in MCI patients. For the normal, a decrease in the delta in the prefrontal (e.g., F3, Fz, F4) and central areas (e.g., C3, Cz, C4) implies a concomitant cognitive decline in the hippocampus area (Fauzan & Amran, 2015). In addition, the localization of neuronal generators of Event-Related Potentials (ERPs) components was found as markers of MCI, while high-density EEG data were recorded. The latency of P300 was relatively high, and the amplitudes and latencies of the mismatch negativity (MMN) correlated with the MMSE score on MCI, especially the grand average ERP waveforms at the Pz electrode (Tsolaki et al., 2017). Moreover, In MCI patients, P300 latency was delayed significantly (Papaliagkas et al., 2008). P300 latency was related significantly to disease severity in people with probable AD. P300 latency had the highest correlation coefficients with cognitive measurement (Fruehwirt et al., 2019; Gozke et al., 2016). Moreover, the N400 component could be

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connected to verbal memory and learning. The N400 amplitude correlates negatively with semantic expectancy and is inversely proportional to the semantic processing load. P600 has also been linked to memory encoding and retrieval processes (Olichney et al., 2008). As a result, EEG is a valuable technology for collecting biomedical data from participants pre- and post-test to track changes in the difference in brainwaves after participating in the experiments.

On the neuropsychological assessment side, most cognitive function assessments in a neuropsychological battery are associated with the MMSE and provide a brief overview of functioning in essential attention, memory, and language spatial-constructional skills (Nelson & O'Connor, 2008). Nevertheless, a cross-sectional study in medical centers and three systematic reviews showed that the Montreal Cognitive Assessment (MoCA) has higher sensitivity and specificity than the MMSE (Chen et al., 2021). The MoCA test was shown to be a potential technique for diagnosing MCI in research conducted in Thailand. The MoCA had a sensitivity of 90% and specificity of 87%, with a cut-off score of 24 or higher considered normal (Phongthara Vichitvejpaisal et al., 2015). Moreover, there has been a significant increase in the use of computerized neuropsychological assessment because it provides accurate results that would otherwise be impossible to obtain using traditional paper-based methods, while also reducing test administration errors and application costs while maintaining reliability (Galindo-Aldana et al., 2018). The flexibility of computerized test batteries over traditional paper-and-pencil assessments in terms of quick adjustment to performance levels is a benefit of computerized test batteries over traditional paper-and-pencil assessments. In response to test results, many batteries may automatically change test sequence, presentation pace, and level of difficulty (Wild et al., 2008). Especially in MCI and AD, slow response time and memory impairment appear to be the most common symptoms of cognitive impairment, and clinical signs should be considered while selecting a test (de Oliveira & Brucki, 2014).

Thus, a program utilizing a common approach to cognitive stimulation therapy will be studied and developed within the Thai context. Specifically, computerized cognitive and multisensory stimulation will be used to improve the cognitive functions of older adults and delay the progress of MCI to dementia. Moreover,

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neuropsychological, EEG, and ERP assessments will be employed to evaluate the effectiveness of the developed program.

Research questions

1. What are the effects of the developed computerized multicomponent cognitive stimulation (CMCS) program on cognitive functions in older adults with MCI?

2. What are the strengths of differences between experimental groups, with and without multisensory integration, and control groups post-intervention on cognitive functions in older adults with MCI?

3. What changes do various EEG analyses reveal during the resting stage and neuropsychological tasks of pre-and post-test CMCS performed by older adults with MCI in experimental groups?

4. What differences between experimental and control groups do EEG analyses reveal when conducted during the resting stage and neuropsychological tasks in older adults with MCI?

5. What changes do various ERP analyses reveal during the neuropsychological tasks of pre-and post-test CMCS performed by older adults with MCI in experimental groups?

6. What differences between experimental and control groups do ERP analyses reveal when conducted during the neuropsychological tasks in older adults with MCI?

Research objectives

This study aims to:

1. Develop a Computerized Multicomponent Cognitive Stimulation (CMCS), a combined cognitive stimulation therapy with multisensory integration training.

2. Investigate the effects of the developed CMCS on cognitive functions, including learning and memory, executive, language, visuospatial, psychomotor, emotions, and multisensory integration in older adults with MCI using standardized

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and computerized neuropsychological tests in both experimental and control groups post-intervention.

3. Examine the changes in various EEG analyses, including alpha, theta, beta, and delta, reveal during the resting stage and computerized neuropsychological tasks of pre- and post-test CMCS performed by older adults with MCI in experimental groups.

4. Compare a combined cognitive stimulation therapy with and without multisensory integration and control groups in terms of the effect on EEG frequency bands as measured during the resting stage and computerized neuropsychological tasks.

5. Examine changes in ERPs, that is, N100, P200, P300, N400, and P600, analyses revealed during the computerized neuropsychological tasks of pre- and post-test CMCS performed by older adults with MCI in experimental groups.

6. Compare a combined cognitive stimulation therapy with and without multisensory integration and control groups in terms of the effect of CMCS on the N100, P200, P300, N400, and P600 ERP components, as measured during participants' performances of the neuropsychological tasks.

Research hypotheses

1. The developed Computerized Multicomponent Cognitive Stimulation (CMCS) will have an effect on cognitive functions in older adults with MCI.

2. After CMCS intervention, older adults with MCI in experimental groups will perform standardized and computer-based neuropsychological tests, consisting of 1) paired associates learning tasks, 2) verbal fluency tasks, 3) Wisconsin card sorting test, 4) reaction time tasks, 5) Corsi block-tapping and mental rotation tasks and 6) multisensory integration task, better than the control group.

3. EEG frequency bands, including relative alpha, theta, beta and delta power, measured before and after the intervention during the resting-state and computerized neuropsychological tasks will significantly differ among older adults with MCI in experimental groups.

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4. After CMCS intervention, the EEG frequency bands, including relative alpha, theta, beta and delta power, in experimental groups will significantly differ from those in the control group among older adults with MCI.

5. The N100, P200, P300, N400, and P600 ERP components measured before and after the intervention during the computerized neuropsychological tasks will , consisting of 1) paired associates learning tasks, 2) verbal fluency tasks, 3) Wisconsin card sorting test, 4) reaction time tasks, 5) Corsi block-tapping and mental rotation tasks and 6) multisensory integration task, significantly differ among older adults with MCI in experiment groups.

6. After CMCS intervention, the N100, P200, P300, N400, and P600 ERP components in experimental groups will be significantly different from those in the control group among older adults with MCI.

Contribution to Knowledge

1. The new computer program of integration between cognitive stimulation therapy and multisensory integration training improved cognitive functions in older adults with MCI.

2. The EEG and ERP markers can measure cognitive functions and multisensory integration in older adults with MCI to determine the effectiveness of the intervention.

Conceptual framework

The developed CMCS program will be examined for its capacity to improve cognitive functions in older adults with MCI. The domains of cognitive functioning are (1) learning and memory, (2) language, (3) visuospatial, (4) executive, and (5) psychomotor. The brain localizations of these domains are roughly correlated. Only one of these domains must be damaged for a diagnosis of MCI (Knopman & Petersen, 2014). Furthermore, (6) emotional changes are expected in MCI (Sturm et al., 2013). Many studies showed an emotion-specific deficit for MCI patients in the emotions of anger, sadness, and fear (Elferink et al., 2015). Especially, anxiety was more common in MCI patients in clinic-based samples than in community-wide samples. Moreover,

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subjective cognitive decline (SCD) has been found to connect with anxiety symptoms closely, which shows independent risks of MCI/dementia (Liew, 2020). On other emotional dysfunction, depression were found in older adults in the early stages of cognitive impairment (Ma, 2020a). Moreover, The symptoms of a depressive episode are frequently present in individuals with cognitive impairment in the sense of MCI or onset dementia. Patients with depression, in contrast to patients with MCI or dementia, generally do not show memory impairment in neuropsychological testing; their attentional performance is comparable to that of MCI patients. (Wunner et al., 2022). Lastly, MCI people have cognitive functional impairments, which lead to disparities in (7) multisensory integration performance compared to healthy older adults (Wu et al., 2012).

Group-based cognitive stimulation therapy (CST) and individual CST (Aguirre et al., 2014; Spector et al., 2003; Yamanaka et al., 2013; Yates et al., 2014; Yates et al., 2017), along with multisensory stimulation (Setti et al., 2014; Yang et al., 2018) will be applied in the development of the program to enhance cognitive functions and multisensory integration in older adults with MCI.

According to the evidence base, CST describes how to improve cognitive function and quality of life for people with dementia (Spector et al., 2003) and is also used to enhance cognitive functions in older adults with MCI (Gomez-Soria et al., 2020). The guiding principles of CST and maintenance CST were adapted to create the 15 fundamental principles of individual CST as follows: 1) mental stimulation, 2) develop new ideas, thoughts, and associations, 3) use of orientation in a sensitive manner, 4) focus on opinions, rather than facts 5) use reminiscence 6) provide triggers to help memory 7) stimulate learning and communication 8) stimulate language and discussion 9) stimulate everyday planning ability 10) use a person-centered approach 11) offer choice of activities 12) enjoyment and fun 13) maximize potential 14) spend quality time together and 15) strengthen the caregiving relationship (Yates et al., 2017). Moreover, iCST will be applied to develop activity sessions on computer applications for improving cognitive functions in people with MCI. Each activity sessions include my life (life history), current affairs, food, being creative, number games, quiz games, sounds, physical games, categorizing objects, household treasures, useful tips, thinking cards, visual clips, art discussion, faces/scenes, word

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games, slogans, associated words, orientation, using money, and childhood. In addition to multisensory stimulation, virtual drums game will be used to stimulate audiovisual integration in older adults with MCI.

On the investigating side, many neurotransmitter changes, such as noradrenergic, serotonergic, and dopaminergic, occur in the brains of AD (Anand & Dhikav, 2012). In the worst phases of AD, the ACh index revealed a significant drop. The Ach index and cognitive function were found to have a strong relationship. In patients with MCI and prodromal AD, the index was lower, indicating lower cholinergic activity. When looking at the distribution of the Ach index in a group of healthy older people, it was discovered that there is an age-related threshold beyond which cholinergic activity begins to drop. Attention, learning, and memory have all been related to the cholinergic system. The two cognitive tests used were the MMSE, which examines general cognition, including memory, and the Digit Symbol Substitution Test, which analyzes executive function and is mainly connected to attention. The Ach index was associated with two cognitive measures. The Ach index was created by combining EEG characteristics with training data from a pharmacological challenge that was connected to the cholinergic system (Johannsson et al., 2015). The existence of functioning neurotransmitters on the neuronal surface was discovered thanks to electrophysiological recordings from brain neurons.

In addition, the EEG resting-state measure of the MCI group was compared to typical healthy aging, which indicated an increase in upper beta power across the right anterior area. However, the theta and alpha increases are more prevalent, showing symptoms of cognitive impairment in MCI. Moreover, A decrease in the delta is associated with cognitive decline (Fauzan & Amran, 2015). Atrophy of the hippocampus and entorhinal regions of the medial temporal lobe, the posterior cingulate cortex. In addition, hypometabolism in the temporoparietal and posterior cingulate cortices. The hypoperfusion of the parietal cortices and the hippocampus are among the indications of MCI (Anderson, 2019). A decrease in delta for the normal in the prefrontal (F3, Fz, F4) and central regions (C3, Cz, C4) suggests the associated cognitive decline in the hippocampal area (Fauzan & Amran, 2015). The cerebrovascular score was found to have a significant positive correlation with delta power and a significant negative correlation with alpha1 and alpha2 power when

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correlated with spectral band power. EEG markers, hippocampal volume, and amygdalar volume within amygdalar-hippocampal atrophy are closely associated. Amygdala and hippocampal volumes were separate. The theta/gamma ratio correlated with amygdalar and alpha3/alpha2 ratio for hippocampal decreasing volume (Moretti et al., 2012).

Furthermore, Auditory event-related potentials were elicited using the oddball paradigm, a simple discrimination task. The median MMSE performance of patients with MCI was 27.7. In MCI patients, P300 latency was significantly delayed (Papaliagkas et al., 2008). P300 latency was significantly related to disease severity in people with probable AD. P300 latency, which had the highest correlation coefficients with MMSE, increased significantly in probable AD patients throughout the 18-month study period (Wolfgang Fruehwirt et al., 2019). In addition to auditory ERPs, visual ERPs were used to support MCI assessments. Fz was used to obtain P300 latencies (Gozke et al., 2016). Moreover, A higher risk of later developing AD is linked to abnormalities of the N400 and P600 in MCI and AD. The N400 component could potentially be connected to verbal memory and learning. The N400 amplitude negatively correlates with semantic expectancy and is inversely proportional to the semantic processing load. The P600 has been linked to both memory encoding and retrieval processes. P600 generators have been discovered in a number of areas crucial for declarative and episodic memory, which have previously shown significantly diminished P600 word repetition effects in moderate AD and restricted amnesia. These ERP components could provide helpful biomarkers for the early diagnosis and staging of AD (Olichney et al., 2008).

This study will develop computerized multicomponent cognitive stimulation for improving cognitive functions, emotions, and quality of life in older adults with MCI as illustrated in Figure 1.

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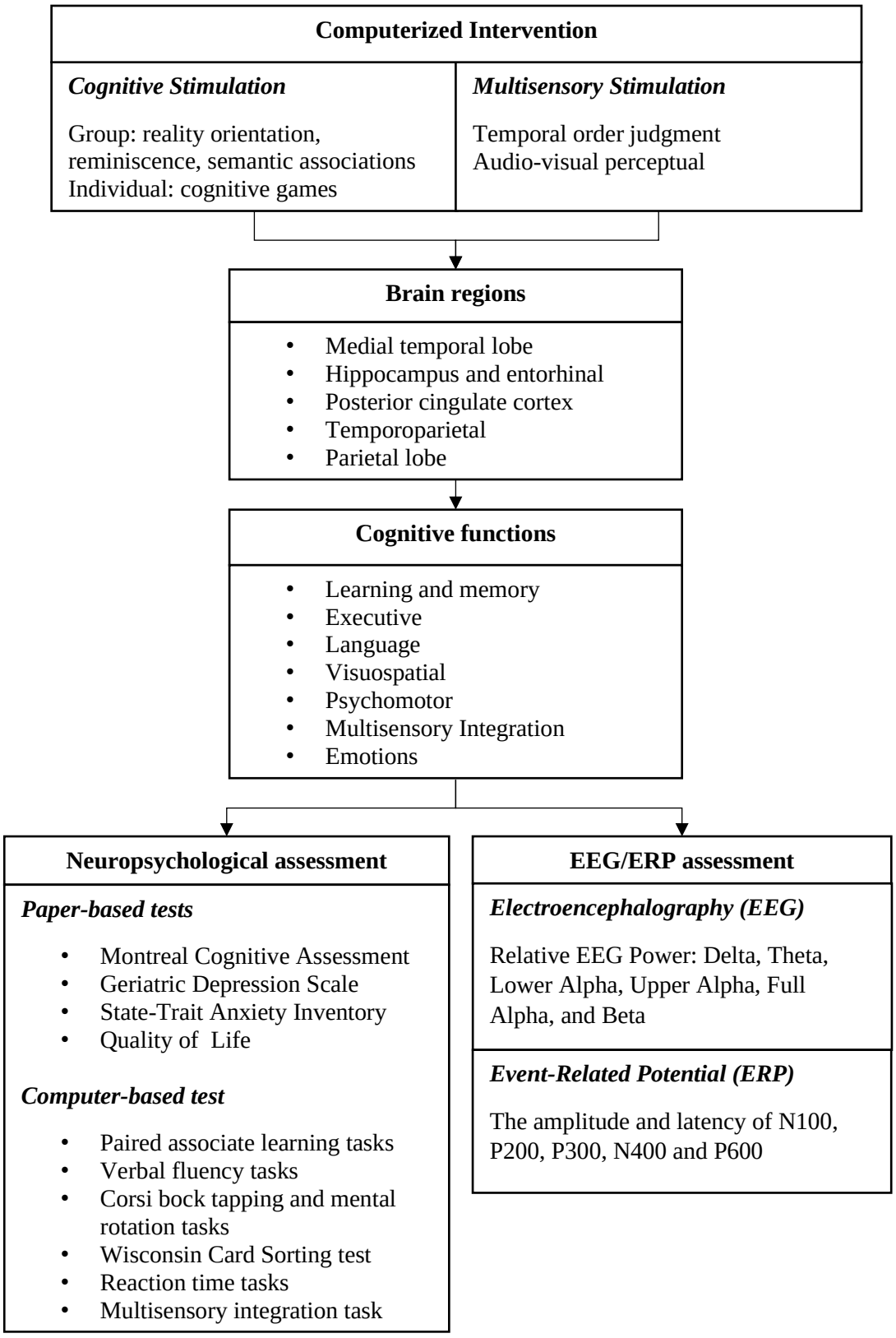

Figure 1 A conceptual framework

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Scope of the study

The emphasis of this study was to improve the cognitive functions of older adults with MCI who were recruited from communities, elderly clubs, and community elderly schools (The school, as an activity center, aims to provide health promotion activities rather than academic action that focuses on socially linked older groups) in the area of Chonburi province, Thailand. The criteria included the performance of older adults with objective memory impairment based on test scores (i.e., MoCA and CDR), who were not demented and were older than 60 years. After screening, reasons for exclusion included illiteracy or advanced dementia, systemic illness, and refusal to participate.

Independent variables were 1) the Computerized Multicomponent Cognitive Stimulation program, 2) the Computerized Cognitive Stimulation program.

Dependent variables were the cognitive functions of older adults with MCI, which are the following: learning and memory, executive function, language, visuospatial skills, psychomotor and emotions, and multisensory integration. Therefore, it is separated into two categories as follows:

(1) Psychological features: The scores were assessed from the neuropsychological tests.

(2) Brain signal features: The parameters were measured by using EEG/ERP assessment.

Definition of terms

1. Older adults with MCI are defined as elderly aged equal to 60 years old and above. Their MoCA and CDR scores are within the range of diagnosis criteria (MoCA score between 17 and 24, and CDR = .5/1).

2. Computerized Multicomponent Cognitive Stimulation (CMCS) denotes the program computer developed and based on the Cognitive Stimulation Therapy (CST) and multisensory integration (MSI) approaches. The application aims to improve cognitive functions such as learning and memory, language, visuospatial, executive, psychomotor, and emotion. Also, it improves multisensory integration, especially the integration of both auditory and visual inputs.

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The cognitive functions and emotions are the following:

(1) Learning and memory: Learning is newly created memory traces that go through a consolidation stage. They are reinforced, stabilized against interference, and, in some circumstances, rearranged in the brain. Memory is the process of retaining, retrieving, and using information about stimuli, visuals, events, ideas, and talents when the original information is no longer available. Paired associate learning tasks in the computer-based test are used to measure learning and memory.

(2) Language is a system of communication that allows a person to communicate their feelings, thoughts, ideas, and experiences through sounds or symbols. Language measures are employed by using computer-based verbal fluency tasks.

(3) Visuospatial skills are the ability to recognize visual and spatial links between objects. The computer-based Corsi block tapping and mental rotation tasks are used to index visuospatial skills.

(4) Executive refers to the adaptive performance that enables a person to override automatic or established behaviors. Set shifting, response inhibition, and working memory tasks, particularly those requiring the solution of a novel issue.

(5) Psychomotor is the ability to accurately conduct physical bodily motor movements (e.g., fingers, hands), with coordination, or with strength.

(8) Multisensory integration is the ability to bind together spatiotemporally congruent inputs from audio and visual sensory to produce single salient representations. Older adults with MCI perceived the illusion (i.e. 2 beeps and 1 flash) more often than controls or healthy people.

(7) Emotions are reaction patterns, behavioral and physiological elements that reflect the personal significance of a thing, an event, or a state of affairs. The current study focuses on emotional dysfunction such as depression and anxiety. The Geriatric Depression Scale and The State-Trait Anxiety Inventory (Form Y-1) will be used to measure emotions.

3. Cognitive Stimulation Therapy (CST) refers to an approach, evidence-based treatment for people with MCI. The intervention is delivered in tablet-based intervention of ten face-to-face group sessions delivered in groups of seven to ten

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participants over ten weeks. The sessions included (1) orientation and physical activity, (2) music and sound, (3) childhood, (4) food and cooking, (5) travel, (6) occupations, (7) sports, (8) shopping, (9) household, (10) team games, and termination.

4. Multisensory stimulation refers to audio-visual improvement in brain processing through tasks involving various sensory data integration. The intervention is delivered in tablet-based intervention of ten face-to-face group sessions delivered in groups of seven to ten participants over ten weeks. The multisensory integration training sessions are modified and included to in the sessions at (2), (5), and (7).

5. The electroencephalogram (EEG) is a psychophysiological tool for capturing spontaneous electrical activity in the brain at a specified time. Using EMOTIV Flex devices with 32 channels, electrodes are placed on the scalp to get the recording. The frequency ranges of EEG signals include delta (1-4 Hz), theta (4-8 Hz), lower alpha (8-10 Hz), upper alpha (10-13 Hz), full alpha (8-13 Hz) and beta (13-30 Hz).

6. Event-Related Potentials (ERPs) are minimal voltages produced in brain areas as a result of certain events or stimuli. They are time-locked EEG alterations that provide a safe and non-invasive way to examine psychophysiological aspects of mental activities. Human ERPs are classified into two groups. The early waves, or components peaking within milliseconds following input, are sensory or exogenous since they are highly dependent on the stimulus's physical properties such as N100, P100 and P200. Furthermore, the timing of endogenous ERP components are identified as indices of perceptual and cognitive processes such as the P300 N400, and P600.

N100 is negativity peaking around 100 milliseconds (ms). Long considered an exogenous response sensitive to the physical features of an auditory and visual.

P200 is defined as the maximum positive peak at midline frontal and central clusters and bilateral frontal, frontocentral and central clusters between 160–220 ms.

P300 is an ERP component in a positive peak, apparent at centro-parietal scalp areas, and usually elicited within 250–500 ms after the stimulus

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presentation. In addition, the Late Positive Component (LPC) is a positive peak that occurs between 500 and 700 ms, continuing from the P300 following the stimulus.

N400 is a negative-going deflection that peaks around 400 ms post-stimulus onset.

P600 is characterized as a positive-going deflection with an onset around 500 ms after the stimulus that elicits it; it often reaches its peak around 600 ms after the presentation of the stimulus and lasts several hundred milliseconds.

7. Electrode sites refer to specific scalp locations where electrodes are placed to record brain activity, following the standard 10-20 system. These sites correspond to different cortical regions, enabling the analysis of neural activity across frontal, central, parietal, occipital, and temporal areas.

Frontal electrodes: Fp1, Fp2, AF3, AF4, Fz

Central electrodes: FC1, FC2, C3, C4, Cz

Parietal electrodes: CP1, CP2, P3, P4, Pz

Occipital electrodes: PO3, PO4, O1, O2, Oz

Left temporal electrodes: F7, F3, FC5, T7, CP5, P7

Right temporal electrodes: F8, F4, FC6, T8, CP6, P8

Left temporoparietal junction electrodes: CP5, P3, P7

Right temporoparietal junction electrodes: CP6, P4, P8

Midline electrodes: positioned along the midline cortical structures, including frontal (Fz), central (Cz), parietal (Pz), and occipital (Oz) regions.

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CHAPTER 2
LITERATURE REVIEW

This literature review includes an overview of previous research on computerized cognitive stimulation on cognitive functions in older adults with mild cognitive impairment. The chapter is organized into four parts: (1) Mild cognitive impairment, (2) cognitive functions and multisensory integration, (3) Computerized cognitive stimulation, and (4) Neuropsychological and EEG/ERP assessment.

Part 1 Mild cognitive impairment

- Definition, epidemiology, causes, symptoms, and diagnosis of mild cognitive impairment
- Measurement
- Treatments

Part 2 Cognitive functions and multisensory integration

- Learning and memory
- Language
- Visuospatial
- Executive
- Psychomotor
- Emotions
- Multisensory integration

Part 3 Computerized cognitive stimulation

- Cognitive stimulation therapy
- Multisensory stimulation
- Computerized cognitive stimulation
- Development of computerized cognitive stimulation program

Part 4 Neuropsychological and EEG/ERP assessment

- Neuropsychological assessment
- EEG and ERP assessment

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Part 1 Mild cognitive impairment

Definition

The term mild cognitive impairment (MCI) has been in the literature for almost four decades (Petersen, 2016). Many research focused on early clinical detection and treatments before the beginning of AD. Related to the long work period directed by Petersen and colleagues was referred to as the transitional stage between normal aging and probable AD (Petersen et al., 1997). These individuals have some cognitive impairment, but not low severity constitutes dementia (Petersen, 2004). Those who are more severely affected on the clinical spectrum, whether due to memory loss or other cognitive impairments, are more likely to develop dementia more quickly (R. C. Petersen et al., 2009). People with MCI have actual proof of cognitive impairment that indicates a drop from previous levels. However, they function independently or almost independently in their everyday lives in a way that is indistinguishable from previous levels (Knopman & Petersen, 2014).

Epidemiology

MCI is increasingly common as individuals with age, from 6.7% of 60- to 64-year-olds to more than 25% of 80- to 84-year-olds, an estimated 15% to 20% of people over age 65 meet the criteria for MCI (Petersen et al., 2018). Furthermore, in developing-country epidemiologic research with amnestic and multiple domains MCI, the total incidence rate is 14.89 %, with the age group of 50-59 accounting for 12.42 % (Das et al., 2007). Worldwide population-based studies have been conducted to establish the prevalence of MCI, which develops dementia at a rate that varies between 8% and 15% each year (Petersen, 2016). MCI patients have a greater chance of developing dementia than age-matched controls. MCI patients may remain stable, revert to normal neurological function, or develop dementia (Petersen et al., 2018).

Changes in the brain accompany aging, including general atrophy, particularly in the hippocampus, an imbalance of amyloid formation and degradation, inflammatory activation, and neuron fragility in memory-related locations (Jia et al., 2020). The old age groups showed significant differences in the prevalence of MCI but no difference in sex (Overton et al., 2019). There were no statistically significant variations in the prevalence or incidence of amnestic MCI between men and women.

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Women had a substantially greater frequency of non-amnestic MCI, but not an incidence, than males (Au et al., 2017).

Causes

Overall, MCI symptoms can be impacted by somatic diseases and other modifiable risk factors that are physiologically reasonable when linked to the traditional cardiovascular risk factors, hypertension, diabetes, and hyperlipidemia (Etgen et al., 2011). Moreover, rural residence, lower education, living alone, and smoking are also changeable risk factors in MCI shared similar with dementia (Jia et al., 2020).

According to factors affecting brain aging, neuronal and microglial cellular senescence is critical in brain aging. These alterations include neural stem cell fatigue, increased cellular apoptosis, protein aggregation, mitochondrial malfunction with increased reactive oxygen species and oxidative damage to proteins and lipids, and buildup of DNA damage. There is an increase in intraneuronal calcium early in the aging process due to increased calcium entry into cells and reduced systems that remove calcium from the brain. Calcium is important for memory and also inhibits neuronal cell death (Morley, 2018).

In the early stages of AD, linked to a unique pattern of hippocampal atrophy, i.e. aging with volume loss in CA1 and MCI with volume loss in the CA1-2 transition. For discriminating between patients diagnosed with MCI and healthy persons, volume loss in the CA1-2 transition was superior to total hippocampus volume (Mueller et al., 2010). Similarly with grey matter volume loss, patients with MCI exhibit grey matter reduction in the posterior parietal brain (Jacobs et al., 2012). In addition, a consistent relationship between memory function and medial temporal lobe atrophy in the early cognitive dysfunction related to MCI (Sánchez-Benavides et al., 2010).

Furthermore, energy metabolism was shown to be impaired. Likewise, mitochondrial dysfunction has been observed in those with MCI as well as those with AD. Glucose transport in neurons has been demonstrated to be hampered by stress. It is unclear if these are the causes or consequences of AD (Anand & Dhikav, 2012). Whether a demanding cognitive activity such as making a perceptual judgment and motor reaction is required, the metabolism of the posterior cingulate cortex is

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responsive to the cognitive state. However, compared to the high levels of baseline activity, perfusion variations caused by changes in cognitive state are minor. As a result, even when a task causes a drop in the posterior cingulate cortex activity, the area still has consistently greater blood flow levels than nearly all other brain regions (Leech & Sharp, 2014). In addition, age, education, and diabetes mellitus were the significant risk factors associated with MCI. The prevalence of MCI in older Thai people in a rural area had very low education, mainly only four years or less. In addition, most of them were farmers and had a small income (Griffiths et al., 2020).

Symptoms

Patients with MCI have symptoms that may be divided into two categories: cognitive and neuropsychiatric. While some cognitive decline is typical with age, individuals with MCI have a marked decrease in processing speed and executive control activities, as well as severe memory loss (Ghosh et al., 2013). The most noticeable sign is typically memory loss. Memories are gone, not only hard to retrieve, as is the case with those who have age-related memory loss. People with MCI have difficulties recalling current discussions and are prone to forgetting key appointments or social occasions, although they are usually able to recall prior occurrences (Choe et al., 2018; Emrani et al., 2018; Petersen et al., 1997; Sánchez-Catasús et al., 2018). Subjective memory complaints can sometimes properly indicate general cognitive loss, whereas at other times, they appear as a generic criterion (Choe et al., 2018; Ghosh et al., 2013). Patients with MCI, unlike those with AD, are more conscious of their symptoms and are bothered by them. Patients with MCI who advance to dementia have a lower perception of symptoms, which can be used as an indication of disease progression (Ghosh et al., 2013).

One-third of all adults over the age of 65 are affected by hearing loss (World Health Organization, 2018). The cognitive function of older adults is influenced by hearing loss. Low-frequency hearing loss is more severe in the elderly than high-frequency hearing loss. Also, the right ear had a greater degree of hearing loss than the left ear (Huh, 2018). Thus, impaired hearing is related to compromised cognitive function, also a condition related to the quality of life in older adults (Palmer et al., 2017). Idrizbegovic and colleagues conducted an experimental study in which the auditory function of AD and MCI participants was assessed using pure tone

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audiometry, speech perception in quiet and background noise, and dichotic digits tests with two or three digits. They discovered that pure tone audiometry and speech perception scores in quiet and background noise were normal for age and did not differ between groups. The dichotic digits tests revealed highly significant differences between the three groups, with the AD group performing significantly worse than the other two and the MCI group performing in the middle. This study found that central auditory processing dysfunction is common in people with AD and, to a lesser extent, in people with MCI (Idrizbegovic et al., 2011).

Depression, anxiety, and apathy are common in MCI patients and are important indicators of dementia progression, emphasizing the importance of assessing depressive symptoms as well as anxiety and apathy in the early stages of cognitive impairment (Ma, 2020b). Patients with these behavioral characteristics frequently have more severe cognitive impairment than those who do not, and patients with depression who have MCI proceed to AD at a faster rate than those who do not. On the other hand, individuals with AD have a higher frequency and severity of neuropsychiatric symptoms than patients with MCI (Ghosh et al., 2013). Moreover, The previous study comparing cognitive function differences between patients with and without depression within the MCI group discovered that patients with MCI and depression had the most significant deficit in executive function among attention, language, visuospatial, and memory (Lee et al., 2019).

Diagnostic

Petersen et al. (1997) have used the diagnostic criteria to define MCI include the following:

a) Complaint about defective memory.
b) Normal activities of daily living.
c) Normal general cognitive function.
d) Abnormal memory function for age.
e) Absence of dementia.

The four subtypes of diagnostic MCI include amnestic MCI, a single domain that has impairment in memory only, but amnestic MCI with multiple domains of impairment in memory and at least one additional domain. On the other side, amnestic MCI is a non-amnestic MCI is an impairment in a non-memory

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domain, and non-amnestic MCI multiple domains an impairment in two or more non-memory domains (Petersen, 2004).

American Psychiatric et al. (2013) developed the Diagnostic and Statistical Manual for Mental Disorders, Fifth Edition (DSM-5), the American Psychiatric Association, and the term mild neurocognitive disorder (mild NCD) to describe MCI. The clinical criteria for mild NCD include as following:

a) There is evidence of a significant cognitive decline in one or more cognitive domains (complex attention, executive function, learning and memory, language, perceptual-motor, or social cognition).

b) The cognitive deficits interfere with independence in everyday activities.

c) Cognitive deficits do not occur exclusively in delirium.

d) Another mental disorder does not better explain cognitive deficits (e.g., major depressive disorder, schizophrenia).

Knopman and Petersen (2014) were adapted the diagnosis of Alzheimer's diagnosis as follows:

a) Concern about a change in cognition in comparison with the person’s previous level.

b) Objective evidence of significantly worse performance in one or more cognitive domains than would be expected, given the patient's age and educational background.

c) It does not substantially interfere with daily activities, although complex functional tasks performed previously, such as paying bills, preparing a meal, or shopping, may take more time or be performed less efficiently. Independence in daily life is preserved with minimal aid or assistance.

d) Not explained by delirium or psychiatric disorder

The European Consortium on Alzheimer’s Disease Working Group on MCI has recently proposed a novel diagnostic procedure that modification of Petersen’s criteria (Portet et al., 2006) as follows.

a) Cognitive complaints come from the patients or their families.

b) The reporting of a decline in cognitive functioning relative to previous abilities during the past year by the patient or informant.

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c) Cognitive disorders as evidenced by clinical evaluation (impairment in memory or in another cognitive domain).

d) Absence of major repercussions on daily life (the patient may, however, report difficulties concerning complex day-to-day activities).

e) Absence of dementia.

Measurement

The Brief Interview for Mental Status is a valuable tool with high reliability and convergent validity that can be administered quickly (in around 3 minutes on average) and is appropriate for paraprofessional usage. The Brief Interview for Mental Status was never meant to be sensitive to the whole cognitive scale, and it does not stage dementia levels. Cognitive screening measures such as the MMSE or the MoCA were used to address cognitive impairment diagnostic criteria in clinical practice. The MoCA was superior to the MMSE in distinguishing between people with moderate cognitive impairment and those who did not. When examining the capacity to distinguish MCI in cognitively healthy older people, the area under the curve for generating results ranged from 0.71 to 0.99, while for MMSE, it ranged from 0.43 to 0.94 (Pinto et al., 2019).

The poor strength of these linkages, on the other hand, shows that this test cannot be utilized as a stand-alone evaluation tool (Tosi et al., 2020). Though the MMSE is insufficient in detecting MCI, the MoCA is insufficient to identify the exact cognitive domains impacted to define the MCI subtype (Anderson, 2019). The Modified Mini-Mental State Examination, which appears to have low sensitivity to MCI, is one of the cut scores used to identify residents with and without cognitive impairments. (Tangalos & Petersen, 2018). Better MCI diagnosis tools combine MoCA, daily living activities, and the CDR's clinical impression (Qarni & Salardini, 2019). The MCI diagnosis tools combine MoCA, activities of daily living, and the clinical impression is the CDR (Qarni & Salardini, 2019).

For dementia patients, MoCA and MMSE were more comparable, although MoCA spreads MCI cases throughout a more comprehensive score range with a more negligible ceiling effect. A cutoff of 17 may assist in detecting early and late MCI patients; depending on the amount of sensitivity needed, cutoffs of 18 or 19

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may be employed. Dementia can be ruled out using a functional evaluation (Trzepacz et al., 2015).

Treatment

MCI represents what researchers and clinicians view as a “window” in which it may be possible to intervene and delay the progression of dementia (Anderson, 2019). Individuals with isolated memory loss in cognitive aging, which may reflect the pre-clinical phase of AD, are referred to as amnestic MCI (aMCI) in the clinical context. Theoretically, detecting MCI may allow for early intervention to prevent the disease from progressing to dementia (Waldemar & Burns, 2017). MCI is still a contentious issue in research, with lots of randomized controlled trials underway to find effective interventions (Petersen, 2016). MCI treatments are separated into two categories, pharmacological and non-pharmacological treatments, shown in the following sections below:

Pharmacological

The first class of drugs, cholinesterase, may minimize or postpone home-care costs or maintain independence in daily tasks. Are challenging to evaluate in terms of cost-effectiveness. The majority of prescription insurance plans cover one or more cholinesterase inhibitors. Furthermore, the memantine of the second class is no evidence to back up the usage of memantine in MCI patients. As a result, memantine's cost-effectiveness would be considered weak (Kelley, 2015). The results of the pharmacological investigations are disconcerting. However, there are a number of great randomized controlled studies examining pharmacological therapy for MCI, but none of them were able to meet their primary goals. Further research was halted due to methodological or safety concerns. As a result, there is no evidence-based therapy option for MCI (Karakaya et al., 2013). Moreover, the FDA, the European Medicines Agency, and the Pharmaceuticals and Medical Devices Agency in Japan have all approved no pharmacologic therapies for MCI (Petersen, 2016). After all, no high-quality evidence exists to support pharmacologic treatments for MCI (Petersen et al., 2018).

Non-pharmacological

The use of music therapy at a senior center was found to have positive benefits on cognitive function, gait velocity, stride length, depressive symptoms, and

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lower body flexibility. These findings imply that music therapy therapies might be a novel way to treat older individuals with MCI (Domínguez-Chávez et al., 2019). In a group music therapy program, the effect of a cognitive intervention utilizing digital devices that create musical stimuli. The findings revealed that the intervention improved the cognitive function of MCI patients. The method took into account the viewpoints of a clinician, a musical therapist, an industrial designer, and a computer scientist for the aged (Han et al., 2020). In addition, for music therapy, a system and a meaningful game have been developed. A meaningful game was created and used for music therapy, and it was meant to be played on a keyboard or percussion instrument. Both instruments were utilized in the clinical trial for music therapy, which was found to be helpful in improving reactive ability and cognitive ability (Cheng et al., 2019).

A mindfulness awareness program (MAP) improves participants' ability to focus on and disengage from diverse stimuli. Indeed, the impact of such attentional training would be transferred to a measure of divided attention, in which participants were required to engage and disengage between two sets of stimuli on a regular basis. Furthermore, the MAP was related to increasing working memory performance as evaluated by the digit span forward (Yu et al., 2021). Efficacy of Mindfulness-Based Interventions for cognitive functioning. All of the included studies reported some measure of cognition. Seven of the included studies assessed cognitive functioning through clinical assessment and self-report; few studies utilized objective measures, including brain imaging, fluid markers and other genetic markers. Three studies showed that MBIs led to significant improvements in clinical assessments of cognitive functioning compared to various control conditions, with varying effects that ranged from small to large in magnitude (Shim et al.).

Physical activity and exercise in older adults with MCI, particularly mind-body interventions, and mixed physical activity interventions, had a insignificant effect on global cognition, according to the findings of the meta-analyses, which included 27 articles and 28,205 participants with MCI or dementia. Physical activity/exercise was found to improve cognitive and non-cognitive outcomes in RCTs, but the evidence strength was overall very low-to-moderate (Demurtas et al., 2020). However, exercise training within six months exercise

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training is likely to improve cognitive measures, and cognitive training may improve cognitive measures (Petersen et al., 2018).

The belief in cognitive stimulation that applying this principle in various mental activities improves cognitive and social functioning informs cognitive stimulation treatments. According to empirical data, individuals who remain dynamically engaged in tasks that involve cognitive functions may have a decreased chance of acquiring dementia and slower progression of cognitive decline (Eckroth-Bucher & Siberski, 2009). Interventional studies have been carried out in a relatively small number of cases. Although there was no control group, no randomization, and no assessment of the intervention's long-term effect, research looking at the effects of cognitive stimulation treatment on pre-and post-intervention performance on neuropsychological assessments found improvements on numerous measures (Kelley, 2015).

Altogether, older adults who engage in a diverse variety of activities (including physical, cognitive, and social activities) are less likely to acquire dementia than those who engage in only one or none. Multicomponent treatments integrate non-pharmacological interventions such as cognitive training, physical exercise, and social group activities into a single intervention. This combination form has been found to be helpful in enhancing cognitive abilities, activities of daily living, depression, sleep problems, functional capabilities, as well as physical health stride and posture in persons with MCI and dementia, as well as reducing caregiving time (Lissek & Suchan, 2021).

Part 2 Cognitive functions, emotions, and multisensory integration

In terms of MCI, the diagnosis of MCI correlated with five domains of cognitive functions (1) learning and memory, (2) language, (3) visuospatial, (4) executive, and (5) psychomotor. The brain location of these domains is roughly correlated. Only one of these domains must be damaged for a diagnosis of MCI, but more than one domain must be impaired for a diagnosis of dementia (Knopman & Petersen, 2014). Moreover, emotions and multisensory integration were impaired in older adults with MCI.

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Learning and memory

Learning and memory are closely associated concepts. Learning is a process that can result in changes in behavior, and since brains drive behavior through changes in neural activity, it is apparent that learning is connected to new patterns of brain activity (Cluck et al., 2016). Memory is the process of retaining, retrieving, and using information about stimuli, visuals, events, ideas, and talents when the original information is no longer available (Goldstein, 2018). Following learning, newly created memory traces go through a consolidation stage in which they are reinforced, stabilized against interference, and, in some circumstances, rearranged in the brain (Humiston et al., 2019). In charge of retaining data for extended periods of time, which can range from minutes to a lifetime, requires long-term memory. Episodic recollections are long-term memories of previous events, such as the picnic. Procedural memory is a form of long-term memory that allows one to ride a bicycle or do any other activity that requires muscular coordination (Goldstein, 2018).

Neurons, which make up the nervous system's building blocks, have the ability to change their function and the way they process information. Furthermore, learning experiences may have a significant influence on a person's brain shape as well as their learning and memory capacities (Cluck et al., 2016). The hippocampus is one of the brain's most well-studied areas. It is thought to be responsible for the storage of declarative memories and is located in the medial temporal lobe of the brain. The medial temporal lobe receives highly processed neocortical information from all sensory inputs at the macroscopic level. The entorhinal cortex transports these processed impulses to the hippocampus (Yu et al., 2017).

People with MCI underline the existence of consolidation impairments by requiring a poor score on a delayed recall task in the prose passage. Subjects with MCI exhibit significant learning difficulties due to inefficient utilization of learning methods, especially when a free recall is complicated. Furthermore, a lack of semantic grouping methods might contribute to their memory problems (Ribeiro et al., 2007). Older adults with MCI have difficulty remembering current conversations and are prone to forgetting essential appointments or social events, despite recollecting previous events (Knopman & Petersen, 2014; Petersen et al., 1997). Significantly, the

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capacity to recall episodic parts of autobiographical events was considerably slowed down in people with MCI. (Sheldon et al., 2015).

Language

Language is a system of communication that allows us to communicate our feelings, thoughts, ideas, and experiences through sounds or symbols. Broca and Wernicke showed that various brain regions were responsible for different elements of language, such as language generation and interpretation. (Goldstein, 2018). Moreover, the relevance of the bilateral temporal cortex for auditory and single-word processing, extending into the left lateral temporal cortex and inferior frontal gyrus (IFG) in the context of sentence-level information, is reflected in neuroanatomically restricted models of spoken language comprehension. Language processing in elderly persons can only be understood as part of a larger picture of age-related cognitive decline and brain adjustment and compensating processes (Peelle, 2019).

Verbal fluency, auditory, reading, and oral spelling comprehension all appear to be impaired in older adults with MCI (Tsantali et al., 2013). In notable, the story retells and syntax comprehension and spelling of irregular words. Some functions may decline earlier and more rapidly than others on a continuum between amnestic MCI with multiple domains and AD (Jokel et al., 2019).

Visuospatial

Visual and spatial information are handled by the visuospatial sketch pad, which is engaged in the process of visual imagery—the formation of visual imagery in the absence of a physical visual stimulus (Goldstein, 2018). There was a strong link between physical lateralization and asymmetry on visuospatial tasks and a bigger parietal-frontal network in the right hemisphere than the left, indicating that hemispheric specialization is connected to an imbalanced speed visuospatial processing (de Schotten et al., 2011). Comparing between healthy and elderly with MCI the map and route learning, there was more atrophy in the frontal and medial temporal regions, as well as a distinct pattern of association between grey matter values and visuospatial ability, with more widely dispersed parts of the occipital and middle temporal cortex (Mitolo et al., 2013).

Young adults and older adult participants acted equally in 2D models with a visuospatial ability. In other words, there was no difference between young adults and

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older people in terms of the proportionate increase in task completion times from low to high visuospatial complexity conditions. However, many studies have found that the capacity to rotate visual pictures mentally, recollect spatiotemporal sequences, and use visuospatial imagery declines with age (de Bruin et al., 2016). For example, delay lengths impacted the initial timing of the eye and hand reaction time. However, capacity changes of set size affected accuracy measurements, suggesting that temporal and spatial information storage are separate systems in the brain and are affected differently by age (Burke et al., 2014). In the areas of item recognition and location, map learning, and route learning, MCI patients performed much worse than healthy older people (Mitolo et al., 2013). Patients with MCI and those with dementia may be distinguished using their visual-spatial abilities. During the early stages of MCI, episodic memory appears to deteriorate faster; however, as dementia progresses, visuospatial function deteriorates faster than memory (Yin et al., 2015).

Executive

Executive functions are goal-directed, adaptive activities that enable a person to override automatic or established behaviors. Set shifting, response inhibition, and working memory tasks, particularly those requiring the solution of a novel issue, are believed to be indicators of executive function (Piper et al., 2012). Furthermore, executive functions encompass a variety of activities, including attention management and coping with conflicting reactions (Goldstein, 2018). The most likely major cause of decreased executive function in nondemented older individuals is a change in frontal-striatal pathways. In an older adult, it shows diffuse white matter lesions in particular. Because of its brilliant spotty appearance, this frequent kind of white matter alteration is called "white matter hyperintensities" (Buckner, 2004).

Older adults with MCI have experienced difficulty with response inhibition, switching, cognitive flexibility, and abstract thinking, covering various components of executive function (Traykov et al., 2007). Planning/problem-solving and working memory were shown to be selectively reduced in MCI compared to cognitively normal older people, but not judgment. Furthermore, even individuals with "pure" amnestic MCI, the least severely affected category, had significant deficits in these two executive domains. Compared to single-domain MCI patients, multiple MCI

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patients exhibit more substantial planning/problem-solving and working memory impairments (Brandt et al., 2009).

Psychomotor

The ability to conduct physical bodily motor movements (e.g., fingers, hands, and legs) with accuracy, coordination, or strength is psychomotor. In neuropsychological evaluations, psychomotor abilities are an essential element to consider. The Dean-Woodcock Neuropsychological Battery, for example, comprises numerous activities that assess gross and fine motor abilities. Understanding standard and atypical neuropsychological functioning, as well as recognizing any neurological or neuropsychological disease, requires the psychomotor ability (Flanagan & Dixon, 2013).

Slower perceptuomotor and decision-making cause a psychomotor slowing in AD, although MCI did not differ from healthy persons (Bailon et al., 2010). The movement abnormalities correlated with clinical cognitive scores or altered neurophysiological measures of the primary motor cortex that finger-tapping movements in aMCI patients were characterized by less rhythmic movement than healthy people, as tested by kinematic analysis and transcranial magnetic stimulation (Colella et al., 2021).

Emotions

Emotional changes are expected in MCI (Sturm et al., 2013). Many studies from a systematic review showed an emotion-specific deficit for MCI patients in the emotions of sadness and fear (Elferink et al., 2015).

Depression

Previous research on the relationship between depression and MCI showed consistent results. For instance, Song et al. (2018) found that depression symptoms are significantly notable in older adults with MCI after controlling sociodemographic, health-related, and lifestyle-related factors (Song et al., 2018). Moreover, MCI patients with depression showed significantly reduced performance in specific neurocognitive functions compared to MCI patients without depression, including deficits in verbal memory, executive function, attention/processing speed, and visual memory (Dong et al., 2016). Specifically, an episode of severe depression increases the risk of progression from MCI to AD (Gałecki et al., 2015).

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Patients with MCI and AD may have different relationships between depression and cognitive performance in different cognitive domains, and the link between depression and cognitive function is more vital in MCI than in AD (Lee et al., 2019). According to functional imaging research with a two-year clinical follow-up, older depressed persons with persistent cognitive impairment (PCI) had baseline reduced activity in the dorsal anterior cingulate cortex, hippocampus, inferior frontal cortex, and insula. Similar brain networks that have been linked to the onset of AD in non-depressed people revealed lower activity in depressed patients with PCI (Steffens, 2012). In clinical practice, hybrid patterns are frequently observed. For example, many patients with cognitive impairment in the sense of MCI or beginning dementia also display symptoms consistent with the diagnosis of a depressive episode (Wunner et al., 2022). These findings indicated how critical it is to assess and deal with this psychological condition in this expanding population.

Anxiety

Less research has been done on the symptoms of anxiety than depression, and the connection between anxiety and cognition is complicated (Ma, 2020b). Researchers found that higher cortical amyloid deposition and clinical anxiety interacted synergistically and additively to increase the likelihood of incident MCI. As a result, the combined presence of anxiety and amyloid positivity was bigger than the expected arithmetic sum of their independent effects (Pink et al., 2022). Moreover, subjective cognitive decline (SCD) has been found to connect with anxiety symptoms, and older people closely frequently report both SCD and anxiety symptoms at the same time. With the greatest odds of 1.9 and 1.3, respectively, SCD and anxiety symptoms showed independent risks of MCI/dementia. Participants with co-occurring SCD and anxiety symptoms showed the greatest risk; after 3.1 years, they had a 25% chance of acquiring MCI or dementia, compared to 8.2 years for those without SCD or anxiety. Even after considering symptom intensity and consistency over the course of the first two yearly visits, the results were still reliable (Liew, 2020).

Multisensory integration

Multisensory integration is the act of combining inputs from two or more senses to generate a product that is different from, and hence cannot be reassembled from, the components from which it was created. This is defined operationally as a

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statistically significant difference between the reaction elicited by a cross-modal combination of stimuli and the response induced by the most effective of its components individually, whether considering brain signals or behavioral performance. This comparison is conducted between the total number of impulses or firing rates elicited by stimuli and their combinations in single-neuron physiology (Stein et al., 2014). Behavioral research followed the first neurophysiological observations of this sensitivity, proving that reasonable intuitions about the behavioral repercussions of these physiological data were valid. The same stimulus combinations that raise an event's physiological salience also increase its behavioral effect (i.e., the chance of detecting, localizing, and orienting toward the originating stimuli). Reduced physiological salience, on the other hand, reduces the behavioral effect of stimuli, reducing or eliminating behavioral reactions to the stimuli (Stein et al., 2020).

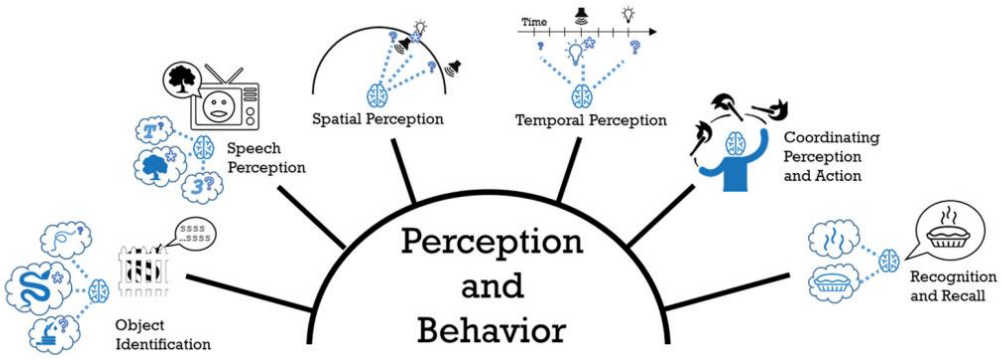

Figure 2 Multisensory integration enhances performance in a number of perceptual and behavioral domains

(From Stein, Barry E.; Stanford, Terrence R.; Rowland, Benjamin A.. Multisensory Integration and the Society for Neuroscience: Then and Now., 2020. Reprinted with permission from Copyright Clearance Center, license ID: 1156308-1)

In the mid-1980s, the multisensory transformation was initially discussed at Society of Neuroscience meetings. It was evident that location and time should be guiding principles for integrating cross-modal inputs in the cat superior colliculus, but scaling the integration products was less pronounced. Multisensory integration's physiological foundations may be assessed in various ways, and it manifests differently in different brain areas. Inputs from another modality can modify the phase

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of background oscillations to resonate with an incoming signal from left to right. In distinct brain areas, "Unisensory" neurons can coordinate their activity to increase the impact of their signals on target structures. Individual multisensory neurons can integrate incoming information as soon as they come to increase response amplitude. Gross responses are detected at the ensemble level using Event-Related Potential and local field potential approaches. Multisensory integration can help in discrimination by generating more consistent activity distributions in a feature map and more coherent activation patterns in large-scale networks, indicating more efficient information processing (Stein et al., 2020).

Strong evidence has developed to support the hypothesis that multisensory integration is linked to cognitive function. As previously noted in regard to aging, extended vulnerability to the SIFI across lengthy SOAs is related to poor overall cognitive performance (e.g., MoCA), as well as executive function and memory. Several more lines of evidence support SIFI as a measure of cognitive function in the elderly and clinical subgroups. For example, older persons with MCI are still vulnerable to the SIFI at longer SOAs, but increasing cognitive load in young adults enhances SIFI susceptibility (Hirst et al., 2020).

Multisensory integration is most commonly assessed by considering the effectiveness of a cross-modal stimulus combination, component stimuli, for evoking some response from the organism (Stein & Stanford, 2008). Multisensory processing occurs at the early stages of sensory processing and modality-specific cortices, in the superior temporal sulcus and the intraparietal sulcus, and at relatively late stages of sensory processing (Fiorini et al., 2021). MCI people have cognitive functional impairments, which lead to disparities in audiovisual integration performance improvements compared to healthy older adults (Wu et al., 2012).

Furthermore, using Event-Related Potential, MSI of peripherally presented audiovisual stimuli in older adults revealed two periods of significant interactions: the right occipital area at 160–200 ms after the stimulus presentation and the left frontocentral area at 300–600 ms after the stimulus presentation. In addition, behavioral data revealed that response times to bimodal audiovisual stimuli were quicker than response times to unimodal visual or auditory stimuli (Yang et al., 2012). In MCI patients, P300 latency was significantly delayed (Papaliagkas et al., 2008).

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Moreover, the inclusion of an auditory synced to changes in a visual target feature produced a pip-and-pop effect that reduced mistakes and expedited visual search. These behavioral advantages were evident regardless of whether the audio stimuli were spatially aligned or misaligned with the visual search display. This is supported by an increase in the ERP N1 component in AV situations, regardless of AV spatial alignment. The final auditory stimulus preceding the participant's reaction on each trial, which was most likely integrated with the visual target, tended to elicit the most excellent N1 response. This result is consistent with AV synchronization boosting the AV target's salience (Fleming et al., 2020).

When opposed to healthy elderly, older adults with MCI incorporate more (perhaps irrelevant) audiovisual information. The sound-induced flash illusion (SiFi) is an audio-visual illusion that presents two beeps and one flash. It may be feasible to acquire a more thorough picture of the condition and deliver a more accurate diagnosis to persons who may have a language impairment by combining perceptual activities into a clinical diagnostic (Chan, Kaiser, Brandl, Matura, Prvulovic, J Hogan, et al., 2015). Furthermore, this illusion might be modulated by doing a flash counting activity with a partner (confederate) who had to identify the number of beeps provided. When the flash counting activity was done with a confederate, the sound-induced flash illusion was perceived considerably more often than when it was done alone. However, if visual access between the two persons is restricted, this impact is lost. When paired with earlier data, these findings show that doing a multisensory task simultaneously—in this case, an audiovisual activity—reduces an individual's attention to visual information, affecting the multimodal integration process (Wahn et al., 2020).

Part 3 Computerized cognitive stimulation

Cognitive stimulation therapy

Spector et al. (2003) first described the efficacy of an evidence-based cognitive stimulation therapy program for people with mild-to-moderate dementia. The intervention is mainly performed in a group environment and includes 14 sessions of themed activities such as current affairs, word associations, and money. The technique encourages participants to express their thoughts, actively stimulating

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and engaging them in an optimal learning environment, usually with group advantages. This evidence shows the usefulness and acceptability of CST for older adults with mild-to-moderate dementia.

The quality of life of the CST group improved significantly. It is worth noting that individuals in CST groups reported a higher quality of life, particularly in terms of memory, energy, relationships, and chore management. This finding supports the development of therapies aimed at improving cognitive performance in patients with dementia if they can also improve well-being. If the findings from psychological research can be applied to pharmacological investigations, then drugs with a primary effect on cognition may have more benefits (Woods et al., 2006).

Scholars translated and followed the instructions published by Spector et al. (2003) to build the Japanese version of group CST (CST-J). As a result, they used a single-blind, controlled clinical trial to look at the program's impact on Japanese patients with mild-to-moderate dementia in long-term residential care settings, as well as the intention-to-treat analysis from the original UK study. This finding showed a significant effect on cognitive function, increasing scores of MMSE and COGNISTAT (Yamanaka et al., 2013).

Participating in cognitive stimulation may stimulate neurons, which can then improve and safeguard their functioning, according to the "use it or lose it" theory. Cognitive activities may also activate neuronal systems directly, improving neural pathways involved in cognitive skills like memory and language. In a similar manner, there is evidence that social engagement can help to protect cognition. "Social interaction" can refer to a conversation between two or more people. Personal preferences may influence the kind of interactions a person engages in (Yates et al., 2014).

The previous randomized controlled trial showed the benefits of iCST in participants with MCI. The study aims to assess the results of the iCST program that helped improve cognitive performance that showed a significant improvement in post-test of cognitive function, as measured by the Spanish version of the MMSE, also significant in 6-month follow-up. Moreover, the Barthel Index result used to assess daily living activities shows differences between intervention and control groups. The control group declined scores during the intervention period while the Intervention

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group maintained their score. However, this does not show improvements in specific cognitive functions, and a lack of methodological uniformity could explain the variability of results. Implementing RCTs with a multimodal intervention and a broader range of assessment tools would be helpful. (Gomez-Soria et al., 2020).

Scholars discovered that home-based iCST followed by Making a Difference 3 (MD3) could increase cognitive performance when is implemented by caregivers. The intervention group contained about 57 percent of the patients with MCI or mild dementia, which might explain the increased favorable reaction to the intervention. Current data reveals that the smaller the cognitive impairment, the better the neuroplastic capacity and ability to learn, as well as the potential to induce neurogenesis (Silva et al., 2021).

Yates et al. (2017) provide a step guide for CST adaptation. The first step to take when adapting CST to a different culture is to decide which stakeholders to involve in the adaptation process and when to involve them. According to the formative method for adapting psychotherapy (FMAP), stakeholders may include;

1) participants,

2) mainstream health and mental healthcare providers,

3) community-based organizations and agencies,

4) traditional and indigenous healers

5) spiritual and religious organizations.

For the purposes of adapting CST, it is recommended that the following stakeholders relevant to each culture are approached:

1) participants and family caregivers

2) community health workers, such as village health workers

3) mental healthcare staff (psychiatrists, psychologists, social workers, therapists, and healthcare assistants)

4) other older people with knowledge of relevant historical, cultural, and religious issues.

In the Asian context, a South Asian variant of the CST program was created. Most activities were adapted to each individult, with cultural and ethnic concerns pertinent to the Indian subcontinent being used as inspiration. Two bilingual doctors in their first language, as well as a support worker, ran the program. It was

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decided that the day, time, and place of discussion at the start of each session would focus on events and issues relevant to localities in group members' countries of origin, such as local community news, news about their own families and friends, or news from the daily TV shows they were watching. For the number games session, they used a 'Carom board,' familiar sounds from their past like Rickshaw and Tonga (horse cart) for the sounds session, a discussion about the immigration process, routes, and difficulties for the orientation session, and famous historical figures from the Indian subcontinent for the faces session (Yates et al., 2017).

However, researchers should consider how varied culturally defined conceptions of old age and dementia in the various socioeconomic settings where the intervention is implemented would shape and affect the intervention's success in other cultures. There has been minimal evidence-based study on how cultures differ in their diagnostic methods availability and usage, as well as their use of diverse outcome metrics. In order to better understand the effectiveness of these customized therapies, the current study will investigate and address these limitations (Aguirre et al., 2014).

Multisensory stimulation

A Review of multisensory stimulation for people with dementia was found to be a practical nonpharmacological intervention for neuropsychological symptoms. The effectiveness of multisensory intervention in positive effects on the behavior, mood, and cognitive level (Sánchez et al., 2013).

Practical perceptual training in older persons has the ability to affect a variety of cognitive processes. Perceptual performance in older persons often shows greater multisensory interactions, as evidenced by a heightened vulnerability to the sound-induced flash illusion when given impending stimuli from several modalities (Setti et al., 2014). The sound-induced flash illusion is a psychophysical paradigm in which, depending on the stimulus condition, both integration and segregation of auditory-visual signals occur (Shams et al., 2005).

In audiovisual previous study, the Taiko video game was used for AV integrative training. The participants learned to play a Taiko drum (Japanese percussion instrument) to songs chosen through the Playstation 4 rhythm game "Taiko no Tatsujin." The MCI participants improved significantly more than the healthy group in attentional control ability as measured by the Stroop Test and non-dominant

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hand upper limb function as measured by the Purdue Pegboard Test (L. P. Lee et al., 2020).

A previous review of sensory intervention in older adults with dementia by Hayden et al. (2022) developed ten different categories of interventions: art, aromatics, light, multi-component interventions, multisensory rooms, multisensory, music, nature, touch, and taste. Music was the most common type of sensory intervention. 25 of the 40 music treatments were group-based, or group-based and individual-based. Music interventions are unusual in that they are the only intervention category in which more than 35% of the interventions are group-based. As a result, their appeal might be related to their practicality. Music therapies are generally more amenable to group-based delivery since they have a social component. Moreover, Multisensory therapies are intended to provide patients with dementia with a wide range of sensory stimulation. It also includes therapies integrating two distinct sensory stimuli, music and visual stimulation.

Moreover, spatial alignment influences auditory and visual (AV) integration in a more challenging context while competing for multisensory stimuli. An AV foil was added that visually resembled the target and was synchronized to its own stream of synchronous tones. The visual components of the AV target and AV foil occurred in opposite hemifields; the two auditory components were also in opposite hemifields and were either spatially aligned or spatially misaligned with the visual components to which they were synchronized. The search was fastest when the auditory and visual components of the AV target were spatially aligned. Attention modulated ERPs in both spatial conditions, but importantly, the scalp topography of early evoked responses shifted only when stimulus components were spatially aligned, signalling the recruitment of different neural generators likely related to multisensory integration. These results suggest that AV integration depends on AV spatial alignment when stimuli in both modalities compete for selective integration, a common scenario in real-world perception. In all spatial circumstances, attention influenced ERPs, but the scalp topography of early evoked responses varied only when stimulus components were spatially aligned, indicating the recruitment of separate neural generators presumably associated with multisensory integration (Fleming et al., 2020)

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Computerized cognitive stimulation

The well-known training games are one type of cognitive stimulation activity. These programs, which are accessible for phones, laptops, and tablets, may be utilized at any time and from any location. It is also common to be able to modify the difficulty level to fit the skill level of each individual. Lumosity, PSSCogRehab, CogniFit, CogMed, and others are among the training games that may be downloaded or accessed from web browsers.

Lumosity is a commercially available computerized cognitive training software that promises to increase memory, attention, processing speed, mental flexibility, spatial orientation, logical reasoning, and problem-solving abilities. This study chose it as the control condition because of the Lumosity group's claims that its games improve cognitive skills. Exercises are available to improve processing speed, memory, attention, mental flexibility, and problem-solving. The Lumosity cognitive program's main component is a collection of 52 games. Each game is a two-dimensional puzzle game that focuses on one of the aforementioned cognitive skills. The games require players to perform speeded object or pattern recognition, attend to multiple objects simultaneously, associate and memorize visual and verbal information, and identify hidden and changing rules in object sorting or sequencing, even though most game action is limited to pointing and clicking. The presence and quantity of distraction, the time restriction, the salience or complexity of the pattern or rule to be detected, and, therefore, the amount of cognitive effort and skill necessary all determine the game's challenge level. Lumosity is played by logging onto the Lumosity website and playing the games according to a specific training program or sequence. Each cognitive ability group is assigned to a certain sequence (e.g., memory, attention, processing speed, mental flexibility). Each personalized training session consists of five games that take around 5–6 minutes each (Shute et al., 2015).

PSSCogRehab is a Cognitive Rehabilitation Therapy System that is delivered as a computerized program. Attention, problem-solving, memory recall, and visuospatial activities are the main focus of the training. Sequential and nonsequential recall are both used in memory training (e.g., words, digits, and graphics involving auditory and visual tasks). Completing additions and subtractions, building pyramids by stacking smaller disks atop bigger ones with as few moves as possible, and

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arranging marbles in precise color patterns are all part of developing problem-solving skills. Finally, exercises like line and angle discrimination, design completions, block counting, and selecting which pattern is different from the others to use are all part of visuospatial training (Brooks et al., 2020).

CogniFit is a commercially accessible computerized cognitive training platform that has been utilized in a variety of research with a variety of groups. The behavioral components of the treatments were designed primarily in accordance with the BCT taxonomy. A computerized cognitive evaluation that is part of the CogniFit platform and is used to create a profile of each participant's cognitive strengths and limitations. Participants take parts of this exam during their training term, allowing their cognitive strengths and weaknesses profile to be updated on a regular basis. Participants then go on to train on the 33 activities that make up the CogniFit training platform, with task assignments determined by a computer algorithm and modified during the training session depending on the cognitive profile created following the built-in evaluation (Bloom et al., 2017). Auditory short-term memory, hand-eye coordination, general memory, naming, cognitive flexibility, spatial perception, time estimate, and visual perception all improved considerably after Cognifit training (Shatil et al., 2008).

CogMed is a computerized WM training software that was created to help children with ADHD improve their WM. In these and other groups, such as autism spectrum diseases, Huntington's illness, epilepsy, and AUD, CogMed has shown promising outcomes. However, the bulk of research is still done on children, primarily with diseases that are defined by poor WM, such as learning difficulties, ADHD, dyslexia, children with hereditary illnesses like sickle cell disease (SCD), and children born preterm, or with a deficient birth weight. Adults with clinical problems are among the various clinical groups (e.g., symptoms of pain, insomnia, fatigue, depression, and anxiety).The most important outcomes were from CogMed studies on children and adolescents, with evidence of verbal, visuospatial WM, and short-term memory (STM) improvements in children with SCD and those born preterm. The impact of CogMed on nine Huntington's disease patients in the early stages (26-62 years of age). The patients had a total of 25 CogMed sessions (5 days per week for 5 weeks). Patients who completed the program effectively exhibited gains on CogMed

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tasks as well as a positive attitude toward the instruction. These results demonstrate the applicability of CogMed in this group (Brooks et al., 2020).

Not only commercial software but also free applications available are improved cognitive functions. For example, various games, Internet activities, e-mail, and slideshows with music were among the computer activities available. Computer games like block-match, solitaire, and others were available for free or for a fee on many websites. Searching for information, seeing photographs and videos, and listening to music were among the Internet activities. The PowerPoint slideshows used photographs from the National Geographic Photo Gallery program, which were accompanied by soothing and pleasant music that had previously been utilized with dementia patients. Participants were given their own e-mail addresses so that they could communicate with their families if they so desired. An increase in time spent on computer activities (particularly computer games) may be advantageous to cognitive performance in dementia patients. Playing a variety of computer games may be both pleasant and mentally engaging, making it a worthwhile recreation option (Tak, 2020).

In healthy older persons, personalized, computerized cognitive training may give higher cognitive advantages than traditional computer games. Individuals who suffer from cognitive decline may expect even more enormous benefits from personalized cognitive training (Gigler et al., 2013). Furthermore, computerized psychomotor tasks have become an essential tool in cognitive neuroscience. Excellent control over stimulus characteristics, as well as accurate monitoring of their influence on response choices and timing, has shown to be highly useful in sorting out cognitive processes and how they are altered by aging and diseases (Altena et al., 2010). Cognitive functions are improved by training and practice. In older individuals, computerized training, particularly in working memory, has been a significant emphasis. Recent assessments of computerized ef training for adults are cautiously positive, although they do point up significant design problems (Diamond, 2013).

Moreover, clinical telegaming software that evaluates sensory processing deficits, such as our new STEP (Sensory Training and Evaluation for Parkinson's disease) prototype software, will have the potential to diagnose patients at much earlier stages of the disease, allowing for therapeutic intervention to delay the onset of

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more burdensome symptoms. Motor complaints can be directly connected to sensory processing abnormalities. Decreased proprioception and vision, for example, cause problems with balance, walking, and posture, all of which are prominent motor symptoms of Parkinson's disease. As a result, clinical telegaming therapies that target sensory processing will aid in the early detection of Parkinson's disease and may be used as therapeutic tools to improve motor function. A fully updated version of a web application that may evaluate multisensory integration has been produced, with an improved user interface design and extended game-like aspects for user engagement with the software. STEP, a new web-based software system, assesses users' capacity to execute multimodal perception and integration of aural and visual inputs by measuring reaction time and accuracy. Predictably, this program will be used to compare the performance of PD patients to that of healthy control people. In multimodal reinforcement situations, normal volunteers showed significant improvements in reaction time. In multimodal conflict settings involving auditory stimuli, response times were slower in the older age group. (Xu et al., 2015)

Compared to traditional procedures, computerized cognitive intervention offers various advantages. Training tasks are beneficial because they (a) can be tailored to a specific cognitive function (e.g., memory, attention); (b) can be adjusted continuously based on the participant's performance; (c) can be designed to be highly immersive and enjoyable; (d) provide immediate quantitative feedback; and (e) can be accessed via portable digital devices. Indeed, using the same gadgets or computers, it is feasible to use a combination of cognitive stimulation, cognitive training, and cognitive rehabilitation to improve cognitive function (Irazoki et al., 2020).

Concerning computerized intervention, effectiveness must be accompanied by a solid commitment to the intervention's conceptualization, with theory-based assumptions and hypotheses required and explicit. Furthermore, the role of the conceptual framework must be reviewed at each stage of the intervention's development and implementation (Willis & Schaie, 2009). With computerized cognitive exercises and social interactions among participants, the computerized cognitive stimulation program was developed to stimulate multiple cognitive domains. The following was the format for each session: 1) The day's agenda is presented, followed by a review of the previous session and a debate (15 minutes). 2)

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Tablet-based cognitive activities with a brief pause in between (60 minutes). 3) Post-session feedback and group discussion (15 minutes). Computerized cognitive exercises were chosen from the Institution version of KODRO (Altera-Group, Paris, France), a web-based platform with several applications tailored to older adults (such as appointment and event reminders, cognitive games, communication, entertainment, videos and a library). KODRO was chosen because of its extensive library of fun and ecological cognitive activities. When comparing pre-and post-intervention evaluations, there was a trend toward an improvement in the total of three free recalls as measured by the RL/RI-16 and a substantial reduction in TMT-B error. However, this study lacks participant numbers. (Djabelkhir-Jemmi et al., 2017).

Furthermore, both MCI individuals with and without WMH may benefit from this sort of computerized cognitive stimulation program, with benefits seen across several cognitive domains and some gains lasting for a short period of time. However, the varied results in the two groups imply that brain lesions may have an impact on intervention outcomes. MCI-non-WMH patients improved on more cognitive measures than MCI-WMH subjects, who did not show any improvement in some cognitive processes. These study findings revealed that MCI-WMH patients might improve on some aspects of executive functions, processing speed, and memory, indicating that these patients may have cognitive plasticity. At the same time, they are at a higher risk of increasing cognitive decline as lesions progress and acquiring AD and dementia. These findings are promising, and a randomized controlled experiment should be conducted to validate them. (Djabelkhir-Jemmi et al., 2018).

For computerized individual CST, The Individual Cognitive Stimulation Therapy (iCST) approach may be beneficial, converting them to a computer-based platform. This would be useful for those who have trouble managing manuals because the materials may be reused, and if done on a computer tablet, the sessions could be done while out and about. A computer-based software would also be able to track or monitor progress, keep track of session adherence, and assist users in determining which level of exercise (A or B) is best for them. On a computer-based platform, sessions can include media (e.g., photos, video clips, audio tracks) that can be quickly accessed over the internet, and unlike the manual, which is limited in content, a huge bank of activity materials can be made available and updated on a regular basis. A

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computer platform would also include social interaction features like forums and online help, which might be beneficial for users to discuss their program experiences, exchange information and suggestions, and seek help. (Yates et al., 2017).

Recently, scholars were shown a protocol that the iCST app is the first computerized version of iCST that persons with mild-to-moderate dementia and their caregivers may use on touchscreen tablets. Through the use of interactive touchscreen technology, it seeks to give cerebral stimulation as well as spark dialog amongst dyads. This study aims to assess the usability of the iCST app intervention and the feasibility of conducting a full-scale randomized controlled trial (RCT) to compare the clinical effectiveness of the iCST app intervention to treatment as usual for people with mild-to-moderate dementia. The iCST app activities consist of three types including (1) Games only such as being creative, spaceman, trivia quiz, word search, sudoku, being active, brainstorm, (2) Discussion questions only such as past events, useful tips, my life, arts, old wives' tales, toys are us, and (3) games and discussion questions such as sounds, odd one out, the price is right, globe trotter, food, in pairs, sayings, and ispy (Rai et al., 2021).

Development of computerized cognitive stimulation

The software/systems development life cycle (SDLC) is frequently used to define a process model since it is meant to represent the stages that software development goes through. It is characterized as a process paradigm in which each step builds on the previous logically and orderly manner (Rosen, 2020).

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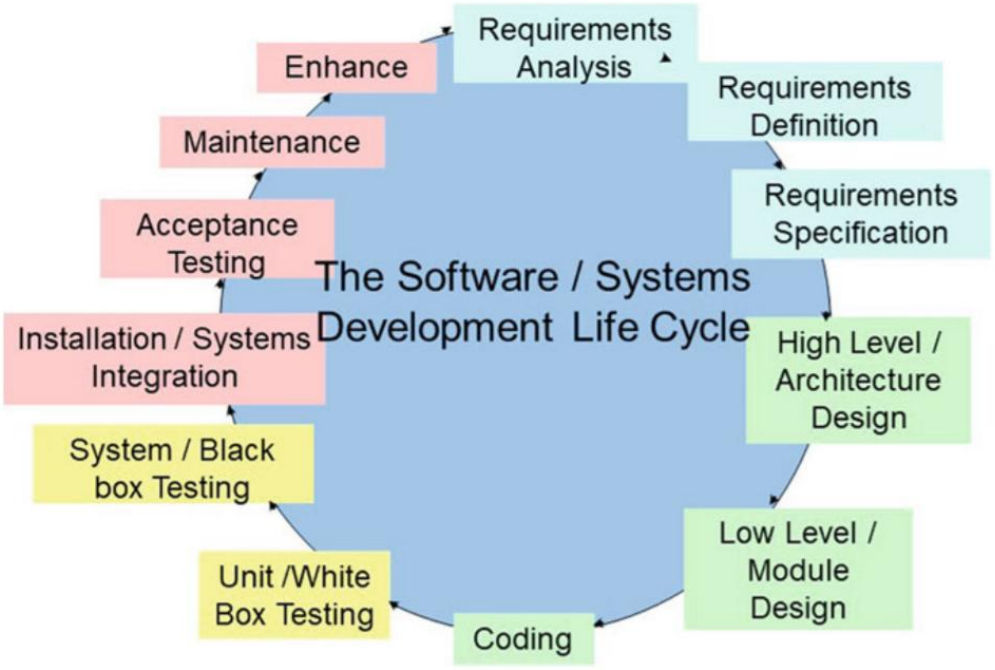

Figure 3 The software development life cycle
(From Rosen, Clive. Guide to Software Systems Development: Connecting Novel Theory and Current Practice, 2020. Reprinted with permission from Copyright Clearance Center, license ID: 1156400-1)

Classical software development with a focus on detailed planning, documentation and design comes under heavyweight. Waterfall, Iterative and spiral are a few examples. Newly developed lightweight models focus on short iterative cycles with minimum documentation to give a better end product in the shortest time. Thus, Waterfall was selected as a model for software development. Several reasons were described as follows (Ateeq & Shuaib, 2014):

1) Simple and straightforward to comprehend and use
2) Due to the rigidity of the model, it is simple to manage.
3) There are specified deliverables and a review mechanism for each phase.
4) Each phase is handled and completed separately.
5) This method works effectively for smaller projects with well-defined needs.
6) Stages that are well defined.

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7) Milestones that are well-understood.

8) Tasks are simple to organize.

9) The process and outcomes are meticulously documented.

The Waterfall SDLC model is a sequential software development process in which progress is viewed as flowing more downwards, similar to a waterfall, through a series of phases that must be completed in order to construct a computer program effectively. The waterfall model runs through requirements, design and implementation, testing, release, and maintenance phases (K. Petersen et al., 2009).

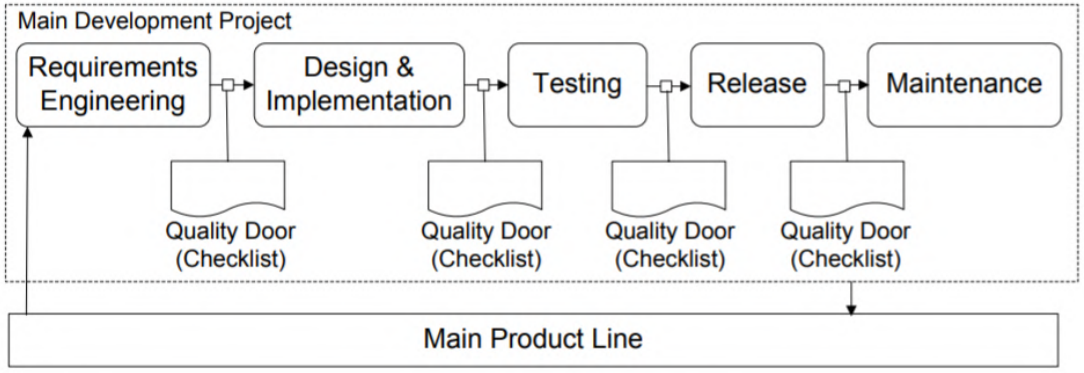

Figure 4 Waterfall development

(From Petersen, Kai; Wohlin, Claes; Baca, Dejan. The Waterfall Model in Large-Scale Development, 2009. Reprinted with permission from Copyright Clearance Center, license ID: 1156406-1)

Requirements phase

Software requirements define what a customer expects from a solution or what the system must do. These can be divided into two categories: functional and non-functional needs. The solution's functionality is directly tied to the functional requirements. These often initiate computations, data processing, file opening, reading, and writing, data manipulation like picture editing, and other system-specific capabilities. Non-functional requirements are those that the user or client would want to see in the solution, but that has no bearing on what it accomplishes. These are referred to as quality standards. Non-function requirements are frequently linked to the system's restrictions. For gathering requirements: Surveys, interviews, reports, and

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observations are commonly used to gather software requirements specification (SRS) data. Data acquired during software development is used to define the project scope, functional and non-functional requirements, and limitations. It may also assist in determining who will be the ultimate users of the program and how the client will use it (Bass et al., 2019).

A definition of software requirements must be generated during this stage of software development. The Software requirements specifications (SRS) must document the functional and performance criteria that have been assigned to the software product. Multiple software configuration item specifications may be used to fulfill the criteria. It should include the operational model's functional behaviors, data exchange needs, interface requirements, and human-machine interface requirements. Different software interface standards may be used to document these interface requirements (Schmidt, 2013).

Furthermore, software interface requirements specification, all interfaces, including human-machine interfaces, should be documented as part of the operational data exchange requirements. Each interface between the product, other systems, applications, and elements of the computing environment should be identified in the software interface requirements specification. Each interface need must be specified in terms of the exchange's informative content as well as the method of data transmission among the participating configuration objects (Schmidt, 2013).

Design and implementation phase

Chemuturi (2018) described that people quickly grasp when discussing the design of a building or a physical product. However, it is more difficult to talk about a software product that is not apparent to the naked eye. When talking about a product's structure, are talking about the logical arrangement of components that:

1) Are frequently unseen from the outside
2) Hold the product together
3) Support the rest of the components
4) Make the product more durable
5) Ensure the product's safety and security

Before passing the produced code to the testing phase, the developers do basic unit testing (K. Petersen et al., 2009). The definition of unit testing can be

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interpreted in a variety of ways. A unit can be a single process, a function, a body of code that implements a single function, source code that fits on one page, a body of code that reflects work done in 4 to 40 hours, or the smallest body of code that can be built and run by itself in a procedural programming language (Jorgensen & DeVries, 2021). The quality gate checklist validates, among other things, that the architecture has been examined, that there are deviations from the requirements when compared to the prior quality gate decision, and that there is a divergence from the intended timeline, effort, or product scope (K. Petersen et al., 2009). The analysis of the code's internal logic and structure in depth When employing the White Box Testing Technique, a tester must have complete knowledge of the source code (Khan & Khan, 2012).

Designing user interfaces for an aging population they are particular users with small percentages. Designers and developers of websites, web apps, desktop apps, mobile apps, and digital appliances should be doing their best to make it useful and usable. While designing the application, vision, motor control, hearing and speech, cognition (attention, learning and memory), knowledge, search, and attitude could be concerned (Johnson & Finn, 2017).

Castilla et al. (2020) describe the main usability for users with MCI were the following:

1) Related to spatial abilities and attention: Because less independent users displayed an attentional concentration on the central area of the screen and attentional blindness to the periphery graphical elements, it was necessary to locate the major interaction elements (e.g., continue the action in step-by-step navigation) in the center of the screen.

2) Related programming interaction: Because consumers expect real-time changes in buttons (such as sinking when pressed), users interacted with them by pushing them repeatedly, resulting in an unexpected interaction result (copying text or activating the secondary browser menu). On the other hand, users wanted to know what buttons they were hitting while pressing them, which explains why they pressed the buttons on the outside.

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3) Related audio help: The typical synthetic speech speed (3 words per second) was too quick, and most users were unable to understand the instructions.

Testing phase

In this step, system integration is evaluated for quality and functionality. Measures of performance (e.g. throughput) are collected in the test laboratory to determine whether the system can be implemented. The phase's results are checked against a checklist to verify if the system has been confirmed (K. Petersen et al., 2009). Testing is obviously concerned with errors, faults, failures, and incidents. A test is an act of exercising software with test cases. A test has two distinct goals: to find failures or to demonstrate correct execution (Jorgensen & DeVries, 2021). Moreover, the user acceptance test is used in which the client verifies the program to see if it is suitable for their usage and meets their business requirements. After the consultants have successfully tested each software component, it is turned over to the customer for acceptance testing (Ganesh et al., 2014). Testing without having any prior knowledge of the application's underlying workings. The Black Box Testing Technique solely evaluates the system's essential characteristics and has no or little significance to the system's underlying logical structure (Khan & Khan, 2012).

Release phase

The product is brought into a shippable state during the release phase. That means release documentation such as customer installation instructions and user manuals is complete (K. Petersen et al., 2009).

Maintenance phase

Maintaining the product once it has been released to the client is necessary. In other words, if customers find flaws in the product, they report them to the firm and receive assistance in resolving them. If product flaws cause difficulties, users will get software update packages (K. Petersen et al., 2009).

Part 4 Neuropsychological and EEG/ERP assessment

Neuropsychological assessment

Neuropsychology is a field of clinical psychology that investigates the interrelationships and effects of cognitive functions on human behavior. It is worth

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noting that because cognitive functions are intertwined, it is difficult to draw clear distinctions between them. Commercially accessible tests that measure attention, memory, perception, and expressive and executive skills are conducted using questions and drawings, commonly known as "pen and paper" exams. (Goulart et al., 2021). Neuropsychological assessment is historically significant because it combines two distinct antecedents from central and eastern European behavioral neurology and American and English psychometrics. Neurologists have always been interested in the behavioral manifestations of structural brain damage. Clinical neuropsychological evaluation has recently emerged as a distinct discipline distinct from general clinical psychology due to members' specific expertise in brain-behavior relationships and nervous system diseases. Both the standard batteries and the individual neuropsychological tests have been expanded (Goldstein & Hersen, 2000).

A wide range of clinical applications in neuropsychological assessment has, from the comprehensive characterization of a wide range of cognitive abilities to identifying a cognitive profile that can aid in predicting future deterioration and functional capacity in older adults (Lu & Lee, 2017). Using neuropsychological assessment in MCI establishes a quantitative cognitive baseline against which future changes can be measured and an objective assessment of a wide range of cognitive domains and well-constructed instruments for systematically gathering and evaluating data on mood, behavior, and functional ability (Nelson & O'Connor, 2008). To better describe MCI patients, a neuropsychological evaluation was conducted using specialized tests in many cognitive domains (Sánchez-Catasús et al., 2018)

Global Cognitive Function

Most of the global cognitive function assessments in a complete neuropsychological battery are associated with the MMSE and provide a brief overview of functioning in terms of essential attention, memory, language, and spatial-constructional skills (Nelson & O'Connor, 2008). However, a cross-sectional study of 229 older adults in four medical centers and three systematic reviews showed that the MoCA has higher sensitivity and specificity than the MMSE. As a result, the MoCA may outperform the MMSE as a comprehensive neuropsychological screening tool (Chen et al., 2021). Furthermore, Clarens and colleagues (2022) discovered that the MoCA Total Score and subscores, Attentional and Executive Index Score, had

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higher sensitivity and specificity than a commonly used screening test, such as the MMSE, in distinguishing groups of MCI patients with and without amyloid physiopathology (Clarens et al., 2020). Because changes in the brain accompany aging, an imbalance of amyloid formation occurs in memory-related locations (Jia et al., 2020).

The MoCA is assessed on seven domains of performance: visuospatial/executive, naming, attention, language, abstraction, memory, and orientation. Individual item performance was used to calculate a global score (range: 0–30). Higher scores indicate improved cognitive performance (Cersonsky et al., 2022). The MoCA test validation study in Thailand revealed that it was a promising tool for detecting MCI. The MoCA had a sensitivity of 90% and specificity of 87%, with a cut-off score of 24 or above regarded as normal (Phongthara Vichitvejpaisal et al., 2015).

Learning and memory

The delayed recall Rey Complex Figure test (RCFT) was used to assess nonverbal episodic memory. Non-verbal episodic memory is a good discriminator between AD and non-AD pathologies, as well as between non-semantic primary progressive aphasias, according to recent research. The digit span was evaluated to assess short-term memory (Sánchez-Catasús et al., 2018).

In the Rey Auditory Verbal Learning Test (AVLT) immediate recall in the high α3/α2 group, memory performance significantly correlated with lower perfusion values in the caudal bank of the right inferior temporal sulcus and the middle frontal gyrus. AVLT delayed recall: The high α3/α2 group memory function correlated significantly with lower perfusion values in the inferior parietal lobule, particularly in the supramarginal gyrus. There demonstrated a desynchronization in the temporoparietal memory-related networks during the successful encoding of new items, whereas synchronization prevents successful semantic encoding (Moretti, 2015)

The diversity in the degree of preference or acceptance among older individuals owing to lack of experience, poor familiarity, or general perception is a significant problem with introducing modern technologies such as computer- or touch-screen device-based testing modalities. Elderly patients, on the other hand, exhibited a high level of acceptance and comfort with technology-based engagement,

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and the majority of participants were ready to do the exams (Morrison et al., 2018). Standardization of administration and stimulus presentation, a suitable method of reaction latencies, automated comparison in real-time with an individual's past performance and age-related norms, and staffing and cost benefits are all advantages of computerized cognitive testing (Wild et al., 2008).

The Hopkins Verbal Learning Test (HVLT) is a short verbal recall and recognition test that takes about 5 minutes to complete. It consists of three free recall learning trials based on the cueing process of lists of words from related semantic categories, followed by a recognition trial. The HVLT is based on more comprehensive verbal new learning tests, such as the California Verbal Learning Test, and does not appear to suffer from the ceiling effects of the MMSE and CAMCOG verbal learning tasks. The HVLT also has the benefit of having six comparable forms, allowing for accurate re-testing even at short intervals. It may be helpful in the serial evaluation of patients with fluctuating cognitive performance, such as delirium, as well as in the serial assessment of patients with progressing illnesses like AD (Frank & Byrne, 2000).

Language

Language and communication are only significantly damaged in the late stages of AD development. Therefore, early indicators of the disease are most likely connected to noncore linguistic functions like failure to focus. Verbal fluency tests, on the other hand, are adversely affected (Wallentin, 2020).

Moreover, the Boston Naming Test (BNT), which consists of 60 black and white line drawings of items, is a confrontation naming measure that considers that patients with dysnomia have a more challenging time naming low-frequency objects (Roth, 2011). It can determine the degree of difficulty in identifying words experienced by healthy older people as well as those in the early stages of dementia (Soares et al., 2015).

Visuospatial

The Rey Complex Figure Test (RCFT) was used to measure visuospatial skills. Token and verbal fluency tests were used to assess the language domain. The attentive matrices were used to evaluate the executive function, and the

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trail building A and B tests were used to assess attention (Sánchez-Catasús et al., 2018). The Rey–Osterrieth Complex Figure (ROCF) test is widely used to investigate the neural relevance of structural functions in healthy people as well as the mapping disorders of patients with dementia and other brain diseases like AD, Lewy body dementia, frontotemporal dementia, Parkinson's disease dementia, cerebral small vessel disease, and MCI. In various mental disorders, such as attention deficit hyperactivity disorder, eating disorder, and schizophrenia, the ROCF test has also been used to assess visuospatial ability, learning, visual memory, and executive dysfunction (Zhang et al., 2021).

Furthermore, the mental Rotation Test has been shown to activate Brodmann's Area (BA) 7 in the parietal lobe, BA 8 in the frontal cortex, and visual area MT/V5 in the occipital lobe. BA 8 controls eye motion, BA 7 for locating objects in space, and visual area MT/V5 for responding to stimuli motion (Berteau-Pavy et al., 2011).

Executive

The tests and domains of executive functions most frequently used by research groups worldwide to evaluate older adults include: 1) Trail Making Test (TMT) Form B; 2) Verbal Fluency Test (VFT) - F, A, and S; 3) VFT Animals category; 4) Clock Drawing Test (CDT); 5) Digits Forward and Backward subtests (WAIS-R or WAIS-III); 6) Stroop Test, and 7) Wisconsin Card Sorting Test (WCST). Mental flexibility, verbal fluency, planning, working memory, and inhibitory control were the most commonly tested executive function domains (Faria et al., 2015).

The Trail Making Test (TMT) is divided into two stages, with the time it takes to complete each portion used to assess central executive function. Part A (TMT-A) requires the participant to draw a line from 1 to 25 connecting consecutive integers. The participant links numbers and letters in an alternate progressive sequence in Part B (TMT-B), such as 1 to A, A to 2, and 2 to B. The time taken to complete TMT-B emphasizes central executive processes of task-set inhibition, cognitive flexibility, and the ability to maintain a response set, and the time taken to complete TMT-A, which has little executive input, is calculated to measure central executive functioning. The TMT-B to TMT-A ratio can also be employed (McMorris, 2016).

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The phonological VFT (P-VFT) seeks to generate as many words as possible that begin with a particular letter within 60 seconds. The letters F, A, and S are commonly used in the literature and correspond to the test's original stimulus. However, other studies changed the letters to accommodate language and culture, such as adding M because it is one of the most common letters in the Spanish language. (Rodríguez-Lorenzana et al., 2020).

In the category VFT or Semantic Fluency, the most general category is "animals," and the examinee is given one minute to come up with as many animal names as possible. Food names (fruits and vegetables) have also been employed, as well as "items in the kitchen," "things in the store," "things to wear," "things that get you from one location to another," and "first names," and so on. Other forms of the exam include a mix of phonetic and semantic fluency, as well as "action fluency" or a "switching format," in which the participant must alternate between categories such as fruits and furniture, colors and birds, in order to put more pressure on executive functions (Strauss et al., 2006).

In a primary care context, the Clock Drawing Test (CDT) is a rapid, easy, and cost-effective method for diagnosing dementia. It is beneficial for identifying people with moderate to severe AD, but it has limits when it comes to detecting MCI and early-stage AD. It's also great for assessing participants at different levels of education and across cultures. Currently, CDT and MMSE are being tested together to see whether they may enhance MCI case identification. In the original CDT, the subject is handed a pre-drawn clock and instructed to draw the clock hands, showing 10 minutes past 11 o'clock. The grading method is straightforward and based on a 10-point scale. The scoring is determined by how the clock was painted with analog clock markings: 12 numerals, with the hour-hand and minute-hand in the proper position (T. Khan, 2016).

Wisconsin Card Sorting Test (WCST) A shortened standardized form of WCST, Berg’s Card Sorting Test, the card sort task uses a modified 24-card deck in which none of the cards matches the sort piles on more than one attribute (i.e., number, shape, or color). Rule changes are made after five correct sorts in a row, and participants complete 64 total sorts. The cards are shown on a screen in the computerized version of the WCST (top left part). The four stimulus cards are the

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same as in the card version, but the participant responds using the keyboard (numerical keys 1, 2, 3, and 4). Each trial begins with one answer card in the center of the screen, which the participant must match to one of the four stimulus cards. The four locations of the stimulus cards, which appear on the upper left side of the screen, are represented by the numerical keys on the keyboard (Wagner & Trentini, 2009).

The computerized WCST version was utilized to reduce the complexity of the WCST administered and to improve data-collecting efficiency. WCST parameter indices will be collected in the following order: (1) Percent errors (PE); (2) Percent perseverative responses (PPR); (3) Percent perseverative errors (PPE); (4) Percent non-perseverative errors (PNPE); (5) Percent conceptual level responses (PCLR); and (6) Number of categories completed (CC) (Shan et al., 2008).

Psychomotor

Different reaction time (RT) activities can be used to measure psychomotor abilities. Participants in the choice reaction time (CRT) experiment must choose between two response alternatives based on the nature of the stimulus given. Subjects reply as quickly as possible to a single stimulus in the simple reaction time task (SRT). While both tasks have a psychomotor speed component, CRT also includes a choice selection component. In normal aged controls, extra decision-making time is decreased when a trustworthy signal precedes the stimulus (Levinoff et al., 2005). Moreover, when compared to healthy patients without MCI, the frequency of finger tapping in MCI subjects' left hands was considerably lower. An infrared photoelectric sensor was used to detect finger tapping movements, and the resulting data was sent to a computer through a serial connection with a millisecond precision setting (Zhang et al., 2018).

Emotions

Depression

Even though there are several tools for measuring depression, the Geriatric Depression Scale (GDS), which was developed by Sheikh and Yesavage (1986) has been widely evaluated and utilized with the elderly population (Greenberg, 2012). Especially older individuals who are healthy, medically sick, or have mild to severe cognitive impairment. It has been utilized in a variety of settings, including community, acute care, and long-term care. The Thai version of the 15-item Geriatric

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Depression Scale (TGDS-15) was effective at screening for MDD in elderly cognitively intact Thai (Wongpakaran et al., 2013). After adjusting for age, education, gender, and Mini-Mental State Examination score, it was shown that the aMCI group had higher depression levels than the cognitively normal group for both ethnic groups. Poorer scores in confrontation naming and semantic memory for just the European Americans group, as well as moderately lower executive function scores for HA participants, were also predicted by higher levels of sadness. GDS-15 scores below 4 also indicated a lower probability of an aMCI diagnosis (Lang et al., 2021).

Anxiety

Freud described anxiety as "something felt," an emotional condition characterized by sensations of dread, tension, uneasiness, and concern coupled with physiological arousal. Freud noted that anxiety was adaptive in driving action that helped people cope with stressful situations and that acute anxiety was common in most mental diseases, which is consistent with Darwin's evolutionary viewpoint. In 1966, Cattell stressed the significance of separating anxiety as an emotional state from individual variations in anxiety as a personality feature when measuring anxiety (Spielberger, 2010). Previous systematic review studies show that nearly 2/3 of 149 neuropsychological tests reported some relationship between test performance and anxiety (Dorenkamp & Vik, 2018). The gold standard for measuring anxiety in adults is the State-Trait Anxiety Inventory Form Y (STAI). The STAI-S Anxiety scale evaluates the fundamental characteristics of anxiety, tension, nervousness, and worry (Spielberger, 1983). This study will use the State-Trait Anxiety Inventory Form Y-1 because we focus only on preoperative anxiety. The STAI-state has the 20-item Thai version and has been validated by Darawan Thapinta (Thapinta, 1991).

Multisensory integration

The sound-induced flash illusion (SIFI) is a psychophysical paradigm in which, depending on the stimulus condition, both integration and segregation of auditory-visual signals occur (Shams et al., 2005). The SIFI illustrated multisensory integration phenomena that are dominated by the auditory system. When a single flash of light is followed by many auditory beeps, the single flash is interpreted as multiple flashes, and the temporal window of these audiovisual interactions is roughly 100 milliseconds (Shams et al., 2002).

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The SIFI has also been utilized to discover sensory processing changes across MCI, possibly due to the task's simplicity (Hirst et al., 2020). Researchers discovered that a group of individuals with MCI and healthy controls experienced SIFI. Over longer auditory time intervals, MCI participants perceived considerably more illusions than HC participants. This shows that, when compared to HCs, MCIs incorporate more audiovisual information. It may be feasible to acquire a more thorough picture of the condition and deliver a more accurate diagnosis to persons who may have a language impairment by combining perceptual tasks into a clinical diagnostic (Chan, Kaiser, Brandl, Matura, Prvulovic, Hogan, et al., 2015).

Moreover, Previous studies on EEG and ERP in sound-induced flash illusion. According to EEG research, the apparent illusion boosts early ERP components in the occipital brain. Short-latency ERP activity in the auditory cortex and polymodal cortex of the temporal lobe and gamma bursts in the visual cortex were linked to the perception of the double-flash illusion. The importance of quick interactions between unimodal and polymodal cortical areas in achieving multisensory integration was highlighted in this study (Mishra et al., 2007).

In addition, there were three types of stimuli in the Audiovisual Integration task: unimodal visual (V) stimuli, unimodal auditory (A) stimuli, and bimodal audiovisual (AV) stimuli. Each task's accuracy and response time (RT) were assessed to observe the tasks, and the RTs were examined using cumulative distribution functions (Wu et al., 2012).

For an example of stimuli 1) Auditory-Alone, an audible female voice was presented speaking the word red (duration ~180 ms) from speakers placed bilaterally to the computer screen. The volume control was adjusted to the halfway mark to ensure a comfortable and easily discernible sound level, which was the same volume for each participant. 2) Visual-Alone, A red circle (diameter 30 cm) appeared on the screen for 60 ms, placed centrally in the vertical and horizontal plane. 3) Multisensory: The auditory and visual stimuli occurred simultaneously from speakers and a computer screen adjacent to one another (McCracken et al., 2019).

EEG and ERP assessment

Biomarkers are the most widely researched indicators of the existence of certain lesions in AD. Beta-amyloid protein is a major aspect of senile plaque, while

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hyperphosphorylated tau protein is a key component of neurofibrillary degeneration. One of the most constant characteristics of AD is hippocampal atrophy in the brain (Portet et al., 2006). It is the first and most seriously damaged part of the brain. According to the popular hippocampal-cortical-dissociation concept, early injury to the hippocampus creates a dissociation in the cerebral cortex, resulting in the failure to register information originating from the hippocampus. (Anand & Dhikav, 2012). Similarly, hypoperfusion and hypometabolism in the temporoparietal cortices, medial temporal lobe atrophy, notably in the rhinal cortices, increased tau and phosphorylated tau in the cerebrospinal fluid, and brain $A\beta_{42}$ deposition are all neurobiological characteristics of MCI (Anderson, 2019).

A multitude of neurotransmitter changes, such as noradrenergic, serotonergic, and dopaminergic, occur in the brains of AD (Anand & Dhikav, 2012). In the worst phases of AD, the ACh index revealed a significant drop. The Ach index and cognitive function were found to have a strong relationship. In patients with MCI and prodromal AD, the index was lower, indicating lower cholinergic activity. When looking at the distribution of the Ach index in a group of healthy older people, it was discovered that there is an age-related threshold beyond which cholinergic activity begins to drop (Johannsson et al., 2015).

Magnetic resonance imaging (MRI) modalities have proven to be quite useful in finding biomarkers for AD and MCI pathology (Chandra et al., 2019). Therefore, PET imaging in MCI patients is often used to look for hypoperfusion, hypometabolism, and increased amyloid buildup in all parietal regions, especially in the posterior cingulate gyrus and inferior parietal lobule. In the early stages of AD, the amount of research combining MRI and PET methods has lately increased. However, these investigations found grey matter differences in all parietal regions and longitudinal neuroimaging measures between the groups under examination. Nonetheless, numerous investigations have revealed no structural differences in the parietal brain, suggesting that structural results in the parietal lobe are less outspoken than those in the temporal lobe (Jacobs et al., 2012). These biomarkers, on the other hand, are not suitable for community health care since they are costly, time-consuming, intrusive, and radiational.

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Despite recent efforts to develop a biomarker-based guideline for diagnosing MCI, there is still space for improved biomarker accessibility, reliability, and validity. Electroencephalography (EEG), on the other hand, is a potential option because it is non-invasive and very inexpensive. As a result, EEGs may offer much promise in aiding in the clinical diagnosis of MCI and AD (Trinh et al., 2021).

Electroencephalography

EEF's history dates back to the early 1300s, and it has continued to develop clinical, experimental, and computational studies for the discovery, recognition, diagnosis, and treatment of a wide range of neurological and physiological brain abnormalities, as well as the rest of the human central nervous system (CNS), on a daily basis. EEGs are currently recorded utilizing completely computerized equipment, both invasively and noninvasively. The EEG machines come with a variety of signal processing capabilities and sensitive and precise measuring electrodes, and adequate memory to record for many hours (Sanei & Chambers, 2021).

The EEG is a representation of electrical potentials from the cerebrum. However, it only gives a very restricted picture of brain activity. Because of the distance between the electrodes and the brain generators and intervening resistant tissues, EEG has poor sensitivity. Because currents are generating the potential flow according to the architecture of the cerebral surface, and EEG is insensitive to fields that are tangential to the scalp, the fields recorded by EEG represent only a tiny portion of cerebral current flow. This causes EEG to be biased toward longer-duration potentials, which are more likely to overlap in time and so synchronize. As a result of their extended durations, EEG displays excitatory and inhibitory postsynaptic potentials. EEG's spatial resolution is likewise reduced to this scale due to the required synchronization region. Despite this, EEG has a high temporal resolution and may detect changes in electrical potentials as small as milliseconds (Stern & Engel, 2013).

The five primary brain waves are differentiated by the frequency ranges in which they occur. These frequency ranges, which range from low to high, are known as alpha (α), theta (θ), beta (β), delta (δ) and gamma (γ). *Delta* waves have a frequency of 0.5–4 Hz. These waves are most often linked with profound sleep, but

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they can also be found in the waking state. *Theta* waves have a frequency of 4–7.5 Hz. It is possible that theta was selected to refer to its thalamic origin. A theta wave is frequently accompanied by other frequencies and appears to be linked to arousal level. *Alpha* waves emerge at the back half of the head, generally over the occipital area of the brain, and may be found in all sections of the brain's posterior lobes. The frequency of alpha waves is 8–13 Hz, and they usually appear as a round or sinusoidal form signal. Alpha waves are considered to represent both a relaxed awareness and a lack of focus or concentration. The alpha wave is the most noticeable rhythm in all of the brain activity, and it may extend over a broader range than previously thought. A *beta* wave is the brain's electrical activity that varies between 14 and 26 Hz. However, some literature does not specify an upper limit. Typical adults have a beta wave, which is the brain's normal waking rhythm linked with active thinking, active attention, concentrating on the outside world, or addressing real issues. The *gamma* range, often known as the high beta wave, corresponds to frequencies over 30 Hz, primarily up to 45 Hz. Detection of these rhythms can be used to establish the presence of specific brain disorders, despite the fact that their amplitudes are very low and their occurrence is rare (Sanei & Chambers, 2021).

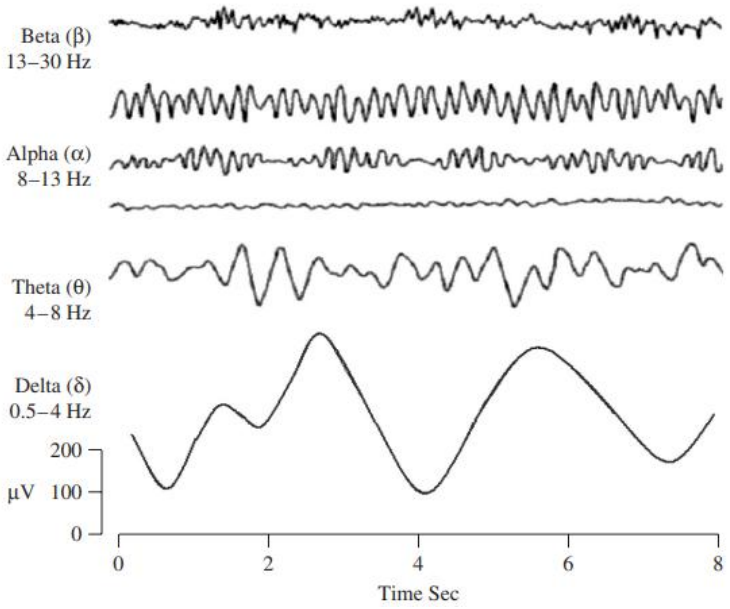

Figure 5 Four typical dominant brain normal rhythms, from high to low frequencies

(From Sanei, Saeid., Chambers, Jonathon. EEG signal processing, 2007. Reprinted with permission from Copyright Clearance Center, license ID: 1156049-1)

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Age-related neuronal loss is indicated by a decrease in cortical volume. The reduction in cerebral blood flow may be a common cause of brain aging. The most common anomaly in EEG is a decrease in the alpha frequency. This causes a more extensive anterior spread in the frontal areas, reducing the alpha wave blocking response and responsiveness. The degree of bilateral slowing in the delta and theta waves is somehow connected to decreased mental function. Although alterations in high-frequency brain rhythms are not fully understood, an increase in beta-wave activity may be seen as an early indicator of intellectual loss (Sanei & Chambers, 2021).

Research on the delta frequency band in MCI has shown that there is a significant increase in delta power in individuals with MCI compared to healthy controls. This increase in delta activity is associated with cortical slowing, which is a common feature in the progression from MCI to AD. Delta power increases are thought to reflect the brain's response to neural damage and are linked with impaired cognitive function, particularly in tasks requiring attention and memory (Abásolo et al., 2005; Poil et al., 2013). This slowing of brain activity is a marker of neural dysfunction and is considered one of the earliest signs detectable through EEG in individuals who are likely to progress from MCI to AD (Cassani et al., 2018; Choi et al., 2023). Additionaly, the analysis of delta power, particularly in resting-state EEG, helps in distinguishing MCI patients from healthy individuals and provides insight into the underlying neural deterioration associated with cognitive impairment (Babiloni, Lizio, et al., 2013).

In the same vien, studies have consistently shown an increase in theta power in individuals with MCI, which correlates with the severity of cognitive decline . Increased theta activity is often observed in both resting-state and task-based EEG recordings and is linked with impaired cognitive processing and synaptic dysfunction. Theta power is particularly elevated in MCI patients during tasks that require memory and attention, indicating difficulties in cognitive control and processing speed (Fernández et al., 2006). This elevation in theta activity may also reflect compensatory mechanisms where the brain attempts to maintain cognitive function despite underlying neural damage. As such, theta power is a valuable biomarker for

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early detection of cognitive impairment and for monitoring the progression of MCI to more severe forms of dementia (Hogan et al., 2011; Hogan et al., 2012).

Research on the alpha frequency band in MCI has revealed significant findings. MCI individuals with a greater alpha ratio are more likely to acquire AD, while people with MCI had a significant proportion exhibited more overall cortical atrophy than the other categories (Moretti, 2015; Moretti et al., 2014; Moretti et al., 2012). Previous studies have shown that individuals with MCI often exhibit reduced alpha power compared to healthy controls. This reduction is associated with disruptions in cortical connectivity and cognitive processing, particularly in tasks involving attention and memory (Babiloni, Lizio, et al., 2013; Babiloni et al., 2010). The alpha rhythm, which is prominent during relaxed wakefulness with closed eyes, tends to diminish in power as cognitive impairment progresses. This decline in alpha activity can serve as an early indicator of neurodegenerative changes, helping to differentiate between normal aging and pathological cognitive decline (Moretti et al., 2014; Moretti et al., 2012). Additionally, the variability in alpha frequency, particularly in the upper alpha range, has been linked to cognitive performance, with lower variability correlating with better cognitive outcomes (Klimesch, 1999; Moretti et al., 2014). Furthermore, both the left and right hemispheres show substantial shrinkage in two particular brain regions, the precuneus and the supramarginal gyrus. As a consequence, the link between EEG markers and grey matter changes in MCI and AD. Precuneus structural and functional abnormalities were discovered (Moretti et al., 2014). A significant positive correlation between regional brain perfusion in the high alpha3 / alpha2 group and the other groups, Babcock test was found in the high alpha3 / alpha2 group between logical memory performance on the Babcock test and lower perfusion values in the bilateral precuneus and cortex in the superior temporal sulcus. Moreover, a positive correlation was also established with hippocampal atrophy (Moretti, 2015).

The beta frequency band in MCI has revealed mixed results, but generally indicates a reduction in beta power in individuals with cognitive impairment. This reduction is associated with decreased cortical arousal and impaired cognitive function, particularly in tasks requiring motor control and attention (Jeong, 2004). Beta activity is typically linked with active, alert states and cognitive

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processing, and its reduction in MCI patients suggests a decline in these functions. Studies have found that beta power decreases are more pronounced in patients who progress from MCI to AD, making it a potential marker for tracking disease progression (Kaiser et al., 2017). Additionally, beta power reduction is often accompanied by increased power in lower frequency bands, reflecting a general slowing of brain activity as cognitive impairment advances (Fernández et al., 2006). As a result, monitoring changes in beta activity through EEG can thus provide important insights into the neural mechanisms underlying cognitive decline in MCI patients.

Gamma band activity is crucial for comprehending and diagnosing mild brain injury, according to recent research. For instance, early disturbances in gamma band dynamics have been observed in individuals with MCI, which may indicate compensatory activation mechanisms in response to cognitive decline (Missonnier et al., 2010). Additionally, increased gamma band activity (30-100 Hz) has been documented in both AD and MCI patients during cognitive tasks, suggesting its potential as a diagnostic biomarker (van Deursen et al., 2008). These studies often employ high sampling rates and rigorous preprocessing steps, such as maintaining electrode impedance below 5 kΩ and using fast-Fourier transformation, to ensure accurate gamma band measurements (Lee et al., 2022). Task-based EEG paradigms have also revealed altered gamma band synchrony and power in MCI patients, highlighting differences in how they process visual and auditory stimuli compared to healthy controls (Missonnier et al., 2010). Although, these findings underscore the relevance of gamma band analysis in EEG studies for elucidating the neural mechanisms underlying cognitive impairment and developing diagnostic tools for MCI, most studies have not studied the gamma bandwidth due to its low power and sensitivity to noise (Baker et al., 2008).

In summary, EEG of resting-state conditions and cognitive tasks are investigated as likely biomarkers for discriminating between healthy, MCI, and AD groups. These findings suggest that monitoring bands activity through EEG could be a valuable tool for early detection and tracking of MCI, providing insights into the underlying neural mechanisms of cognitive impairment. As a result, EEG is a

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valuable technology for biomedical data collection in participants pre-and post-test to compare the difference in brainwaves after participating in experiments.

Event-Related Potentials

The earliest ERPs on conscious individuals were recorded by Pauline and Hallowell Davis. They published their findings in 1939. Grey Walter and colleagues originally discovered the cognitive ERP component, contingent negative variation (CNV), in 1964 (Nidal & Malik, 2014). ERPs are extremely small voltages that are created in the brain regions in response to specific events or stimuli. They are time-locked EEG alterations that provide a safe and non-invasive way to examine psychophysiological aspects of mental activities. A wide range of sensory, cognitive, or motor activities can trigger event-related potentials. They are hypothesized to represent the summed activity of postsynaptic potentials created when a large number of similarly oriented cortical pyramidal neurons fire in synchrony while processing information (in the hundreds of millions). Human ERPs may be classified into two groups. The early waves, or components peaking within the first 100 milliseconds following input, are referred to as sensory or exogenous since they are highly dependent on the stimulus's physical properties. Later ERPs, on the other hand, indicate how the individual analyzes the stimulus and are referred to as 'cognitive' or 'endogenous' ERPs since they look into information processing. Latency and amplitude are used to characterize the waveforms (Sur & Sinha, 2009).

A large enough number of participants is typically required for an ERP study. For one ERP experiment, the participants in the most recent articles vary from 15 to 30 people. Furthermore, the paper's conclusion is predicated on the sum of all of these individuals' data. The averaged ERP waveform's figure, on the other hand, is frequently included in the publication. This averaged ERP waveform is called the grand average ERP waveform because it is formed by averaging together the averaged waveforms of all the individuals. The average between subjects is a term for this approach. Averaging participants' ERPs helps attenuate some random noise in each subject, similar to averaging trials that help mitigate some random noise in each trial. The impact of averaging the ERP between subjects is seen in Figure 6 Example of the application of ERP averaging between subjects.

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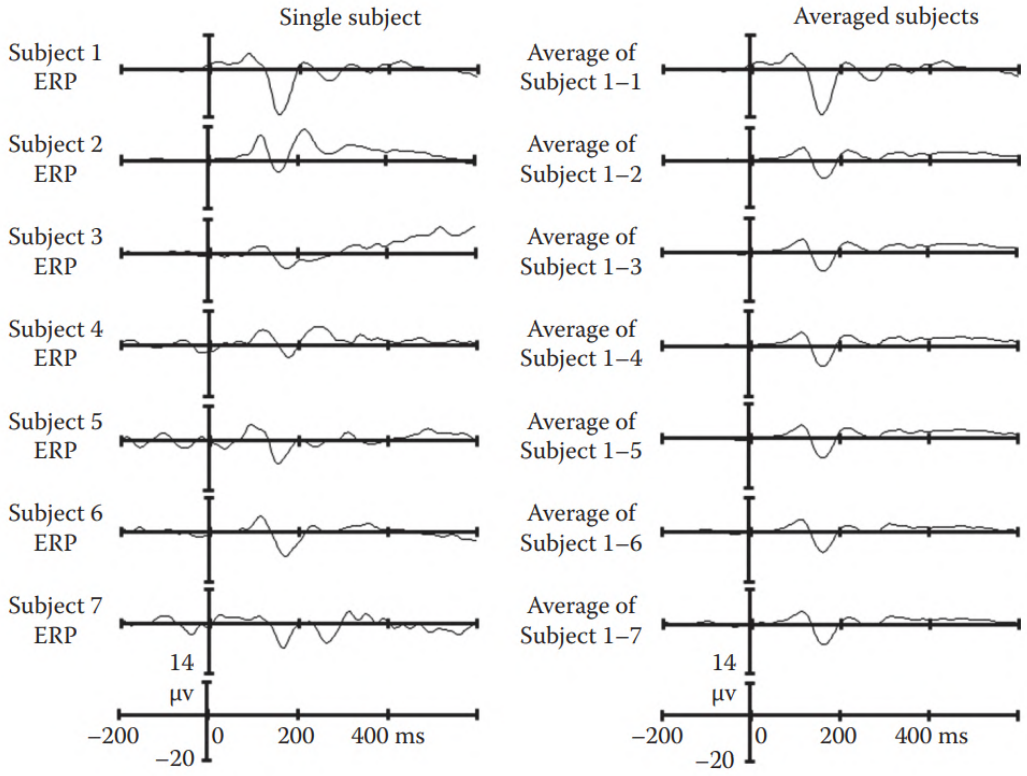

Figure 6 Example of the application of ERP averaging between subjects (From Kamel, Nidal; Malik, Aamir Saeed. EEG/ERP Analysis: Methods and Applications, 2014. Reprinted with permission from Copyright Clearance Center, license ID: 1156505-1)

Visual ERP is a sensitive measure of brain activity linked to attention and recent memory formation. P300 latency is inversely related to mental function in healthy people. The better the cognitive performance, the shorter the delay. Increases in the latency and decreases in the amplitude of ERP components can be predicted as a result of neurobiological changes as people age. Longer P300 peak latencies reported in the age-matched control group in dementia research highlighted the P300 component as a potentially significant indication in assessing cognitive functioning. Studies with longer follow-up periods show that the degradation of cognitive abilities caused by the evolution of sick diseases causes P300 latencies to lengthen. Before the P300 wave appears, the N200 wave peaks, which is considered to reflect a stage in the discriminating process (Gozke et al., 2016).

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The current state of assessing older adults with MCI for monitoring changes post-intervention lies primarily in the accessibility, reliability, and practical applicability of biomarkers. While biomarkers such as beta-amyloid, tau proteins, and neuroimaging techniques like MRI and PET have been extensively studied and used to identify AD and MCI, these methods are often costly, time-consuming, and invasive. Additionally, their reliance on complex equipment and specialized settings limits their widespread use in routine community healthcare. Thus, despite their scientific robustness, these biomarkers are not feasible for regular monitoring of MCI progression or response to interventions in a broad, real-world setting.

EEG presents a promising alternative for the clinical assessment and monitoring of MCI. EEG is non-invasive, cost-effective, and offers high temporal resolution, making it suitable for regular use in community healthcare settings. However, the challenge lies in improving the sensitivity and specificity of EEG markers for MCI and AD. Although recent studies suggest potential in using EEG to detect changes in brain activity patterns and to correlate these with cognitive decline, more research is needed to refine these methods and establish standardized protocols. The development of reliable EEG-based biomarkers could bridge the gap in accessible, continuous monitoring of cognitive changes in older adults, thereby enhancing the ability to evaluate the efficacy of interventions in this population.

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CHAPTER 3
RESEARCH METHODOLOGY

An essential aspect in designing clinical trials to assess intervention effectiveness remains in conducting appropriate data analysis of the experiment's results. The present research reviews essential issues related to assessing the program's effectiveness and uses an observing procedure that accounts for individual variation among subjects. To minimize risk factors (i.e., adverse health effects, progression of cognitive decline, or complications related to the intervention), the intervention and procedures used in this study was conducted with older adults with MCI to the experimental groups. Essential considerations were made in using the computerized multicomponent cognitive stimulation (CMCS) program to improve cognitive functions in older adults with MCI.

This study aimed to develop and better understand the effect of the CMCS program and examine the effectiveness of the CMCS program for improving cognitive functions in older adults with MCI. This chapter outlines the methodology used in the study and details the participants, stimuli materials, procedures, data collection, and data analysis (see Figure 7).

The significant steps involved in the research process are as follows:

Phase 1 Development of the computerized multicomponent cognitive stimulation program and modification of neuropsychological tests

Part 1 Development of the computerized multicomponent cognitive stimulation program

Part 2 Development and modification of neuropsychological tests

Phase 2 Investigation into the effect of the computerized multicomponent cognitive stimulation program on cognitive functions in older adults with MCI

1. Research design
2. Participants
3. Measurements and methods
4. Data collection
5. Data analysis

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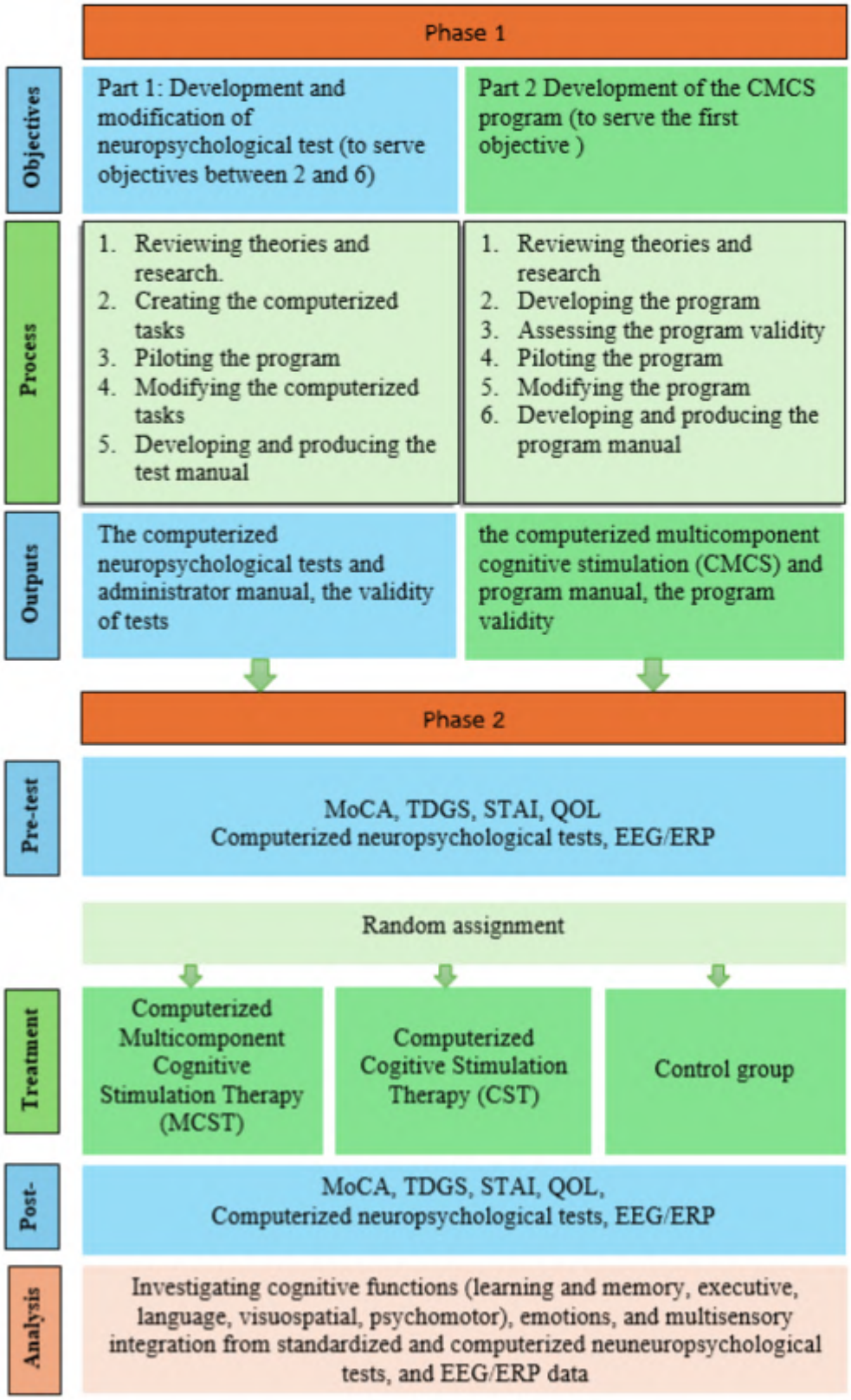

Figure 7 Research process flowchart

Phase 1 Development of the computerized multicomponent cognitive stimulation program and modification of neuropsychological tests

Part 1 Development and modification of neuropsychological test

The procedure in the process represents the process that was used to develop and to modify on PsychoPy program, which forms the basis of the current research (see Figure 8).

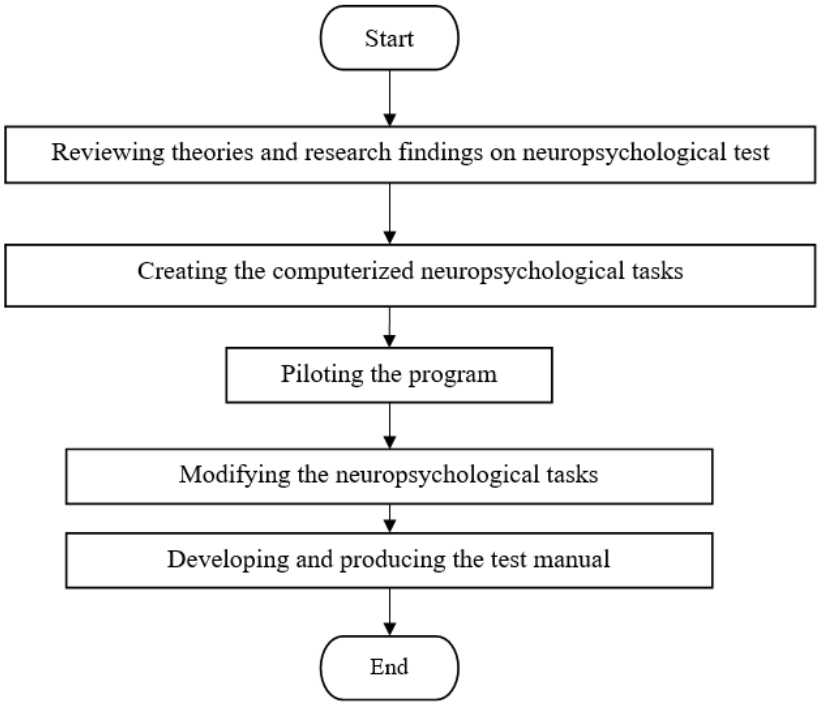

Figure 8 The computerized neuropsychological tests modification process

Step 1 Literature review of investigations, analysis, and evidence-based research related to computerized neuropsychological assessment

The purpose of the stage is to review the theoretical framework, models, and theories involved in applying and implement in computerized neuropsychological tasks. The test development for the study begins with an overview of theoretical concepts related to testing the cognitive functions. These has been used to modify in many studies assessing cognitive functions as described below:

1) Paired associates learning tasks (to measure learning and memory domain). This simple task asks participants to learn and recall pairings

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between words. The test includes different types of word pairs, including related words, unrelated words, and name-word pairings. Participants are instructed to learn unrelated word pairs (such as stove and letter). In order to test a person's memory for those pairs of words at a later time, one of two methods is to ask them to recall one of the words in response to the word it was paired with during encoding (for example, recall the word that was paired with "stove") or to distinguish between word pairs that were encoded together (for example, stove and letter) and word pairs made up of two studied words that weren't paired during encoding (for example, stove and dance) (Arndt, 2012).

2) Verbal fluency tasks (to measure language domain). The verbal fluency test is a short test of verbal functioning. It typically consists of two tasks: category or semantic fluency and letter or phonemic fluency. In the standard versions of the tasks, participants are given 1 min to produce as many unique words as possible within a semantic category (category fluency) or starting with a given letter (letter fluency). The participant's score in each task is the number of unique correct words (Shao et al., 2014).

3) Wisconsin Card Sorting Test (WCST). The test of frontal function or executive (metacognitive) function is scored according to nine categories. Before testing, color blindness needs to be excluded (e.g., by the Ishihara Plate Test) so that it does not influence the test result (Hoffmann, 2009). A shortened standardized form of WCST, Berg’s Card Sorting Test, is used with the card sort task uses a modified 24-card deck in which none of the cards matches the sort piles on more than one attribute (i.e., number, shape, or color). Rule changes are made after five correct sorts in a row, and participants complete 64 total sorts. The cards are shown on a screen in the computerized version of the WCST (top left part). The four stimulus cards are the same as in the card version, but the participant responds using the keyboard (numerical keys 1, 2, 3, and 4). Each trial begins with one answer card in the center of the screen, which the participant must match to one of the four stimulus cards. The four locations of the stimulus cards, which appear on the upper left side of the screen, are represented by the numerical keys on the keyboard (Wagner & Trentini, 2009). The scoring includes the following: percentage errors, perseverative responses, perseverative errors, nonperseverative errors, conceptual

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level responses, categories completed, trials to complete first category, failure to maintain set, learning to learn (Hoffmann, 2009). See to Figure 9 for an example screen from the Psychology Experiment Building Language (PEBL) program (Berteau-Pavy et al., 2011).

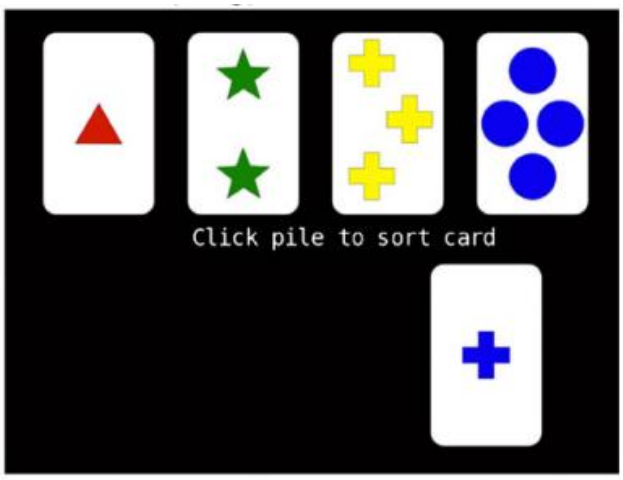

Figure 9 Wisconsin Card Sorting (Berg, 1948)

4) Reaction time (RT) tasks (to measure psychomotor domain) RT consists of various forms, access psychomotor speed by using a simple reaction time (SRT) task, and identify focused attention by choice reaction time (CRT) task with/without out cueing (Levinoff et al., 2005).

5) Corsi block-tapping task (to measure visuospatial domain) Nine blue squares are randomly put on the screen as placeholders in each trial (A). Some of the squares would change color from blue to yellow in a sequential way throughout the encoding phase (B), and participants would be asked to recall the position and sequence of such a presentation. In the interference condition, participants undertake the modified Luria manual sequencing task during the 5-s delay retention phase (C), but in the non-interference condition, no manual activity is performed. Finally, in the recall phase (D), participants were asked to point out the colored squares in the right placements, either forward or backward. See Figure 10 for an example screen.

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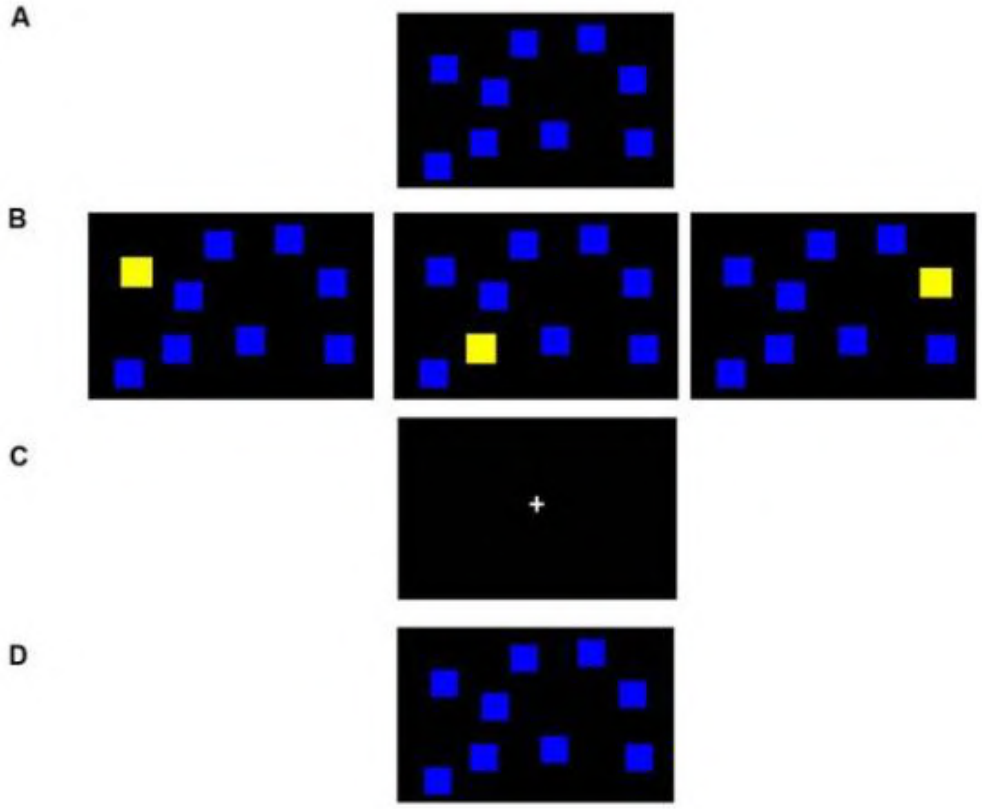

Figure 10 Computerized Corsi block tapping task (CBT)

6) The PEBL Mental Rotation Task (to measure visuospatial), a digitized version of Shepard and Metzler's mental rotation task, has been applied to assess the ability to imagine how an object would look if rotated from its current orientation. The examiner must determine whether two objects rotated relative to one another (geometrical forms) are identical or mirror images. The task consists of 64 stimuli, and each correct answer is worth one point (Berteau-Pavy et al., 2011).

7) The sound-induced flash illusion (SiFi) (to measure multisensory integration), participants have been asked to perform tasks consist of three-block including vision-only, auditory-only, audiovisual. In the vision-only block, one or two flashes will be presented, and the participants' task will be to indicate how many flashes are presented. In the auditory-only block, one or two beeps were presented, and the participants indicated how many beeps they heard. The SOA that will be used in these blocks were: 0 ms (one stimulus event), 50 ms, 100 ms, 150 ms, 200 ms, 250 ms, 300 ms, and 500 ms. A randomly permuted SOA will be used in

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both blocks when two stimuli are presented. There are 130 trials in each of the unimodal conditions, 60 trials where one stimulus will be presented and the remaining trials where two stimuli are presented, with an equal number divided between the SOA conditions (10 trials in each remaining SOA condition). The audio-visual block consisted of three conditions: two control conditions (1 beep/1 flash and 2 beeps/2 flashes) and the illusion condition (2 beeps/1 flash and 1 beep/2 flashes).

In the control conditions, the auditory and visual stimuli will be presented simultaneously. In the illusion condition, the visual flash was presented at the same time as the first auditory beep. In the 2 beeps/2 flashes and 2 beep/1 flash conditions, the SOAs used are between 50 ms and 500 ms. These conditions will be randomly presented within the block to avoid any response biases. The participants' task will be to ignore the auditory stimuli and indicate how many visual flashes are presented. The audio-visual block contained 210 trials, with 70 trials within each condition (Chan, Kaiser, Brandl, Matura, Prvulovic, Hogan, et al., 2015).

Step 2 Creating the computerized neuropsychological tasks

Creating and modifying the neuropsychological tasks have been designing the stimuli for assessing cognitive functions. The PsychoPy software was applied to build the computerized neuropsychological tasks.

Step 3 Piloting the computerized neuropsychological tasks

1) 30 Volunteers with characteristics similar to the research participants have been invited to use the computerized neuropsychological tasks.

2) The volunteers performed computerized neuropsychological tests. They participated in the piloting program so that the researcher would receive their feedback.

Step 4 Evaluating and modifying the computerized neuropsychological tasks

The computerized neuropsychological tasks were evaluated and modified with the recommendation of the supervisor and co-supervisor.

Step 5 Creating the computerized neuropsychological test manual

The computerized neuropsychological tests were built according to the theoretical frameworks, and documents and materials were prepared for inclusion in a

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user manual booklet. All strategies were clarified and shown in the manual for administrators who manage the tests to access cognitive functions.

Part 2 Development of the computerized multicomponent cognitive stimulation program

The procedure represents the process that was used to develop the CMCS program, which form the basis of the research (see Figure 11).

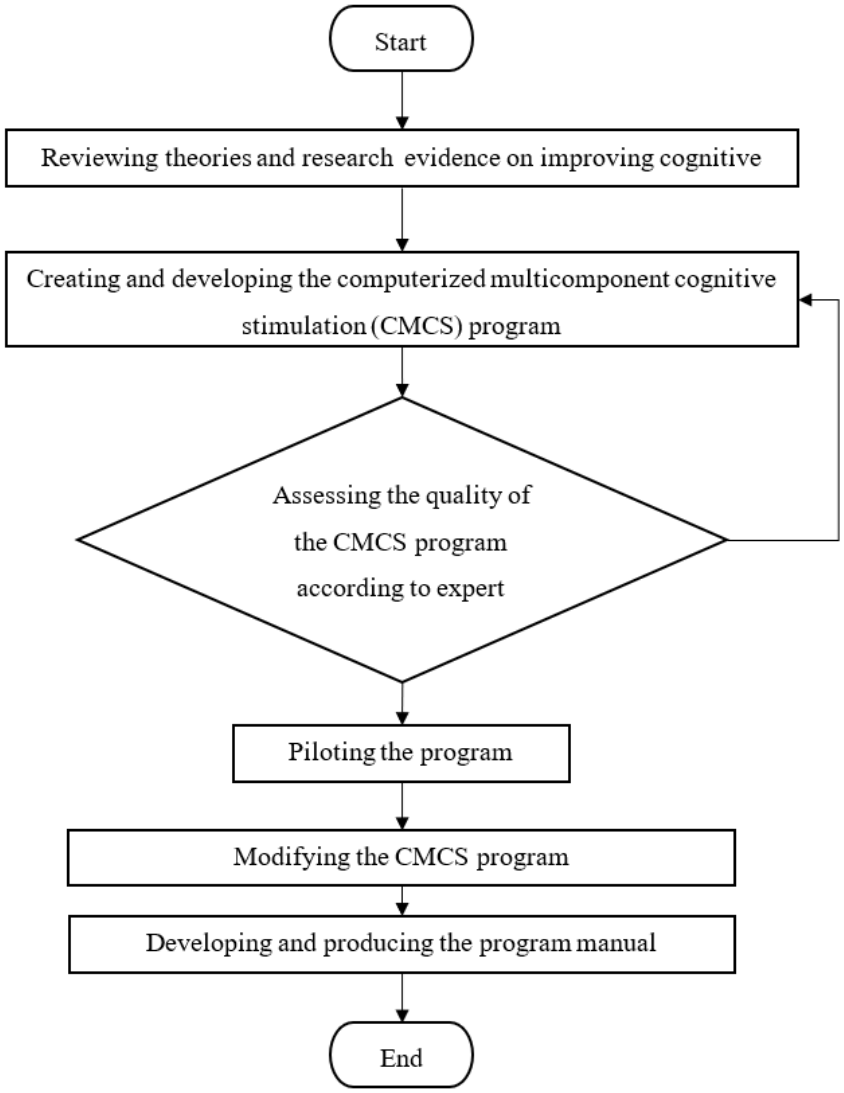

Figure 11 The CMCS program development process

Step 1 Literature review of investigations, analysis, and evidence-based research related to computerized cognitive stimulation

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The purpose of the stage was to review the theoretical framework, models, and theories involved in applying and implementing the simulation program. The stimulation program development for the study begins with an overview of theoretical concepts related to cognitive stimulation therapy and multisensory integration.

Step 2 Creating the CMCS program

Creating and developing the CMCS program has been designing the stimuli for cognitive functions.

Cognitively stimulating activities

The cognitively stimulating activities are split into six themes. The group-based CST has been applied as the theme. The intervention consisted of 45 min/week sessions for ten weeks. Each session included four parts: (a) Reality orientation: questions about the date, time, and place, using calendars, clock, and posters indicating the place and address where the participants were situated; (b) Explanation of the cognitive aspect that will be going to be focused on in each session; with alternatives including 1) “memory” (changes with aging, types of memory, strategies such as association and categorization); 2) “orientation” (temporary, spatial and personal); 3) “language”; 4) “praxis” (ideomotor, ideational and constructive); 5) “gnosis”; 6) “calculation”; 7) “perception”; 8) “reasoning”; 9) “visual attention”; 10) “executive functions” (Gomez-Soria et al., 2020). In the same period, all participants received the computerized version of the Individual Cognitive Stimulation Program, whichwas derived from Making a Difference 3 (MD3). The iCST program was implemented in activity sessions. Each session included the group-based CST. The iCST sessions featured number games, quiz games, and sounds applied to multisensory integrated stimulating activities. The procedure for a structured group session presents in Figure 12.

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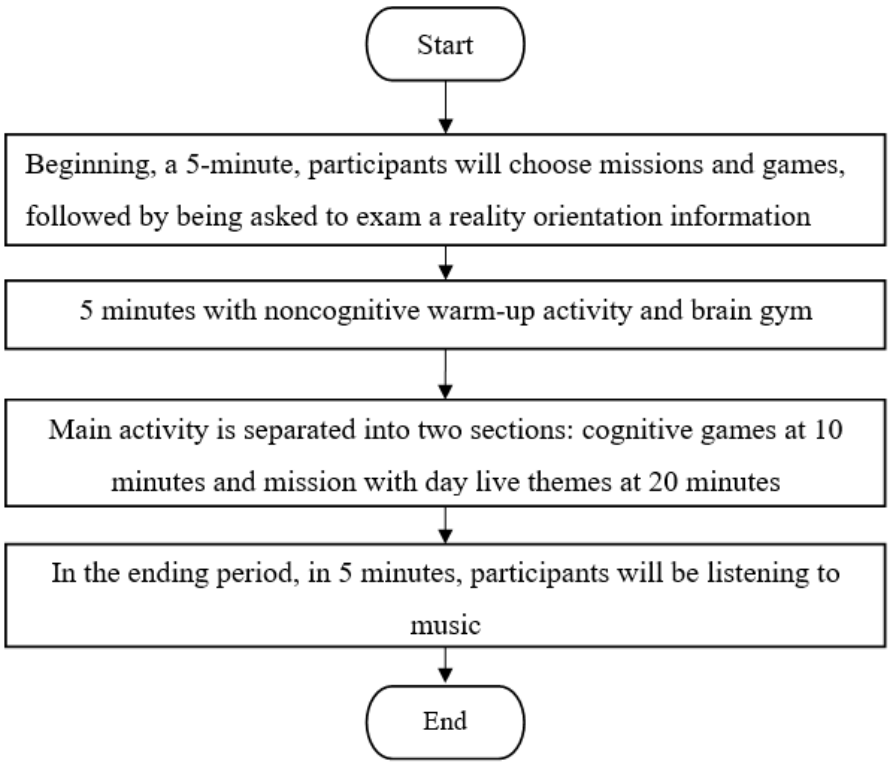

Figure 12 The procedure for a structured group session in the CMCS program

Multisensory integrated stimulating activities

The multisensory stimulating activities apply from temporal order judgment (TOJ) (Setti et al., 2014) and audio-visual perceptual training (Yang et al., 2018)

Temporal order judgment (TOJ) training

Following the presentation of an auditory beep and a visual flash, participants were asked to say whether the sound or the picture came first. A stairwell technique has been used to increase the chances of practical training. The staircase adjusted the stimulus onset asynchrony (SOA) between the visual and auditory stimuli. Each SOA had a 50% chance of hearing the beep first (or seeing the flash first) across all trials. The individual received comments on his or her performance after each trial. The initial SOA was set at 350 milliseconds to guarantee that most participants could easily complete the work and become comfortable with the task protocol. Following three right replies for each given SOA, the SOA has fallen by 40 ms in increments of 40 ms and increased by 40 ms after one incorrect

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response for any given SOA. After 30 reversals, the procedure came to an end automatically. The shortest SOA that would have been achieved was 30 milliseconds. There are three testing blocks of trials within each session, and participants can take a self-timed break after each block. The number of trials in each block changed depending on the participant's success with the stairwell procedure.

Audio-visual perceptual training

The bimodal audio-visual stimulus is the simultaneous or asynchronous presentation of visual and auditory stimuli in the same or separate hemispace. Visuals were applied, such as pictures, including places and activities. Visual and auditory stimuli have been delivered synchronously in the same (left or right) or different hemispaces and visual and auditory stimuli have been presented asynchronously in the same (left or right) or different hemispaces. Participants were taught to reply as fast and precisely as possible to consistent spatiotemporal situations by pushing the left button and to control unpredictable spatiotemporal conditions by pressing the right button. Following an answer, feedback was given in a green checkmark or a red fork, indicating the correct response.

Step 3 Evaluating the CMCS program

1) Experts in cognitive enhancement among older adults with MCI recommended and examined the list of tasks relating to Thai culture.

2) The computerized multicomponent cognitive stimulation program was examined by experts in the area of cognitive enhancement with the computer program.

3) A quantitative assessment of reliability is carried out using the content validity index (CVI).

4) The computerized multicomponent cognitive stimulation program is modified according to the received recommendations from experts.

Step 4 Piloting and implementing the CMCS program

1) 30 Volunteers with characteristics similar to the research participants will be invited to use the CMCS program.

2) The volunteers will perform neuropsychological tests, including the pre-test, paper-based tests such as MoCA, TGDS, QoL, and IADL.

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3) All participants have been trained following the manual program and then balanced, separated into three groups, participants with CMCS.

4) The participants have been asked for their opinions and have performed paper-based tests such as MoCA, TGDS, QoL as the post-test. Participated in the CMCS program in order that the researcher would receive their feedback.

Step 5 Evaluating and modifying the CMCS program

The CMCS program is evaluated and modified with the recommendation of the supervisor and co-supervisor.

Step 6 Creating and producing the computerized multicomponent cognitive stimulation program manual

The CMCS program is built according to the theoretical frameworks, and documents and materials were prepared for inclusion in a user manual booklet. All strategies are clarified and shown in the manual for participants.

Phase 2 Investigation into the effect of the CMCS program on cognitive functions in older adults with MCI

Research design

This study employed an experimental research design with a randomized pre- and post-test control group. It aims to investigate the effectiveness of the CMCS program in improving cognitive functions among older adults with MCI.

A random assignment has been allocated to older adults with MCI into intervention groups for the experiment to ensure group equivalence. Hence, the research design used a random technique to allocate older adults with MCI. Table 1 and Figure 13 illustrates this method.

Table 1 The experimental research design with randomized pre-and post-test control groups.

Group	Assignment	Pretest	Treatment	Posttest
1	R	O_1	X_1	O_2
2		O_1	X_2	O_2
3		O_1		O_2

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Note:

R = Random assignment

X_1 = Computerized Multicomponent Stimulation

X_2 = Computerized Cognitive Stimulation without Multisensory stimulation

O = Assessments: Montreal Cognitive Assessment, Clinical Dementia Rating, Geriatric Depression Scale, State-Trait Anxiety Index (Form Y-1), Activities of Daily Life, Quality of Life, Computer-based neuropsychological tests, and EEG/ERP measurement.

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Participants

Participants were recruited by the old schools and clubs in Chonburi province, Thailand. The sample size is 93, and 80 people were calculated using G-power, to detect an effect size of 0.45 with power of 95% using a 5% significance level and one covariate, and then 13 subjects were added for an attrition rate around 15% (Aguirre et al., 2010) and equivalent group. They were separated into three groups with randomization.

Inclusion criteria

Inclusion criteria for experimental and control groups are as follows:

1) Thai native speakers.
2) Age more than 60 years.
3) The performance of objective memory impairment is based on test scores from assessment tools MoCA, TGDS, STAI, ADL, and QoL.
4) Right-handed according to the Edinburgh Handedness Inventory.
5) Normal color vision according to the Ishihara Plate Test.
6) No chronic illness, deafness, blindness, or major neurological disorder.
7) Not demented
8) Able to read with comprehension
9) Able to use computer devices.

Exclusion criteria

Exclusion criteria for experimental and control groups are as follows:

1) Participants were diagnosed with dementia after participating in the study.

2) Participants with systemic illness.

3) Participant's refusal to participate.

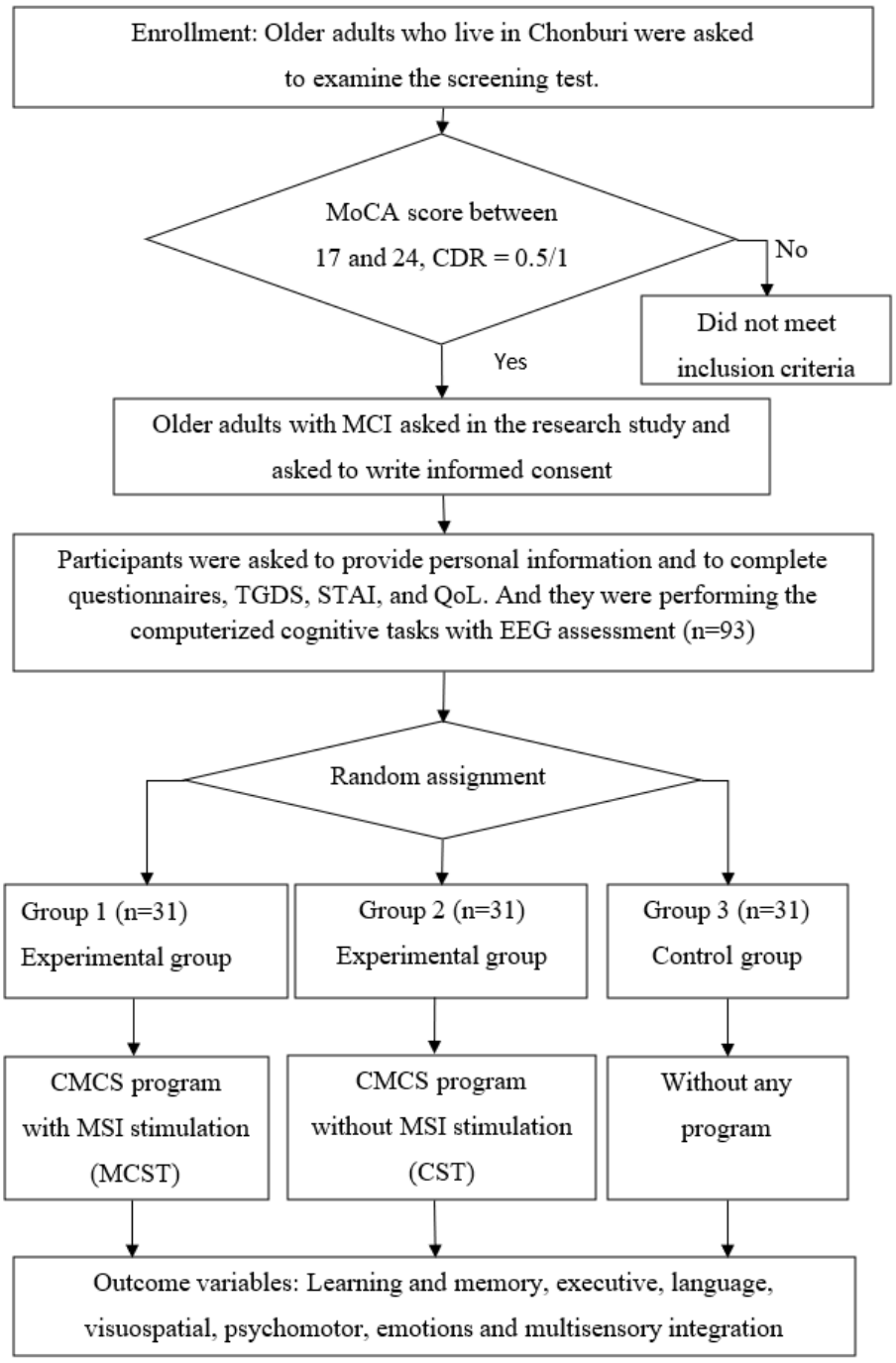

Figure 13 The steps that have been taken to determine the participants in each group.

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Measurements and methods

A set of experiments have been undertaken using different parameters each time**.** Measurements in this research are carried out in two parts, as follows: (1) neuropsychological tests (2) EEG and ERP tests.

Neuropsychological tests

The standardized tests and assessments will be used to identify cognitive impairment levels among the elderly. Consequently, all participants completed paper-based assessments as described below:

Montreal Cognitive Assessment

The MoCA is the most frequently used screening test, and it was produced as a quick screening tool for MCI and dementia in its early phases. The assessment is made up of 12 tasks divided as follows: The short-term memory recall task (5 points) consists of two learning trials of five words followed by delayed recall after around 5 minutes. A clock-drawing exercise (3 points) and a three-dimensional cube copy (1 point) are used to measure visual ability. An alternation task derived from the Trail Making B task (1 point), a phonemic fluency task (1 point), and a two-item verbal abstraction task (2 points) are used to measure several components of executive function. A sustained attention test (target detection using tapping; 1 point), a serial subtraction problem (3 points), and forward and backward digits (1 point each) are used to assess attention, concentration, and working memory. A three-item confrontation naming test with low-familiarity animals (3 points) and repetition of two syntactically challenging phrases (2 points) are used to measure language. Finally, time and place orientation is graded (6 points). The measures are grouped into seven cognitive domains: (1) visuospatial/executive (5 points), which assesses the ability to understand spatial relationships and perform complex cognitive tasks such as drawing a clock and copying a cube; (2) naming (3 points) evaluates the ability to name objects depicted in pictures; (3) attention (6 points) assessed through tasks like digit repetition, identifying specific letters in a sequence, and performing serial subtractions; (4) language (3 points) examines abilities such as sentence repetition, verbal fluency, and comprehension; (5) abstraction (2 points) tests the capacity to understand abstract concepts by explaining the similarities between objects; (6) memory (5 points) tests short-term memory recall through the repetition of a list of

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words both immediately and after a delay; and (7) orientation (6 points) checks awareness of time and place by asking for the current date, month, year, day, place, and city. Additionally, The Memory Index Score (MIS) consisted of the number of words recalled in delayed-free, category-cued, and multiple-choice conditions, multiplied by 3, 2, and 1, respectively (0–15 points). However, MIS is not included in the total score. Scores are added together to get totals for each domain and an overall total score out of a possible maximum score of 30. One point is added for persons with fewer than 12 years of education. A threshold score of 26 has been determined to indicate cognitive impairment (Nasreddine et al., 2005). All participants in this research received the original version (8.1). The range of possible values is 0 to 30, with higher scores indicating a more significant cognitive function (Yang et al., 2021). A cut-off of 17 may assist in detecting early and late MCI patients; depending on the amount of sensitivity needed, a cut-off score of 18 or 19 may be employed. Dementia can be ruled out using a functional evaluation (Trzepacz et al., 2015). This study will use the Thai version of the MoCA.

Clinical Dementia Rating

The Clinical Dementia Rating (CDR) is calculated using a semi-structured interview with the subject and the caregiver (informant) as well as the clinician's clinical opinion. Memory, orientation, judgment, problem-solving, community affairs, home and leisure performance, and personal care are assessed in the cognitive and behavioral areas. No dementia (CDR = 0), probable dementia (CDR = .5), MCI (CDR = 1), moderate cognitive impairment (CDR = 2), and severe cognitive impairment (CDR = 3) are all on a scale of 0–3 (T. K. Khan, 2016).

Activities of Daily Life and Quality of Life

The Chula ADL index (CAI) is designed to assess instrumental activities of daily living for Asian populations. It has strong hierarchical properties and high correlations with the mean (SD) Office of Populations Censuses and Surveys (OPCS) disability score and the Barthel ADL Index. The CAI is acceptable for use among senior Thais living in communities aged 60 and up. The questionnaire consists of five questions and scores on the person's usual ability. (Jitapunkul et al., 1994).

The Thai version's Older People's Quality of Life Questionnaire (OPQOL-Brief) will assess participants' quality of life. The Cronbach’s alpha

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coefficient of OPQOL-Brief was .94 (95% CI; .88, .97), and the consistency from the two-week test-retest reliability analyzed based on the ICC was .75 (95% CI: .47, .90), showing that the first and the second questionnaire response with a two-week interval were highly stability (Phanasathit, 2017).

Geriatric Depression Scale

The GDS can be used with older individuals who are healthy, medically sick, or have mild to severe cognitive impairment. It has been utilized in a variety of settings, including community, acute care, and long-term care. The Thai version of the 15-item Geriatric Depression Scale (TGDS-15) was effective at screening for MDD in elderly cognitively intact Thais. The cut-off scores of 6 assist in detecting depression; the cut-off of 11 significant depression (Wongpakaran et al., 2013). This study was used to assess the depression of older adults.

The State-Trait Anxiety Inventory

The gold standard for measuring anxiety in adults is the State-Trait Anxiety Inventory Form Y (STAI). The STAI-S Anxiety scale evaluates the fundamental characteristics of anxiety, tension, nervousness, and worry (Spielberger, 1983). This study will use the State-Trait Anxiety Inventory Form Y-1 because we focus only on preoperative anxiety. The STAI-state has the 20-item Thai version and has been validated by Darawan Thapinta. The Cronbach's alpha coefficient of the Thai STAI-state was 0.9, which showed high internal consistency (Thapinta, 1991).

Computer-based tasks have been applied to identify cognitive functions in older adults with MCI. Therefore, for all participants who completed the computer tasks, the battery of neuropsychological tests through PsychoPy version 2022.2.5 (Peirce et al., 2019; Peirce et al., 2022). These have been used to modify assessing cognitive functions as described below:

Paired associates learning (PAL) tasks

This task was applied to measure learning and memory skills. This simple task asks participants to learn and recall pairings between words. The test includes different types of word pairs, including related words and unrelated words. Participants are instructed to learn unrelated word pairs (such as stove and letter). In order to test a person's memory for those pairs of words at a later time, one of two

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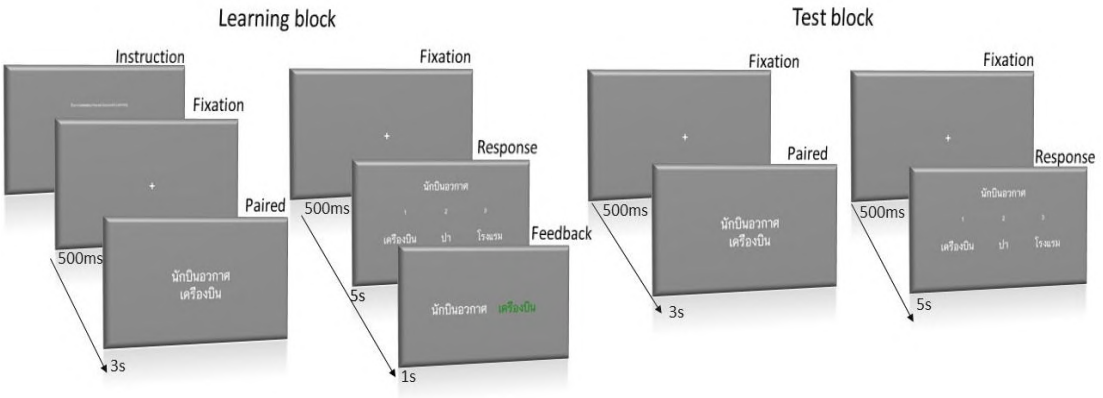
methods is to ask them to recall one of the words in response to the word it was paired with during encoding (for example, recall the word that was paired with "stove") or to distinguish between word pairs that were encoded together (for example, stove and letter) (Arndt, 2012). The exam contains a set of 12 pairs of words, such as related words and unrelated words. Figure 14(a) provides an example of related word pairings. Dursing the learning block, participants are instructed to memorize the word pairs (e.g.,, pilot and airplane). Later, they are tested by choosing the correct pair from three options. After each attempt, the correct word pair is displayed as feedback. In the test block, the same word pairs are presented; however, no feedback is provided. Using a similar structure, participants are also asked to learn and recall pairings of non-verbal stimuli or abstract pictures, as illustrated in Figure 14(b). The total duration of the test is approximately 10 minutes.

(a)



(b)

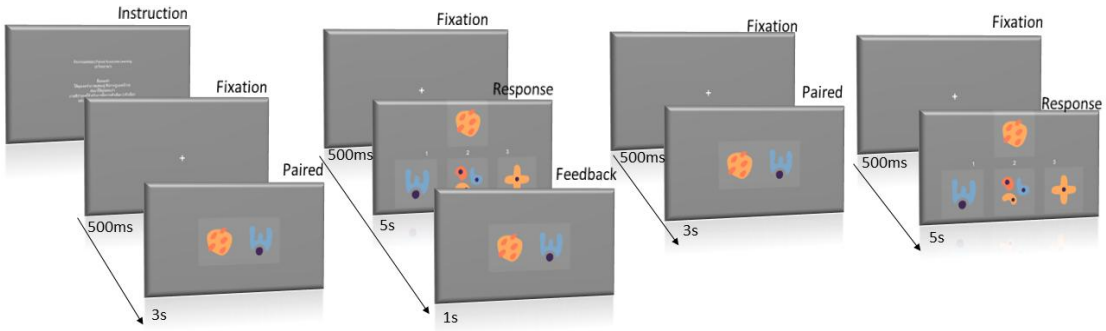


Figure 14 Paired associate learning tasks: example of stimuli, trial structure, and timing

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Verbal fluency tasks

This task was applied to measure language performance. The verbal fluency test is a short test of verbal functioning. It typically consists of two tasks: category or semantic fluency and letter or phonemic fluency. In the standard versions of the tasks, participants are given 1 min to produce as many unique words as possible within a semantic category (category fluency) or starting with a given letter (letter fluency). The participant's score in each task is the number of unique correct words (Shao et al., 2014).

Wisconsin Card Sorting Test (WCST)

This task was applied to measure executive function. The test of frontal function or executive (metacognitive) function is scored according to nine categories. Before testing, color blindness needs to be excluded (e.g., by the Ishihara Plate Test) so that it does not influence the test result (Hoffmann, 2009). A shortened standardized form of WCST, Berg's Card Sorting Test, will be used with the card sort task using a modified 64-card deck in which none of the cards matches the sort piles on more than one attribute (i.e., number, shape, or color). Rule changes are made after five correct sorts in a row, and participants complete 64 total sorts. The cards are shown on a screen in the computerized version of the WCST (top left part). The four stimulus cards are the same as in the card version, but the participant responds using the keyboard (numerical keys 1, 2, 3, and 4). Each trial begins with one answer card in the center of the screen, which the participant must match to one of the four stimulus cards. The four locations of the stimulus cards, which appear on the upper left side of the screen, are represented by the numerical keys on the keyboard (Wagner & Trentini, 2009). Figure 9 presents an example of stimuli, trial structure, and timing. The classification rule changes every five cards. Participants can complete the Wisconsin Card Sorting Test-64 within 10–15 minutes. The scoring includes the following: percentage errors (%), perseverative responses (%), perseverative errors (%), non-perseverative errors (%), conceptual level responses (%), categories completed, trials to complete the first category, failure to maintain set, learning to learn (Hoffmann, 2009).

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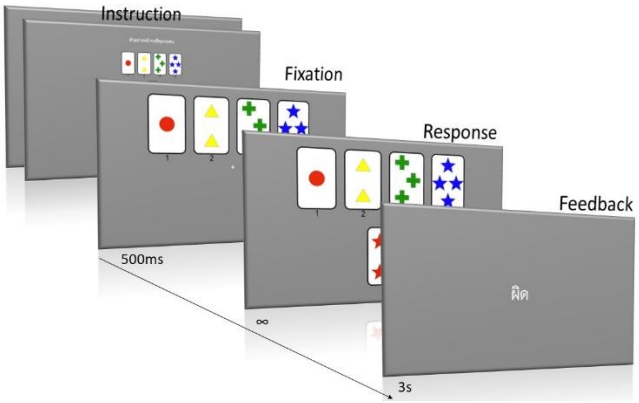

Figure 15 Wisconsin Card Sorting: example of stimuli, trial structure, and timing

Reaction time (RT) tasks

Two reaction time tasks were used, namely, the Deary-Liewald reaction time task and the number's reaction time box. In the simple reaction time (SRT) test , participants had to press a button or key to respond to a single stimulus (see Figure 16 for example). The choice reaction time (CRT) has four stimuli (see Figure 17 for example); participants are asked to press the button corresponding to the correct response. The inter-stimulus interval ranged between 1 and 3 seconds and will be randomized within these boundaries. The task will record each trial's response time and the inter-stimulus interval for measuring (Deary et al., 2011). The total time for the test is approximately 3–5 minutes.

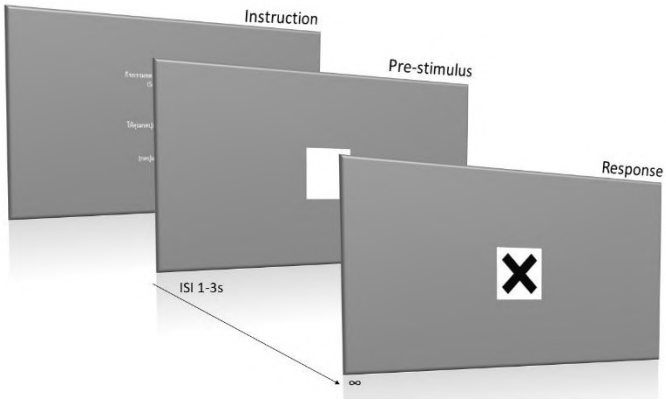

Figure 16 Reaction time tasks: example of stimuli, trial structure, and timing

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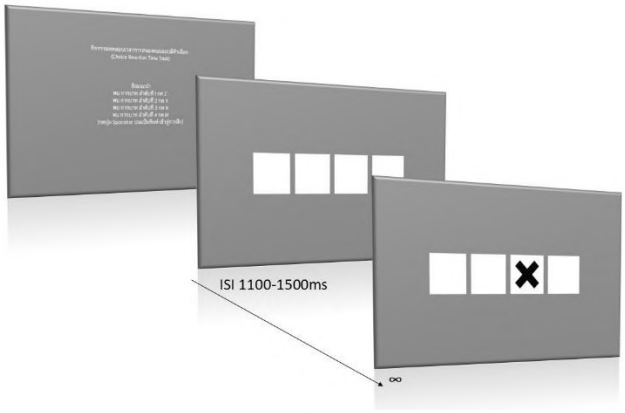

Figure 17 Reaction time tasks: example of stimuli, trial structure, and timing

Corsi block-tapping task

The Corsi Block Tapping Test assesses the ability to perceive and remember spatial relationships by having participants replicate sequences of tapped blocks. Similarly, the MoCA Visuospatial/Executive domain includes tasks like drawing a clock and copying a cube, which requires understanding and visualizing spatial arrangements. Additionally, both tests evaluate executive functions such as planning, problem-solving, and sequencing. In the Corsi block-tapping task, participants were instructed to tap the blocks in the same serial order as presented (two trials per sequence length ranging from two to nine blocks). Participants receive two trials per level, starting from two to nine lengths. Nine white squares are randomly put on the screen as placeholders in each trial. Some of the squares would change color from white to red in a sequential way throughout the encoding phase, and participants would be asked to recall the position and sequence of such a presentation. Measures are the span (number in the longest correct sequence with the possible number from 2 to 9), the score (number of correctly reproduced sequences with the potential number from 2 to 9), and the product (Span x Score) (Claessen et al., 2015). The total time for the test is approximately 2–5 minutes. An example of stimuli, trial structure, and timing show in the Figure 18.

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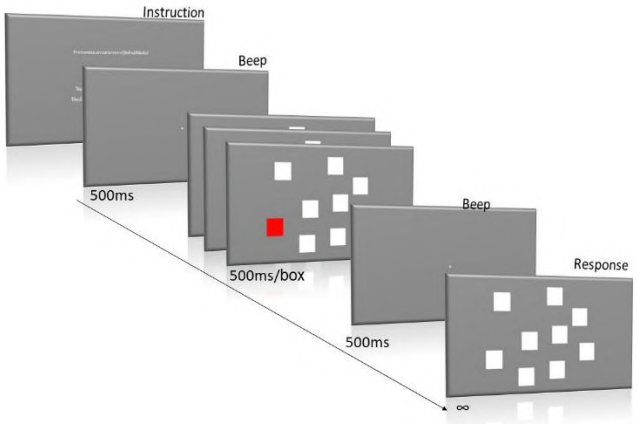

Figure 18 Corsi blocks tapping test: example of stimuli, trial structure, and timing

The Mental Rotation Task

This task was applied to assess visuospatial, a digitized version of Shepard and Metzler's mental rotation task, which was applied to assess the ability to imagine how an object would look if rotated from its current orientation (Berteau-Pavy et al., 2011). Participants are asked whether two objects rotated relative to one another (geometrical forms) are identical or mirror images (Ganis & Kievit, 2015; Shepard & Metzler, 1971). The task consists of 69 stimuli, and each correct answer is worth one point, making a total of 69 points. See an example of stimuli, trial structure, and timing at Figure 19.

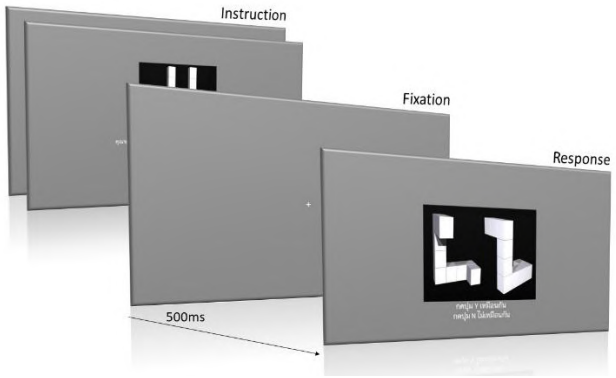

Figure 19 Mental rotation task: example of stimuli, trial structure, and timing

The sound-induced flash illusion (SIFI)

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This task was applied to measure multisensory integration. participants were asked to perform tasks consist three-block including vision-only, auditory-only, and audiovisual (Chan, Kaiser, Brandl, Matura, Prvulovic, Hogan, et al., 2015). However, this study explored only audiovisual conditions. The audiovisual task consisted of two conditions, including the control condition (1 beep/1 flash and 2 beeps/2 flashes) and the illusion condition (2 beeps/1 flash and 1 beep/2 flashes). The auditory and visual stimuli were presented simultaneously in the control conditions. The visual flash was delivered simultaneously with the first auditory beep in the illusion condition. In each condition, the SOAs used are between 150 ms and 300 ms (Chan et al., 2015). For a total of 80 stimuli, participants take approximately 2–3 minutes. Response time and the total error were assessed. An example of stimuli, trail structure, and timing show in Figure 20.

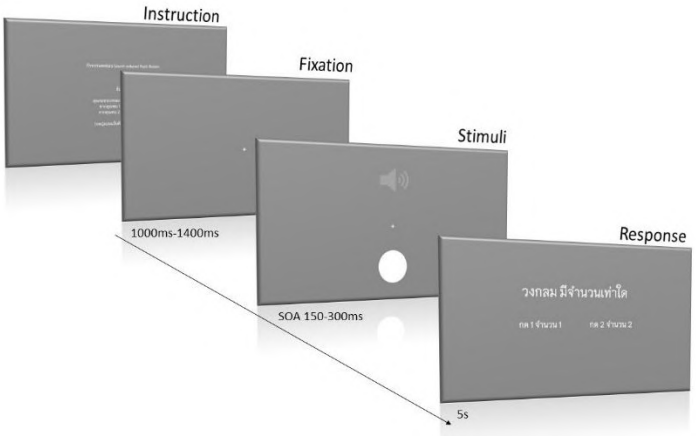

Figure 20 Sound-induced flash illusion task: example of stimuli, trial structure, and timing

EEG and ERP tests

For the purpose of this study, the following key data have been extracted from two main sources: neuropsychological assessment and EEG/ERP assessment. The participants were asked to measure the state of cognition and emotion before and after intervention. This section details the data collection process followed for gathering and measuring information related to the variables of interest.

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At the beginning of the biomarker assessment, the data was gathered to address gaps that are apparent in EEG data. The EEG resting state was measured during eye-closed and open sessions for 5 minutes, and then participants performed the computerized neuropsychological tasks, which is an essential component of the research in data collection. Cognitive functions and multisensory integration tasks will use computer-based tasks to access neuropsychological data by using the PsychoPy program. Individuals have been participating in a different sequence when dealing with order effects and time-related factors, changing the order by using counterbalancing (see Figure 22). Moreover, participants rest for around 2 minutes before beginning the next task.

The Emotiv Flex saline EEG electrode array consists of 32 Ag–AgCl electrodes, with 16 electrodes terminating in a ‘left’ wiring harness and 16 electrodes terminating in a ‘right’ wiring harness. In addition, there is a common-mode sensor (CMS; left side) and a driven-right-leg (DRL; right side) sensor. The CMS and DRL serve as the online reference in ‘active’ sensor EEG setups like Flex. All electrodes accept saline-soaked felt pads and are attached to an EasyCap, which is configurable according to the international 10–20 system (see Figure 21 Emotiv Flex electrode positions for the study). Flex has in-built EEG data pre-processing, including a high-pass filter of 0.2 Hz and a low-pass filter of 45 Hz, digitization at 1,024 Hz and filtering using a digital 5th-order sinc filter, and downsampling to 128 H (Williams et al., 2020)z. EEG data were collected using Emotiv Pro (version 3.8.0.532).

However, before starting the experiment, the participants were informed about the schedule of experimentation, and the researcher has been conducting the investigation to ease the participants’ availability. The EEG device to be used in recording requires the participant to shampoo his/her hair or avoid gel or lotion, and then the researcher has to ensure the participant’s preparation accordingly prior to the experiment (Malik & Amin, 2017).

After all, neuropsychological assessments have asked participants to identify cognitive levels and functional health status with standardized tests and assessments using the Montreal Cognitive Assessment, Clinical Dementia Rating, Quality of Life, and Geriatric Depression Scale.

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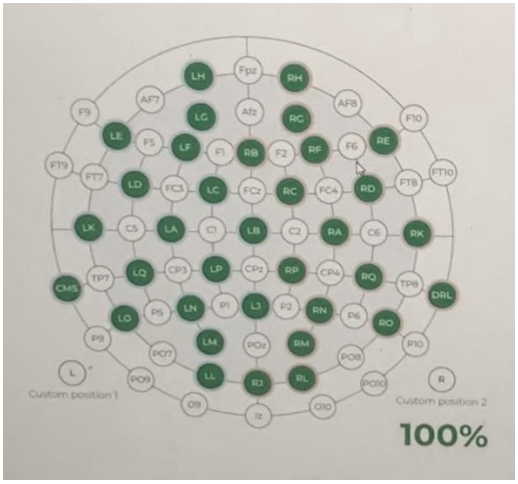

Figure 21 Emotiv Flex electrode positions for the study

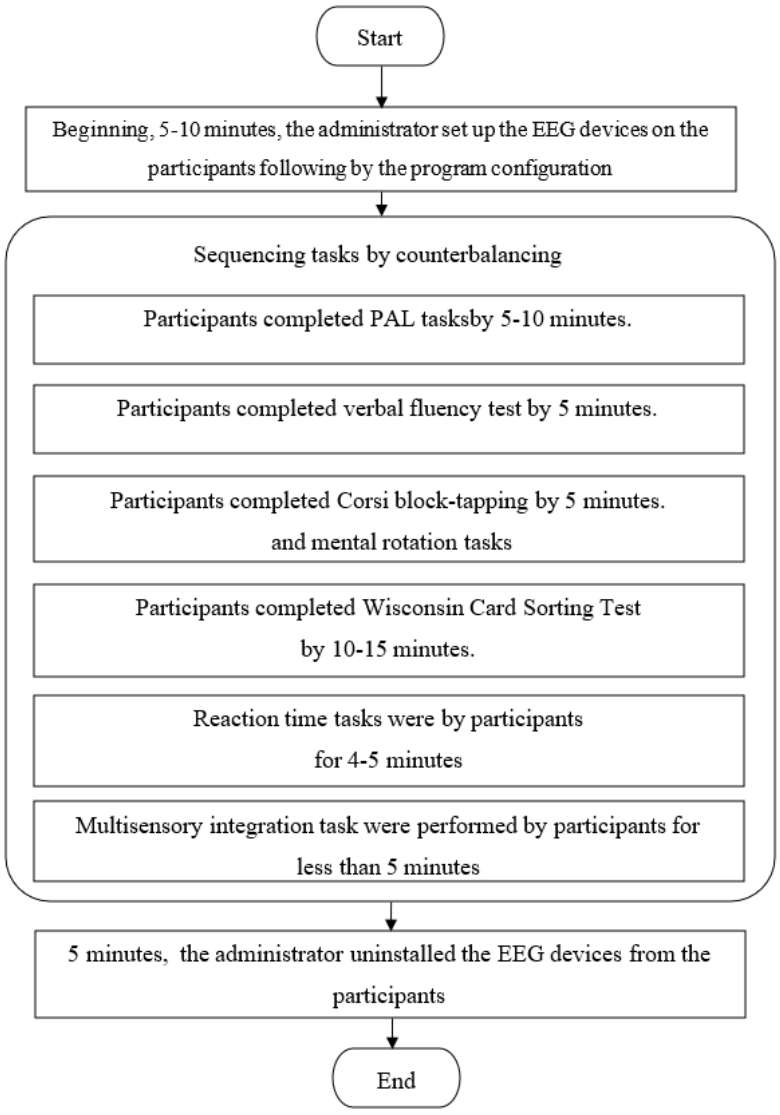

Figure 22 The experimental procedures used to determine the participants' EEG data

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Data collection

Data collection processes, or the procedures followed for gathering and measuring information relating to the variables of interest, are detailed below.

Step 1: Protocol submission form for research involving human participants was submitted to the Burapha University's Human Research Ethics Committee, in order to inform the committee and to request permission to gather data. The protocol has been approved by the Burapha University Institutional Review Board (Approval number: IRB4-191/2566).

Step 2: Protocol submission form for the clinical trals registration was submitted to the Thai Clinical Trials Registry (TCTR), in order to to follow the gold standard in research on intervention effectiveness. The has been preregistered in the TCTR (TCTR number: TCTR20230829004).

Step 3: Invitation information was sent to older adults participating in communities, elderly clubs, and community elderly schools (The school, as an activity center, aims to provide health promotion activities rather than academic action that focuses on socially linked older groups) in the area of Chonburi province, Thailand.

Step 4: Older adults who were candidates were assessed using instruments including MoCA, CDR, TGDS, STAI, ADL, the Edinburgh Handedness Inventory, and the Ishihara Plate Test., following the inclusion criteria.

Step 5: A permission letter requesting a room for collecting the EEG data at the Centre of Excellence in Cognitive Science, Research Methodology and Cognitive Science was submitted, Burapha University. The approval letter was issued between October 5 and December 15, 2023.

Step 6: 93 participants were asked to collect baseline and post-intervention neuropsychological and EEG data at the Centre of Excellence in Cognitive Science, Research Methodology and Cognitive Science was submitted, Burapha University.

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Data analysis

Data analysis of participant demographics, assumption testing, and mean comparison

The statistical analyses were carried out using R Studio (version 2023.12.1), running on R (version 4.3.2) for Windows, with a significance level of $\alpha = .05$ for all tests.

Demographic

The means (M) and standard deviations (SD) have been calculated to explain the general description of cognitive performance, emotional status, quality of life, and EEG/ERP variables (i.e., frequency bands such as relative delta, theta, lower alpha, upper alpha, full alpha, and beta, as well as ERP components such as N100, P200, N300, P300, N400, P600).

Assumption testing

Normality, homogeneity of variance, and homogeneity of regression slope have been performed by using the Shapiro-Wilk test with ‘stats’ library and ‘aov()’ function to get residuals to measure distribution, Battled K-Squared test with ‘stats’ library, and treatment-covariate interaction test with ‘aov()’ function in ‘stats’ library.

Mean comparison

In categorical variables, Chi-square tests were applied to analysts, such as gender, diseases, vision, marital status, and job.

For interval ratio variables with a one-time assessment and a non-normal distribution, the Krukull Wallis test was utilized for group comparison. On the other hand, a one-way analysis of variance (ANOVA) was applied for a normal distribution.

For interval ratio variables with pre-and post-test design, one-way analysis of covariance (ANCOVA) was applied to examine differences in post-test scores of various neuropsychological tests among intervention groups (multicomponent cognitive stimulation therapy: MCST and cognitive stimulation therapy: CST) and control group controlling for pre-test score (Dimitrov & Rumrill Jr, 2003). The purpose of using the pretest scores as a covariate in ANCOVA with a

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pretest-posttest design is to reduce the error variance and eliminate systematic bias (Dimitrov & Rumrill Jr, 2003). The ‘lm()’ and ‘anova()’ functions in R were applied to compute ANCOVA. Additionally, ANCOVA assumptions were carried out, such as the use of the shapiro.test() function to determine the normality of the residuals, the bartlett.test() function to determine the homoscedasticity or homogeneity of the residuals variance for all groups, and the aov() function to determine the homogeneity of regression slopes.

According to EEG/ERP investigation, the analysis was conducted separately for each brain region to focus on region-specific effects without assuming interactions or comparisons between regions. This approach allowed us to evaluate the treatment impact on specific neural activities in distinct areas while accounting for baseline differences. Pre-test EEG/ERP variables were included as covariates to control for individual variability in the resting-state and task measures.

Furthermore, the main effect was assessed for its comparative group effect size using Partial omega squared (ω_p^2) (Olejnik and Algina, 2003), providing an indication of the strength of the treatment effect. Partial omega squared has been suggested by Field (2013) and Olejnik and Algina (2003) as an unbiased alternative to partial eta square when comparing the size of sources of variation across studies from analysis of variance where MSE is the mean squared of the error term. Interpreting the effect size in the context of ANCOVA involves understanding the proportion of variance in the dependent variable that is explained by the independent variable while controlling for covariates, similar to Cohen's (1988) guidelines, 0.0099 constitutes a small effect, 0.0588 a medium effect and 0.1379 a large effect. The ‘omega_squared’ function in R was applied to compute effect size.

Additionally, post hoc analyses were performed using the Bonferroni Test. Cohen’s d-effect sizes were also reported as 0.20, 0.50, and 0.80, small, medium, and large, respectively. A significant level of .05 was used for all statistical comparisons. Estimated marginal means with ‘emmeans()’ and ‘pairs()’ functions in R were obtained.

In case of non-normal distribution or homogeneous were not met, ANCOVA still have been utilized because ANCOVA is robust to violations of normality and equality of variances when sample sizes are equal or some of them

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have been met (Barrett, 2011; Myers et al., 2013). If the ANCOVA assumptions are not met, the analysis still appropriately assesses the impact of the treatment on the post-test scores, pretest-posttest comparison group designs (Gliner et al., 2003).

Data analysis of EEG

This may provide a rich source of data for the result of the study, and the following critical data have been extracted from the biological signal by electronic equipment during participants' performance of the computerized neuropsychological tests.

EEG Preprocessing

The EEG data was re-referenced to the average of all channels to reduce noise and improve the signal-to-noise ratio. A bandpass filter was applied to the EEG data with a low cut-off frequency of 0.1 Hz and a high cut-off frequency of 30 Hz. The data was resampled to 129 Hz to standardize the sampling rate and reduce computational load, ensuring consistent temporal resolution. The EEG data was cleaned to remove artifacts such as flatline segments, noisy channels, and burst noise using a set of predefined criteria (using pop_clean_rawdata('FlatlineCriterion', 5, 'ChannelCriterion', 0.7, 'LineNoiseCriterion', 6, 'Highpass', 'off', 'BurstCriterion', 20,'WindowCriterion', 0.25, 'BurstRejection', 'on', 'Distance', 'Euclidian', 'WindowCriterionTolerances', [-Inf 7])) (Lopez et al., 2022). ICA was performed to decompose the EEG signals into independent components. This step helps identify and remove artifacts such as eye blinks and muscle movements, and then components identified as artifacts have been removed (Sanei & Chambers, 2021).

EEG measurement process

Darbeliai package was applied to measure frequency domain analysis, especially with relative power. Frequency interval (Hz) was analyzed, including delta 1-4 Hz, theta 4-8 Hz, lower alpha 8-10 Hz, upper alpha 10-13 Hz, full alpha 8-13 Hz, and beta 13-30 Hz (Lejko et al., 2020; Rachamanee & Wongupparaj, 2021). According to exclude the gamma band, most studies have not studied the gamma bandwidth due to its low power and sensitivity to noise (Baker et al., 2008), while a few study have investigated EEG frequencies up to 40-50 Hz (Hua-ying & Xin, 2005; Lee et al., 2022; Missonnier et al., 2010; van Deursen et al., 2008).

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Furthermore, the Fast Fourier Transform (FFT) method was utilized to analyze specific parameters such as window length of 2 seconds, 10 spectrum steps in 1 Hz.

This study included two types of EEG data, including resting-state and task-based. For the resting-state EEG, the data were divided into two conditions, eyes closed (EC) and eyes open (EO). Each condition was trimmed at the beginning and end to exclude any artifacts or transitions, resulting in a clean segment of approximately 30 seconds for analysis. The reported power refers to the entire trimmed period of the resting state for each condition. For the task-based EEG, the analysis was conducted on the entire duration of the task without segmenting it into subparts.

Regarding brain regions, electrodes were divided into six regions across the scalp: the frontal lobe (Fp1, Fp2, AF3, AF4, Fz), the central area (FC1, FC2, C3, C4, Cz), the parietal lobe (CP1, CP2, P3, P4, Pz), the occipital lobe (PO3, PO4, O1, O2, Oz), the left temporal lobe (F7, F3, FC5, T7, CP5, P7), and the right temporal lobe (F8, F4, FC6, T8, CP6, P8) (Ahani et al., 2014). Midline electrodes were analyzed separately as metrics, including the frontal (Fz), the central (Cz), and the parietal (Pz) midlines. Additionally, two specific subregions were considered: the left temporoparietal junction (TPJ) (CP5, P3, P7) and the right TPJ (CP6, P4, P8) (Donaldson et al., 2019). All brain regions were analyzed separately, and relative power was examined independently across these regions without grouping them or including regions as factors in the analysis.

EEG comparison

For interval ratio variables with pre-and post-test design, one-way analysis of covariance (ANCOVA) was applied to examine differences in post-test scores of various relative power spectrum bands (i.e. delta, theta, lower alpha, upper alpha, beta) among intervention groups (MCST, CST) and control group controlling for pre-test score (Dimitrov & Rumrill Jr, 2003). The ‘lm()’ and ‘anova()’ functions in R were applied to compute ANCOVA. Moreover, ANCOVA assumptions were performed, including normality of residuals using shapiro.test() function, homoscedasticity or homogeneity of residuals variance for all groups using bartlett.test() function, and homogeneity of regression slopes using aov() function.

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Furthermore, the main effect was assessed for its comparative group effect size using Partial omega squared (ω_p^2) (Olejnik and Algina, 2003). However, if the interaction term is significant (i.e., the interaction between the group and a covariate on the dependent variable, tested by the homogeneity of regression slopes), it was reported in the results section with more details provided in Appendix A. The main effects are not interpreted or reported from this output because they are not independent. To report the results for each explanatory variable, separate simple regression analyses with Ordinary Least Squares (OLS) eastimation were performed for each group individually to examine how the covariate relates to the dependent variable, using 'lm' function in R.

Interpreting the effect size in the context of ANCOVA is explained by the independent variable, similar to Cohen's (1988) guidelines, 0.0099 constitutes a small effect, 0.0588 a medium effect and 0.1379 a large effect. The 'omega_squared' function in R was applied to compute effect size. Additionally, post hoc analyses were performed using the Bonferroni Test. Cohen's d-effect sizes were also reported as 0.20, 0.50, and 0.80, small, medium, and large, respectively. A significant level of .05 was used for all statistical comparisons. Estimated marginal means with 'emmeans()' and 'pairs()' functions in R were obtained.

Data analysis of ERP

ERP preprocessing

Pre-processing and data analyses were completed using the EEGLAB (version 2023.0) and ERPLAB (version 10.04) toolbox. The EEG data was re-referenced to the average of all channels. Re-referencing is a common practice in EEG preprocessing that can help reduce noise and improve the signal-to-noise ratio. A bandpass filter was applied to the EEG data with a low cut-off frequency of 0.1 Hz and a high cut-off frequency of 30 Hz. The EEG data was resampled to 129 Hz. Resampling is often performed to reduce the computational load and to standardize the sampling rate across different datasets. The EEG data was epoched around the events of interest with a time window ranging relative to the event onset. For every measurement window, a baseline correction was applied using the pre-stimulus interval from -100 ms to 0 ms to adjust the data to remove any pre-stimulus noise or drift, ensuring that subsequent analyses focus on the accurate event-related responses.

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Artifact detection and rejection were performed after artifact correction and after the data were epoched and baseline-corrected using the periods (see Table 2 The measurement windows across the computerized neuropsychological tests). Every epoch from every corrected EEG channel was subjected to two algorithms that detected somewhat different kinds of extreme values. Moving Window Peak-to-Peak Threshold was applied to flag epochs where the peak-to-peak amplitude within a moving window exceeds a specified threshold. In this case, the threshold was set at 200 μV, with a window size of 200 ms and a step size of 50 ms. Then, the Step-like Artifacts method flags epochs with abrupt changes in amplitude, indicative of step-like artifacts. The same threshold and time window settings were used.

ERP measurement process

Key metrics, including mean amplitude, peak amplitude, and peak latency, were extracted to analyze the ERP data quantitatively. These metrics provide valuable insights into the temporal and spatial characteristics of the ERP components. Midline electrodes were applied separately as metrics, including the frontal (Fz), the central (Cz), and the parietal (Pz) midlines. Moreover, electrodes divided into six regions over scalp as the frontal lobe (Fp1, Fp2, AF3, AF4, Fz), the central area (FC1, FC2, C3, C4, Cz), the parietal lobe (CP1, CP2, P3, P4, Pz), the occipital lobe (PO3, PO4, O1, O2, Oz), the left temporal lobe (F7, F3, FC5, T7, CP5, P7), the right temporal lobe (F8, F4, FC6, T8, CP6, P8) (Ahani et al., 2014), as well as two specific subregions, including the left TPJ (CP5, P3, P7) and the right TPJ (CP6, P4, P8) (Donaldson et al., 2019).

The measurement windows for each ERP study task are detailed as follows: The Paired Associates Learning task utilized P300 and late potential components, analyzed within two-time windows: early (300–500 ms) and late (500–700 ms) (Bridger et al., 2017). The Verbal Fluency task measured N400 and P600 components within the time windows of 300-500 ms and 500-700 ms, respectively (Kolk et al., 2003; Kutas & Federmeier, 2000; Olichney et al., 2008). The Corsi Block-Tapping task employed P300 and late potential components, represented within the time windows of 300-500 ms and 500-700 ms, respectively (Pergher et al., 2019; Pobric et al., 2022). The Mental Rotation task analyzed N200 and P600 components within the time windows of 200-300 ms and 550-750 ms, respectively

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(Chen et al., 2020; Liu et al., 2022). The Wisconsin Card Sorting Test measured P300 and late potential components within the time windows of 300-500 ms and 500-700 ms, respectively (López Zunini et al., 2016; Parra et al., 2012). Reaction Time tasks utilized N100 and P300 components within the time windows of 0-200 ms and 200-400 ms, respectively (Papaliagkas et al., 2008). Lastly, the Sound-Induced Flash Illusion task measured N1 and P2 components within the time windows of 50-150 ms and 150-250 ms, respectively (Mishra et al., 2007) (see Table 2).

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Table 2 The measurement windows across the computerized neuropsychological tests

Tasks	ERPs	Localization	Electrode sites	Epoch (ms)	Measurement window (ms)
Verbal paired associates learning task	P300	Frontal	Fp1, Fp2, AF3, AF4, Fz	-100 750	300-500
	P3/LPP	Frontal	Fp1, Fp2, AF3, AF4, Fz	-100 750	500-700
		Occipital	PO3, PO4, O1, O2, Oz	-100 750	500-700
Non-verbal paired associates learning task	P300	Frontal	Fp1, Fp2, AF3, AF4, Fz	-100 750	300-500
	P3/LPP	Frontal	Fp1, Fp2, AF3, AF4, Fz	-100 750	500-700
		Occipital	PO3, PO4, O1, O2, Oz	-100 750	500-700
Verbal fluency task	N4	Temporal	*Left*: F7, F3, FC5, T7, CP5, P7	-100 1000	300-500

Tasks	ERPs	Localization	Electrode sites	Epoch (ms)	Measurement window (ms)
			Right: F8, F4, FC6, T8, CP6, P8		
		Parietal	CP1, CP2, P3, P4, Pz	-100 1000	300-500
	P6	Temporal	*Left*: F7, F3, FC5, T7, CP5, P7	-100 1000	500-700
			Right: F8, F4, FC6, T8, CP6, P8		
		Parietal	CP1, CP2, P3, P4, Pz	-100 1000	500-700
Corsi block-tapping task	P300	Frontal	Fp1, Fp2, AF3, AF4, Fz	-100 800	300-500
	P3/LPP	Frontal	Fp1, Fp2, AF3, AF4, Fz	-100 800	500-700
		Ooccipital	PO3, PO4, O1, O2, Oz	-100 800	500-700
Mental rotation task	N2	Temporal	Left: F7, F3, FC5, T7, CP5, P7, Right: F8,	-100 800	200-300

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Tasks	ERPs	Localization	Electrode sites	Epoch (ms)	Measurement window (ms)
			F4, FC6, T8, CP6, P8		
		Parietal	CP1, CP2, P3, P4, Pz	-100 800	200-300
	P6	Temporal	*Left*: F7, F3, FC5, T7, CP5, P7 *Right*: F8, F4, FC6, T8, CP6, P8		
		Parietal	CP1, CP2, P3, P4, Pz	-100 800	550-750
Wisconsin card sorting test	P300	Frontal	Fp1, Fp2, AF3, AF4, Fz	-100 750	300-500
	P3/LPP	Frontal	Fp1, Fp2, AF3, AF4, Fz	-100 750	500-700
		Occipital	PO3, PO4, O1, O2, Oz	-100 750	500-700
Simple reaction time task	N1	Temporal	*Left*: F7, F3, FC5, T7, CP5, P7 *Right*: F8, F4, FC6,	-100 500	0-200

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Tasks	ERPs	Localization	Electrode sites	Epoch (ms)	Measurement window (ms)
			T8, CP6, P8		
		Parietal	CP1, CP2, P3, P4, Pz	-100 500	0-200
	P300	Frontal	Fp1, Fp2, AF3, AF4, Fz	-100 500	200-400
Choice reaction time task	P300	Frontal	Fp1, Fp2, AF3, AF4, Fz	-100 700	200-400
Sound-induced flash illusion task	N1	Temporal	*Left*: F7, F3, FC5, T7, CP5, P7 *Right*: F8, F4, FC6, T8, CP6, P8	-100 300	50-150
		Parietal	CP1, CP2, P3, P4, Pz	-100 300	50-150
	P2	Temporal	Left: F7, F3, FC5, T7, CP5, P7, Right: F8, F4, FC6, T8, CP6, P8	-100 300	150-250
		Parietal	CP1, CP2,	-100 300	150-250

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Tasks	ERPs	Localization	Electrode sites	Epoch (ms)	Measurement window (ms)
			P3, P4, Pz		

ERP comparison

For interval ratio variables with pre-and post-test design, one-way analysis of covariance (ANCOVA) was applied to examine differences in post-test scores of various ERP components among intervention groups (MCST, CST, and control) controlling for pre-test score (Dimitrov & Rumrill Jr, 2003). The 'lm()' and 'anova()' functions in R were applied to compute ANCOVA. Moreover, ANCOVA assumptions were performed, including normality of residuals using shapiro.test() function, homoscedasticity or homogeneity of residuals variance for all groups using bartlett.test() function, and homogeneity of regression slopes using aov() function. Furthermore, the main effect was assessed for its comparative group effect size using Partial omega squared (ω_p^2) (Olejnik and Algina, 2003), Interpreting the effect size in the context of ANCOVA is explained by the independent variable, similar to Cohen's (1988) guidelines, 0.0099 constitutes a small effect, 0.0588 a medium effect and 0.1379 a large effect. The 'omega_squared' function in R was applied to compute effect size. Additionally, post hoc analyses were performed using the Bonferroni Test. Cohen's d-effect sizes were also reported as 0.20, 0.50, and 0.80, small, medium, and large, respectively. A significant level of .05 was used for all statistical comparisons. Estimated marginal means with 'emmeans()' and 'pairs()' functions in R were acquired. When the interaction term is significant (i.e., the interaction between the group and a covariate on the dependent variable, tested by the homogeneity of regression slopes), it was reported in the results section with more details provided in Appendix A. The main effects are not analyzed or presented from this output because they are not independent. To present the results for each variable, separate regression analyses are conducted for each group individually to examine how the covariate relates to the dependent variable, using 'lm' function in R.

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CHAPTER 4

RESULTS

The study aimed (1) to develop a computerized multicomponent cognitive stimulation (CMCS), a combined cognitive stimulation therapy with multisensory integration training, (2) to investigate the effects of the developed CMCS on cognitive functions including learning and memory, executive, language, visuospatial, psychomotor, emotions and multisensory integration in older adults with MCI using standardized and computerized neuropsychological tests in experimental groups and control groups post-intervention, (3) to examine changes do various EEG analyses, including delta, theta, alpha (containing lower, upper, and full alpha), and beta, reveal during the resting stage and computerized neuropsychological tasks of pre-and post-test CMCS performed by older adults with MCI in experimental groups, (4) to compare a combined cognitive stimulation therapy with and without multisensory integration and control groups in terms of the effect on EEG frequency bands as measured during the resting stage and computerized neuropsychological tasks, (5) to examine changes of ERP components including N100, P200, P300, N400 and P600, analyses revealed during the computerized neuropsychological tasks of pre- and post-test CMCS performed by older adults with MCI in experimental groups, (6) to compare a combined cognitive stimulation therapy with and without multisensory integration and control groups in terms of the effect of CMCS on N100, P200, P300, N400 and P600 of ERP components, as measured during participants performing the neuropsychological tasks. The results were separated into two sections depending on phases and hypotheses as follows:

Phase 1 Development of the computerized multicomponent cognitive stimulation program and modification of neuropsychological tests

H1. The developed Computerized Multicomponent Cognitive Stimulation (CMCS) will have an effect on cognitive functions in older adults with MCI.

Phase 2 Investigation into the effect of the computerized multicomponent cognitive stimulation program on cognitive functions in older adults with MCI

H2. After CMCS intervention, older adults with MCI in experimental groups will perform standardized and computer-based neuropsychological tests, consisting of 1) paired associates learning tasks, 2) verbal fluency tasks, 3) Wisconsin card sorting test, 4) reaction time tasks, 5) Corsi block-tapping and mental rotation tasks and 6) multisensory integration task, better than the control group.

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H3. EEG frequency bands, including relative alpha, theta, beta and delta power, measured before and after the intervention during the resting-state and computerized neuropsychological tasks will significantly differ among older adults with MCI in experimental groups.

H4. After CMCS intervention, the EEG frequency bands, including relative alpha, theta, beta and delta power, in experimental groups will significantly differ from those in the control group among older adults with MCI.

H5. The N100, P200, P300, N400, and P600 ERP components measured before and after the intervention during the computerized neuropsychological tasks will , consisting of 1) paired associates learning tasks, 2) verbal fluency tasks, 3) Wisconsin card sorting test, 4) reaction time tasks, 5) Corsi block-tapping and mental rotation tasks and 6) multisensory integration task, significantly differ among older adults with MCI in experiment groups.

H6. After CMCS intervention, the N100, P200, P300, N400, and P600 ERP components in experimental groups will be significantly different from those in the control group among older adults with MCI.

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Phase 1 Development of the computerized multicomponent cognitive stimulation program and modification of neuropsychological tests

Part 1 Development and modification of neuropsychological tests

Aims

The study aimed to evaluate the validity of computer-based neuropsychological tests in older adults with MCI. It hypothesized that the tests would correlate with MoCA or MoCA subscales and relate to other neuropsychological measures.

Methods

Participants

Participants included 30 older adults (Age: M=65.17; SD=4.61, Female=25;83.3%, TGDS-15: M=3.07; SD=2.78) referred for neuropsychological testing after presenting cognitive impairment with subjective memory complaints. This study was conducted in accordance with guidelines on human subject's research and approved by the Burapha University-Institutional Review Board (BUU-IRB: G-HU154/2566).

Instrument

Montreal Cognitive Assessment

MoCA stands for Montreal Cognitive Assessment. The assessment is made up of 12 tasks divided as follows: The short-term memory recall task (5 points) consists of two learning trials of five words followed by delayed recall after around 5 minutes. A clock-drawing exercise (3 points) and a three-dimensional cube copy (1 point) are used to measure visual ability. An alternation task derived from the Trail Making B task (1 point), a phonemic fluency task (1 point), and a two-item verbal abstraction task (2 points) are used to measure several components of executive function. A sustained attention test (target detection using tapping; 1 point), a serial subtraction problem (3 points), and forward and backward digits (1 point each) are used to assess attention, concentration, and working memory. A three-item confrontation naming test with low-familiarity animals (3 points) and repetition of two syntactically challenging phrases (2 points) are used to measure language. Finally, time and place orientation is graded (6 points).

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The measures are grouped into seven cognitive domains: (1) visuospatial/executive (5 points), which assesses the ability to understand spatial relationships and perform complex cognitive tasks such as drawing a clock and copying a cube; (2) naming (3 points) evaluates the ability to name objects depicted in pictures; (3) attention (6 points) assessed through tasks like digit repetition, identifying specific letters in a sequence, and performing serial subtractions; (4) language (3 points) examines abilities such as sentence repetition, verbal fluency, and comprehension; (5) abstraction (2 points) tests the capacity to understand abstract concepts by explaining the similarities between objects; (6) memory (5 points) tests short-term memory recall through the repetition of a list of words both immediately and after a delay; and (7) orientation (6 points) checks awareness of time and place by asking for the current date, month, year, day, place, and city. Additionally, The Memory Index Score (MIS) consisted of the number of words recalled in delayed-free, category-cued, and multiple-choice conditions, multiplied by 3, 2, and 1, respectively (0–15 points). However, MIS is not included in the total score. Scores are added together to get totals for each domain and an overall total score out of a possible maximum score of 30. One point is added for persons with fewer than 12 years of education. A threshold score of 26 has been determined to indicate cognitive impairment (Nasreddine et al., 2005). All participants in this research received the original version (8.1). The Cronbach's alpha and the average inter-item correlation of MoCA obtained from our sample should be acceptable. The average inter-item correlation of .22, a measure of internal consistency not depending on item number, suggested the satisfactory homogeneity of MoCA subtests. the Cronbach's alpha of .74 (95% bootstrap confidence interval = .63 - .79) was in the acceptable range between 0.60 and 0.80.

Computer-based neuropsychological test

This study utilized a desktop application called PsychoPy, which is a Python tool for creating behavioral research experiments with exact spatial control and stimulus timing, such as psychology, neurology, and linguistics. It now offers a choice of interfaces, and users may write scripts in Python if they like or utilize the new Builder interface to build experiments graphically (Peirce et al., 2019). Moreover, PsychoPy is especially available for EEG neuro handsets known as Emotiv. The software can send the command and marker into

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EmotivPro, the program for collection and monitoring data (Peirce et al., 2022). See the example screen at Figure 23. This study applied the experimental tool for measuring cognitive functions, including learning and memory, executive, visuospatial, psychomotor, and multisensory integration (see Table 3).

Figure 23 The PsychoPy Builder interface

Table 3 Brief description of neuropsychological tests

Cognitive domains	Battery name	Battery Brief description	Time (minutes)
Learning and Memory	Verbal Paired associate learning tasks (VPAL) Non-verbal Paired associate learning tasks (OPAL)	Short-term memory and learning skills on word-paired and	10
Executive	Wisconsin Card Sorting Test (WCST)	Executive functions	10-15
Visuospatial	Corsi block tapping task (CBTP)	Visuospatial working memory	2
	Mental Rotation Task	Visuospatial perception	5

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	(MTRT)		
Psychomotor	Simple Reaction Time Task (SRAT)	Psychomotor and attention	3
	Choice Reaction Time Task (CRAT)	Psychomotor and attention	2
Multisensory integration	Sound-Induced Flash Illusion (SIFI)	Multisensory integration	4-5

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Data analysis

Demographic characteristics, MoCA, and their subscores are described using means and standard deviations or frequencies where appropriate. Pearson correlations were applied to explore the relationship between MoCA and neuropsychological measures. Similarly, neuropsychological measures were identified in their relationship to other measures. Additionally, a heatmap was demonstrated to understand the associations better.

Results

MoCA

The analysis of the Montreal Cognitive Assessment (MoCA) subscales provides a detailed overview of cognitive performance across various domains among the participants (see Table 4). The total MoCA score had a mean of 20.00 with a standard deviation of 3.39, ranging from 13 to 25, indicating moderate overall cognitive performance. For the delayed recall (DR) subscale, the mean score was 2.33 (SD = 1.47), with scores ranging from 0 to 4, reflecting variability in participants' ability to recall information after a delay. The Memory Index Score (MIS) had a mean of 10.27 (SD = 3.30), ranging from 3 to 15, indicating differences in participants' memory performance. The visuospatial/executive (VE) subscale had a mean score of 2.40 (SD = 1.40), with scores ranging from 1 to 5, reflecting participants' visuospatial and executive functioning abilities.

In the naming subscale, participants had a mean score of 2.90 (SD = 0.40), with a range of 1 to 3, suggesting that most participants could correctly name common objects. For the attention subscale, the mean score was 4.10

(SD = 1.18), ranging from 1 to 6, showing variability in attentional capacities. The language subscale had a mean score of 1.23 (SD = 1.04), with scores ranging from 0 to 3, indicating differences in language abilities among participants. The abstraction subscale had a mean score of 0.97 (SD = 0.76), with scores ranging from 0 to 2, reflecting variability in abstract thinking skills. Lastly, the orientation subscale had a mean score of 5.73 (SD = 0.45), with scores ranging from 5 to 6, suggesting that most participants were well-oriented in time and place.

In conclusion, the descriptive statistics for the MoCA subscales provide a comprehensive overview of cognitive performance among the participants. The results indicate moderate overall cognitive performance, with notable variability in specific areas such as delayed recall, memory, and attention. While most participants performed well in naming and orientation tasks, differences in visuospatial/executive functioning, language, and abstract thinking skills were observed.

Table 4 Descriptive statistics for the MoCA (N=30)

MoCA subscales	*M*	*SD*	*Minimum*	*Maximum*
Total score	20.00	3.39	13	25
Delayed recall (MoCA-DR)	2.33	1.47	0	4
Memory Index Score (MoCA-MIS)	10.27	3.30	3	15
Visuospatial/Executive (MoCA-VE)	2.40	1.40	1	5
Naming	2.90	0.40	1	3
Attention	4.10	1.18	1	6
Language	1.23	1.04	0	3
Abstract	0.97	0.76	0	2
Orientation	5.73	0.45	5	6

Paired associated learning tests

The descriptive statistics for the PAL variables (see Table 5) and their relationship with the MoCA total score (N=30). For the VPAL condition, immediate recall has a mean (M) of 7.83 with a standard deviation (SD) of 2.59 and a correlation (*r*) of 0.46, which is significant at $p = .01$. The delayed recall

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has a mean of 9.10 with a standard deviation of 2.33. It shows a stronger positive correlation with MoCA (r = .54, p < .01). Conversely, the Response error has a mean of 7.08 with a standard deviation of 4.58. It is negatively correlated with MoCA (r = -.54, p < .01), indicating that higher response errors are associated with lower MoCA scores. For the OPAL condition, participants showed a lower average performance compared to the verbal condition. The immediate recall score had a mean of 4.60 (SD = 2.04) and showed no significant correlation with the MoCA total score (r = .01, p = .96) or with the MoCA-VE subscore (r = .15, p = .42). In contrast, delayed recall had a higher mean of 6.07 (SD = 2.32) and showed a weak, non-significant positive correlation with the MoCA total score (r = .23, p = .22), but a strong and statistically significant correlation with the MoCA-VE score (r = .60, p < .01). The response error score, with a mean of 9.33 (SD = 3.72), was negatively correlated with both MoCA total (r = –.15, p = .43) and MoCA-VE (r = –.47, p = .01), indicating that higher error rates were associated with poorer cognitive performance, particularly in visuospatial/executive functioning.

Table 5 Descriptive statistics for the PAL and relationship with MoCA (N=30)

			MoCA - Total		MoCA - VE	
Variables	*M*	*SD*	*r*	*p*	*r*	*p*
VPAL						
Immediate recall	7.83	2.59	.46	.01		
Delayed recall	9.10	2.33	.54	<.01		
Response error	7.08	4.58	-.54	<.01		
OPAL						
Immediate recall	4.60	2.04	.01	.96	.15	.42
Delayed recall	6.07	2.32	.23	.22	.60	<.01
Response error	9.33	3.72	-.15	.43	-.47	.01

Wisconsin card sorting test

The Pearson correlation analysis highlights significant relationships between Wisconsin Card Sorting Test (WCST) performance metrics and cognitive functioning as measured by the MoCA total score and its

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Visuospatial/Executive (VE) subscale. See Table 6 for more detail. As indicated by higher MoCA total scores, participants with higher overall cognitive functioning tend to perform better on the WCST. Specifically, they complete more sets (r = .47, p < .01), need fewer trials to complete the first set (r = -.53, p < .01), and produce more conceptual-level responses (r =.43, p = .02). These participants also make fewer response errors (r = -.40, p = .03) and non-perseverative errors (r = -.41, p = .03), highlighting the strong link between overall cognitive health and WCST performance.

The MoCA VE subscale, specifically assessing visuospatial and executive functions, shows even stronger correlations with WCST performance. Higher VE scores are associated with completing more sets (r = .62, p < .01), making more conceptual-level responses (r = .54, p < .01), and having fewer failures to maintain a set (r = - .37, p = .04). Additionally, participants with higher VE scores make fewer response errors (r = - .45, p = .01) and non-perseverative errors (r = - .43, p = .02). These findings underscore the importance of visuospatial and executive functions in successful WCST performance.

Overall, the significant correlations between WCST metrics and MoCA scores demonstrate the WCST's utility in evaluating executive functions and their broader relationship with cognitive abilities.

Table 6 Descriptive statistics for the WCST and relationship with MoCA (N=30)

			MoCA - Total		MoCA - VE	
WCST subscales	*M*	*SD*	*r*	*p*	*r*	*p*
Completed set	2.37	2.16	.47	<.01	.62	< .01
The trial to complete the first set	23.73	23.59	-.53	<.01	-.36	.05
Conceptual level responses	16.17	8.19	.43	.02	.54	<.01
Failure to maintain a set	13.40	2.49	-.14	.46	-.37	.04
Response error	33.50	8.26	-.40	.03	-.45	.01
Perseverative errors	11.50	4.75	.02	.91	-.03	.87
Non-perseverative errors	22.00	8.25	-.41	.03	-.43	.02

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WCST subscales	*M*	*SD*	MoCA - Total		MoCA - VE	
			r	*p*	*r*	*p*
Percent response error	52.34	12.91	-.40	.03	-.45	.01
Percent perseverative errors	35.69	13.97	.23	.21	.34	.07
Percent non-perseverative errors	64.31	13.97	-.23	.21	- .338	.07

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Corsi block tapping test

This section presents the results of the Corsi Block Tapping Test for 30 participants and its correlations with three subscales of the Montreal Cognitive Assessment (MoCA): the total MoCA score, the Delayed Recall (DR) subscale, and the Visuospatial/Executive (VE) subscale. See Table 7 for more detail. The mean Corsi span score is 3.67 with a standard deviation of 1.40. The correlations indicate significant relationships between the Corsi span and certain MoCA subscales.

The Corsi span shows a significant positive correlation with the total MoCA score ($r = .45$, $p = .01$), suggesting that higher overall cognitive functioning is associated with better Corsi Block Tapping Test performance. Additionally, there is a significant positive correlation between the Corsi span and the MoCA VE subscale ($r = .42$, $p = .02$), indicating that better visuospatial and executive functioning is linked to higher Corsi span scores. However, the correlation between the Corsi span and the MoCA DR subscale ($r = .25$, $p = .17$) is not statistically significant, suggesting that delayed recall does not strongly influence Corsi Block Tapping Test performance.

In conclusion, the Corsi Block Tapping Test results show significant correlations with overall cognitive functioning and visuospatial/executive abilities, as measured by the MoCA total score and VE subscale, respectively. These findings suggest that the Corsi Block Tapping Test is a valuable tool for assessing visuospatial and executive functions, which are critical components of overall cognitive health. However, delayed recall appears to have a less pronounced impact on Corsi span performance.

Table 7 Descriptive statistics for the Corsi block tapping test and relationship with MoCA (N=30)

			MoCA - Total		MoCA - DR		MoCA - VE	
Variable	*M*	*SD*	*r*	*p*	*r*	*p*	*r*	*p*
Corsi span	3.67	1.40	.45	.01	.26	.17	.42	.02

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Mental rotation test

This section presents data on the performance of participants in the Mental Rotation Test (MRT) at different degrees of rotation and its relationship with the Montreal Cognitive Assessment (MoCA) scores. The degrees of rotation tested were 0, 50, 100, and 150 degrees. The mean (M) and standard deviation (SD) for the MRT scores are reported, along with the correlation coefficients (r) and ps for the relationships between MRT scores and both the total MoCA score and the MoCA visuospatial/executive (VE) score. See Table 8 for more information.

At 0 degrees of rotation, the mean MRT score was 8.03 (SD = 2.97), with correlation coefficients of .30 (p = .11) with the total MoCA score and 0.34 (p = .07) with the MoCA-VE score. For 50 degrees of rotation, the mean MRT score increased to 16.30 (SD = 5.74), showing significant correlations of .43 (p = .02) with the total MoCA score and .53 ($p < .01$) with the MoCA-VE score. At 100 degrees of rotation, the mean MRT score was 14.20 (SD = 5.82), with lower correlations of .15 (p = .42) with the total MoCA score and 0.26 ($p = .17$) with the MoCA-VE score. For 150 degrees of rotation, the mean MRT score was 14.47 (SD = 6.25), with correlations of .19 ($p = .30$) with the total MoCA score and 0.29 ($p = .13$) with the MoCA-VE score. When considering all degrees of rotation together, the mean MRT score was 53.00 (SD = 17.93), with correlation coefficients of .30 (p = .10) with the total MoCA score and 0.41 ($p = .03$) with the MoCA-VE score.

In conclusion, the data indicates that the MRT scores are moderately correlated with MoCA scores, particularly at 50 degrees of rotation, where the correlations are statistically significant. This suggests that performance on mental rotation tasks, especially at 50 degrees of rotation, is related to cognitive

abilities assessed by the MoCA, including visuospatial and executive functions. The overall correlation between mental rotation abilities and cognitive functioning is also supported by the combined combination of all degrees of rotation.

Table 8 Descriptive statistics for the Mental rotation test and relationship with MoCA (N=30)

			MoCA - Total		MoCA - VE	
Degrees of rotation	*M*	*SD*	*r*	*p*	*r*	*p*
0	8.03	2.97	.30	.11	.34	.07
50	16.30	5.74	.43	.02	.53	<.01
100	14.20	5.82	.15	.42	.26	.17
150	14.47	6.25	.19	.30	.29	.13
Total	53.00	17.93	.30	.10	.41	.03

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Reaction time tasks

This section presents data on the performance of participants in various reaction time tasks and their relationship with the Montreal Cognitive Assessment (MoCA) scores. The variables analyzed include Simple Reaction Time (RT), Choice Reaction Time (RT), and the number of correct choices in the Choice Reaction Time task. The table provides the mean (M) and standard deviation (SD) for each variable, along with the correlation coefficients (r) and ps indicating the strength and significance of their relationship with the total MoCA score.

The mean Simple RT was 0.394 seconds (SD = 0.139), showing a negative correlation of -.39 (p = .03) with the total MoCA score. The mean Choice RT was 0.891 seconds (SD = 0.46), also showing a significant negative correlation of -.42 (p = .02) with the total MoCA score. The mean number of correct choices in the Choice Reaction Time task was 62.07 (SD = 58.96), but this variable had a weaker and non-significant negative correlation of -.15 (p = .43) with the total MoCA score.

In conclusion, the data indicate that both Simple Reaction Time and Choice Reaction Time are significantly and negatively correlated

with MoCA scores, suggesting that longer reaction times are associated with lower cognitive functioning as measured by the MoCA. However, the number of correct choices in the Choice Reaction Time task did not show a significant relationship with MoCA scores. This highlights the relevance of reaction time measures in assessing cognitive abilities, with faster reaction times being indicative of better cognitive performance.

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Table 9 Descriptive statistics for the Reaction time tasks and relationship with MoCA (N=30)

Variables	*M*	*SD*	MoCA - Total	
			r	*p*
Simple RT	0.39	0.14	-.39	.03
Choice RT	0.89	0.46	-.42	.02
Choice correct	62.07	58.96	-.15	.43

Sound-induced flash illusion test

The table presents the descriptive statistics for the Sound-Induced Flash Illusion (SIFI) test across different conditions and stimulus onset asynchronies (SOA), along with their correlations with the MoCA (Montreal Cognitive Assessment) total score for 29 participants.

The Pearson correlation analysis of the Sound-Induced Flash Illusion (SIFI) test reveals significant relationships between reaction times (RT) and the Montreal Cognitive Assessment (MoCA) total score across different conditions and stimulus onset asynchronies (SOA). For the "1 beep 1 flash" condition, significant negative correlations are observed at SOAs of 150 ms (r = - .54, p < .01), 200 ms (r = - .50, p <.01), and 250 ms (r = - .52, p < .01), indicating that higher overall cognitive functioning is associated with faster reaction times. However, no significant correlation is found at 300 ms (r = - .20, p = .29). Similarly, in the "1 beep 2 flashes" condition, significant negative correlations at SOAs of 150 ms (r = - .39, p = .04), 200 ms (r = - .46, p = .01), and 250 ms (r = - .41, p = .03) suggest that better cognitive performance correlates with quicker reaction times, but not at 300 ms (r = - .27, p = .16).

For the "2 beeps 1 flash" condition, significant negative correlations are seen only at 200 ms (r = - .41, p = .03), while other SOAs show no significant relationships. The "2 beeps 2 flashes" condition shows significant negative correlations across all SOAs: 150 ms (r = - .47, p < .01), 200 ms (r = - .45, p = .01), 250 ms (r = - .51, p < 0.01), and 300 ms (r = - .46, p = .01), indicating consistently faster reaction times with higher cognitive scores.

For corrected total scores, significant positive correlations are only observed in the "2 beeps 2 flashes" condition, with correlations at SOAs of 150 ms (r = .53, p < .01), 200 ms (r = 0.52, p < .01), 250 ms (r = .44, p = .02), and 300 ms (r = .49, p < .01). Overall, the average reaction time shows significant negative correlations with MoCA scores at SOAs of 150 ms (r = - .44, p = .02), 200 ms (r = - .48, p < .01), and 250 ms (r = - .50, p < .01), but not at 300 ms (r = - .33, p = .08). The average corrected total score shows no significant correlation with MoCA scores (r = - .02, p = .94).

These results suggest that better cognitive performance, as indicated by higher MoCA scores, is generally associated with faster reaction times and better performance in the SIFI test, particularly in conditions with shorter SOAs.

Table 10 Descriptive statistics for the Sound-Induced Flash Illusion test and relationship with MoCA (N=29)

Condition	SOA	*M*	*SD*	MoCA - Total	
				r	*p*
1 beep 1 flash					
RT	150	0.55	0.3	-.54	<.01
	200	0.53	0.36	-.50	.01
	250	0.52	0.45	-.52	<.01
	300	0.5	0.39	-.20	.29
Corrected Total	150	9.45	0.83	.05	.80
	200	9.28	1.36	.12	.54
	250	9.17	1.37	.22	.25
	300	8.72	1.46	.09	.66

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Condition	SOA	*M*	*SD*	MoCA - Total	
				r	*p*
1 beep 2 flashes					
RT	150	0.69	0.39	-.39	.04
	200	0.64	0.37	-.46	.01
	250	0.61	0.36	-.41	.03
	300	0.63	0.35	-.27	.16
Corrected Total	150	3.59	3.91	-.07	.72
	200	3.72	3.88	-.13	.51
	250	3.28	3.55	-.12	.54
	300	3.17	3.65	-.10	.61
2 beeps 1 flash					
RT	150	0.66	0.36	-.25	.20
	200	0.72	0.45	-.41	.03
	250	0.72	0.38	-.36	.06
	300	0.72	0.34	-.24	.20
Corrected Total	150	3.1	3.6	-.22	.26
	200	3.14	3.67	-.23	.23
	250	3.55	3.7	-.23	.23
	300	3.83	3.76	-.26	.18
2 beeps 2 flashes					
RT	150	0.55	0.21	-.47	.01
	200	0.55	0.25	-.45	.01
	250	0.59	0.24	-.51	<.01
	300	0.69	0.32	-.46	.01
Corrected Total	150	9.21	1.99	.53	.00
	200	8.97	2.01	.52	.00
	250	9.1	1.99	.44	.02
	300	8.69	1.91	.49	.01
All in average					
RT	150	0.61	0.28	-.44	.02

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Condition	SOA	*M*	*SD*	MoCA - Total	
				r	*p*
	200	0.61	0.33	-.48	.01
	250	0.61	0.33	-.50	.01
	300	0.64	0.29	-.33	.08
Average		0.61	0.3	-.46	.01
Corrected Total		99.97	28.75	-.13	.50

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Relationships between cognitive metrics across different tasks

In general, the Pearson correlation analysis provides insights into the relationships between various cognitive performance metrics across different tasks, including Verbal Paired Associate Learning (VPAL), Non-verbal Paired Associate Learning (OPAL), Wisconsin Card Sorting Test (WCST), The Corsi Block Tapping Task (CBTP), Choice Reaction Time (CRAT), Simple Reaction Time (SRAT), and Sound-Induced Flash Illusion (SIFI). Significant correlations were observed among these metrics, indicating interconnected cognitive abilities. For instance, VPAL immediate recall and delayed recall show a strong positive relationship, suggesting that strong learning performance predicts strong test performance. Both VPAL immediate and delayed recall are strongly negatively correlated with response errors, indicating fewer errors with better recall. WCST shows significant relationships with VPAL learning and test scores, as well as CRAT correct responses, suggesting interdependencies between these cognitive domains. CBTP displays positive correlations with VPAL and OPAL metrics, indicating that better CBTP performance is linked to improved learning, test accuracy, and fewer errors. MTRT performance is positively correlated with cognitive accuracy measures and negatively with error rates, demonstrating links between mental rotation and cognitive task performance. CRAT and SRAT measures also show significant correlations, indicating that better performance on these reaction time tasks is associated with fewer errors and better performance in mental rotation and SIFI tasks. Moreover, SIFI displays positive correlations with several measures, indicating that better performance on SIFI is associated with improved cognitive accuracy and

reaction times. Please see the overall relationships in Figure 24 (Flags indicate significant values such as *** p < .001, ** p < .01, and * p < .5.)

For more detail, the analysis reveals several significant correlations among these cognitive performance metrics. For instance, the VPAL immediate recall and VPAL delayed recall (VPAL_test_corr) exhibit a strong positive correlation (r = .74, p <.01), indicating that participants who perform well in the learning phase also tend to perform well in the test phase of the VPAL task. Additionally, the VPAL immediate recall shows a strong negative correlation with response errors in the VPAL task (r = - .94, p<.01), suggesting that higher learning scores are associated with fewer errors. Similarly, the VPAL delayed recall is strongly negatively correlated with response error s (r = - .92, p<.01), reinforcing the relationship between better test performance and fewer mistakes. In the OPAL task, the immediate recall has a moderate positive correlation with the VPAL immediate recall (r = .29), though this correlation is not statistically significant. This suggests some level of shared cognitive skills or strategies between the VPAL and OPAL tasks.

The Pearson correlation analysis reveals significant relationships between the Wisconsin Card Sorting Test (WCST) performance metrics and other cognitive scales. *Percent errors* in the WCST percent errors showed strong negative correlations with both VPAL learning scores (r = - .94, p<.01) and VPAL test scores (r = - .92, p<.01), indicating that higher performance in verbal learning tasks is associated with fewer errors in the WCST. A moderate negative correlation was observed between WCST percent errors and CRAT correct responses, suggesting that better performance in choice reaction tasks is linked to fewer errors in the WCST. *Perseverative errors* in the WCST perseverative errors were negatively correlated with VPAL learning (r = - .94, p<.01) and test scores (r = - .92, p<.01), highlighting that better verbal learning and test performance are associated with fewer perseverative errors. Perseverative errors also showed a moderate negative correlation with CRAT correct responses, indicating that fewer perseverative errors are related to better performance in choice reaction tasks. *Non-perseverative errors* in the WCST were relatively stable across other cognitive tasks but did show slight correlations, suggesting some level of interrelation between task performances. *Conceptual-level*

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responses in the WCST had strong positive correlations with VPAL learning (r = .74, p<.01) and test scores, indicating that higher conceptual thinking abilities are associated with better verbal learning and memory performance. Moderate positive correlations with CRAT correct responses suggest that better performance in executive functioning and abstract thinking in the WCST is related to higher accuracy in choice reaction tasks. Overall, these correlations indicate that performance on the WCST is significantly related to other cognitive tasks, particularly those measuring verbal learning, memory, and reaction time accuracy. This underscores the interconnected nature of cognitive abilities and highlights the importance of executive functions as measured by the WCST in relation to broader cognitive performance.

The Corsi Block Tapping Task (CBTP) shows various relationships with other scales. It has a moderate positive correlation with VPAL immediate recall (r = .44, p < .05) and VPAL corrected responses (r = .43, p < .05), indicating that better performance on the CBTP is associated with better learning and test accuracy. There is a low negative correlation with VPAL response error (r = -.31, p < .05), suggesting fewer errors with higher CBTP performance. Similarly, CBTP has low positive correlations with OPAL immediate recall (r = .16, p < .05) and OPAL_test_corr (r = .39, p < .05), as well as a low negative correlation with OPAL response error (r = - .33, p < .05), indicating better performance on learning and test tasks with fewer errors. The task also shows a low positive correlation with WCST conceptual level responses (r = .428, p < .05) and a moderate negative correlation with WCST non-perseverative errors (r = - .413, p < .05), suggesting fewer non-perseverative errors and better conceptual responses. Additionally, there is a low positive correlation with WCST failure to maintain set (r = .42, p < .05) and MTRT corrected total (r = .42, p < .05), indicating better-set maintenance and mental rotation task performance. Lastly, CBTP shows a low positive correlation with SIFI-corrected responses (r = .30, p < .05), suggesting better performance on the sound-induced flash illusion task. Overall, better CBTP performance is generally associated with improved cognitive task performance and reduced error rates.

The Mental Rotation Task (MTRT) has two main measures, MTRT corrected responses and MTRT response time, which show distinct relationships with other scales. MTRT-corrected responses generally exhibit moderate

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positive correlations with learning and test accuracy measures such as VPAL immediate recall (r = .44, p < .05), VPAL delayed recall (r = .43, p < .05), and OPAL immediate recall (r = .34, p < .05), indicating that better performance on the MTRT is associated with better outcomes on these tasks. It also shows moderate negative correlations with error measures like VPAL response error (r = - .431, p < .05) and OPAL response error (r = - .35, p < .05), suggesting that higher MTRT performance is linked to fewer errors. Additionally, MTRT corrected total correlates moderately with WCST conceptual-level responses (r = .43, p < .05) and WCST non-perseverative errors (r = - .413, p < .05), reflecting a similar pattern. The MTRT response time measure, on the other hand, has fewer significant correlations but shows a moderate positive relationship with reaction time measures such as SRAT response time (r = .53, p < .05) and correct response measures like CRAT corrected total (r = .38, p < .05), indicating that faster reaction times and more correct responses are associated with better MTRT performance. Overall, the MTRT measures are positively associated with better cognitive task performance and negatively associated with error rates.

The Choice Reaction Time Task (CRAT) and the Simple Reaction Time Task (SRAT) both exhibit significant relationships with other scales in the correlation matrix. For the CRAT, response time shows a low positive correlation with OPAL immediate recall (r = .31, p < .05), indicating a slight association between better CRAT performance and learning accuracy. It also has a moderate positive correlation with SRAT response time (r = .52, p < .05), suggesting that faster reaction times in CRAT are associated with better performance in SRAT. Moreover, CRAT-corrected response has a low negative correlation with VPAL response error (r = - .30, p < .05) and OPAL response error (r = - .34, p < .05), indicating that better CRAT performance is linked to fewer errors. Additionally, there is a moderate positive correlation with WCST_conceptual_level_responses (r = .37, p < .05) and a low positive correlation with SIFI_total_corr (r = .38, p < .05), suggesting that better CRAT performance is associated with better conceptual responses and performance on the sound-induced flash illusion task. Moving to the SRAT, response time has a low negative correlation with VPAL response error (r = - .30, p < .05), indicating that better SRAT performance is associated with fewer errors.

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It shows a moderate positive correlation with CRAT response time ($r = .52$, $p < .05$), suggesting that better SRAT performance is linked to faster reaction times in CRAT. Furthermore, SRAT response time also has a low positive correlation with MTRT corrected response ($r = .42$, $p < .05$) and a moderate positive correlation with SIFI response time ($r = .43$, $p < .05$), indicating that better SRAT performance is associated with better mental rotation task performance and reaction times. In summary, the CRAT measures demonstrate significant associations with learning accuracy, error reduction, conceptual responses, and performance on the SIFI task, while SRAT measures show significant associations with fewer errors, faster reaction times, and better performance on mental rotation and SIFI tasks. Overall, better performance on both CRAT and SRAT is linked to improved cognitive performance and reaction times across various tasks.

The Sound-Induced Flash Illusion (SIFI) shows various relationships with other scales. The SIFI corrected responses measure has a moderate positive correlation with VPAL delayed recall ($r = .37$, $p < .05$) and OPAL delayed recall ($r = .37$, $p < .05$), indicating that better SIFI performance is associated with better test accuracy. There is a low positive correlation with WCST conceptual-level responses ($r = .35$, $p < .05$), suggesting a slight association with better conceptual-level responses. SIFI-corrected responses also show a moderate positive correlation with CRAT-corrected responses ($r = .37$, $p < .05$), indicating that better SIFI performance is linked to higher correct response rates. Additionally, it has a moderate positive correlation with MTRT_deg_total ($r = .43$, $p < .05$) and a strong positive correlation with SIFI response time ($r = .77$, $p < .01$), suggesting that better SIFI performance is associated with better mental rotation task performance and reaction times. The correlations suggest better SIFI performance is generally linked to improved accuracy and cognitive task performance. Overall, the SIFI corrected response measure indicates that higher performance on the sound-induced flash illusion task is associated with better cognitive performance and reaction times across various tasks.

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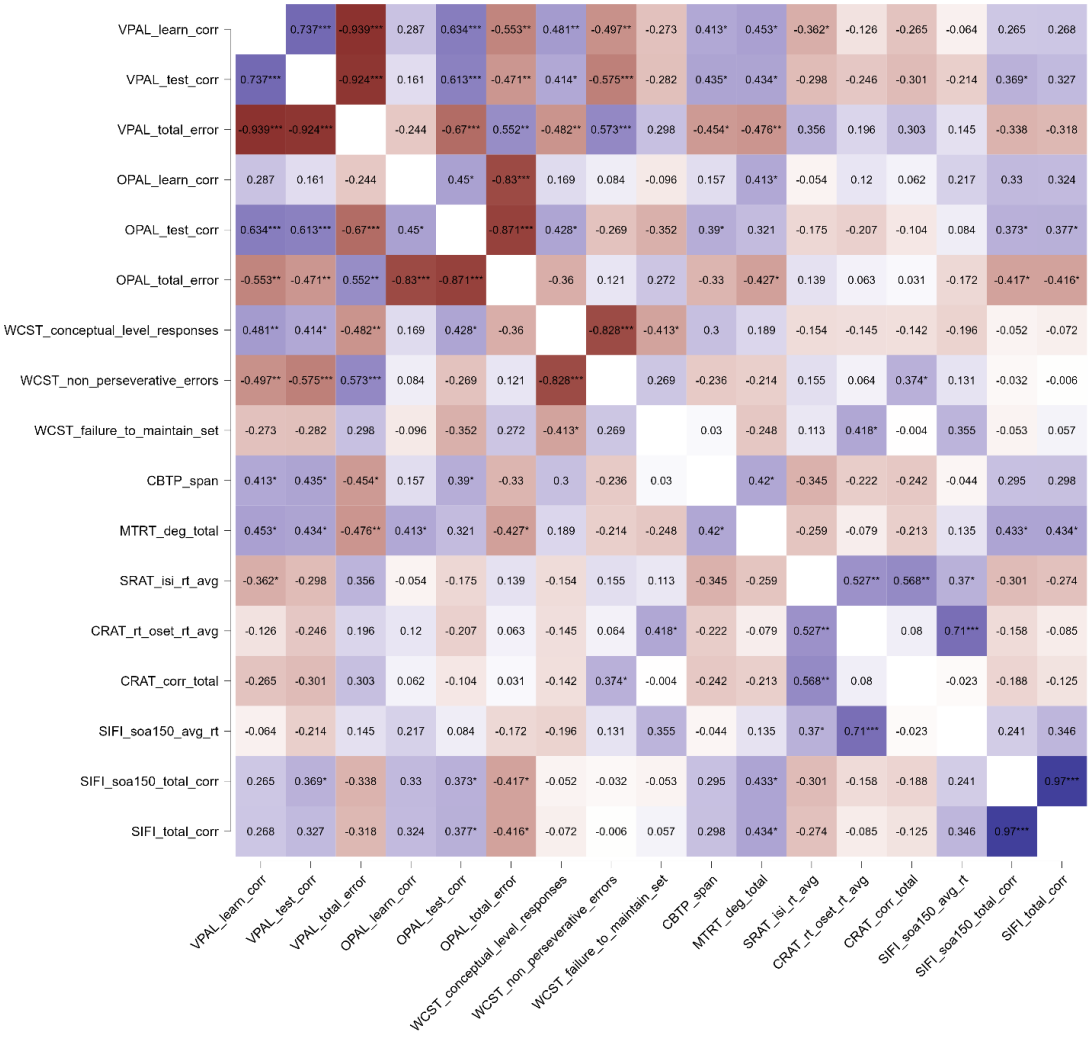

Figure 24 Heatmap of Pearson correlation coefficient matrix. Red and blue colors indicate a negative or positive correlation

Part 2 Development of the computerized multicomponent cognitive stimulation program

Content validity of the CMCS program

Aims

The study aimed to evaluate the validity of the developed CMCS program, including intervention programs and materials for use. It hypothesized that the program would demonstrate excellent content validity.

Methods

The CMCS program development

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The CMCS program was designed based on objectives and key principles that relate to the CST approach and multisensory integration theory (see Table 11). The tablet-based MCST intervention consisted of ten face-to-face group sessions delivered in groups of seven to ten participants over ten weeks. The sessions included (1) orientation and physical activity, (2) music and sound, (3) childhood, (4) food and cooking, (5) travel, (6) occupations, (7) sports, (8) shopping, (9) household, (10) team games, and termination. Moreover, multisensory integration training was included in the sessions at (2), (5), and (7). Participants were asked to use a 10-inch tablet with an Android operating system and the CMCS application installed for each session to participate in all activities.

Table 11 CST sessions adapted to Thai culture

Session	Objective	Key principles and activities in brief
1 Physical activity	(1) To foster familiarity and build positive relationships among participants within the group. (2) To enable participants to comprehend the purpose of engaging in the multifaceted cognitive stimulation program designed for elderly individuals in the early stages of dementia. (3) To ensure participants can proficiently use computer equipment and software programs. (4) To stimulate and coordinate movement between the arms, hands, fingers, and auditory sensory perception.	The activity focuses on establishing familiarity among the activity leader and all participants, leveraging the principle of building positive relationships. The activity leader functions as a facilitator rather than an instructor or expert. The emphasis is placed on stimulating and coordinating movements between the arms, hands, fingers, and auditory sensory perception, creating an enjoyable and engaging atmosphere for the elderly participants. Additionally, physical movement activities are designed to enhance physical skills related to movement and gameplay. These physical movements are integrated into every session as a preparatory phase before the main

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Session	Objective	Key principles and activities in brief
		activity, particularly focusing on the coordination of the arms, hands, fingers, and visual perception. Elderly participants are trained to use computer equipment by interacting with touch screens using these body parts. Participants become accustomed to tablet equipment through the principle of participation, which encourages enthusiasm, learning about technology, and overcoming any fear associated with using technological tools. This approach fosters an environment of mutual learning and exchange of knowledge.
2 Music and sound	(1) To stimulate auditory sensory perception and visual perception. (2) To stimulate multisensory perception involving both auditory and visual stimuli.	The use of sound and music plays a crucial role in stimulating memories associated with previous experiences of those sounds, leading to recollection and recognition. This process helps link visual memories related to those sounds. Stimulating multisensory perception enables the elderly to accurately perceive and process stimuli from both auditory and visual sources simultaneously. This approach creates an enjoyable and happy atmosphere to facilitate better recollection and memory retention.
3 Childhood	(1) To stimulate recollection and memory by linking prior knowledge with new learning.	This activity focuses on recollecting personal memories related to specific times, places, and individuals from the

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Session	Objective	Key principles and activities in brief
	(2) To stimulate language use and abstract meaning comprehension.	past. It emphasizes recalling memories from the past year involving significant individuals, which may be connected to particular locations or people. Additionally, the activity aims to stimulate language skills, particularly in understanding abstract meanings, by analyzing how words relate to one another.
4 Food and cooking	(1) To stimulate cognitive skills related to executive management. (2) To stimulate creative thinking. (3) To stimulate numerical and computational thinking.	Planning, categorizing, and sequencing are integral parts of executive management functions. These are stimulated using food and ingredients commonly found in the daily lives of the elderly. The activity is based on the principle of allowing the elderly to make their own selections, drawing from their experiences or creative thinking. This approach helps stimulate existing memories and activates other brain functions.
5 Travel	(1) To stimulate reality-based perception. (2) To stimulate recall and memory of events, times/periods, and locations.	This activity focuses on enhancing reality-based perception related to current weather conditions and seasons, as well as those occurring in different months in Thailand and the participants' residential areas. It also emphasizes the recollection of personal past experiences tied to specific times and places. Additionally, activities involving provinces and countries help the elderly recognize the locations and distances of places, thereby stimulating

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Session	Objective	Key principles and activities in brief
		spatial relationships.
6 Occupations	(1) To stimulate cognitive skills related to language. (2) To stimulate recall and memory of events and sounds.	This activity focuses on stimulating language skills, particularly in understanding abstract meanings, by analyzing how words relate to each other through vocational activities. Additionally, it involves auditory stimulation by encouraging the elderly to recall memories associated with specific places, which aids in better information retrieval.
7 Sports	(1) To stimulate auditory sensory perception. (2) To stimulate multisensory perception involving both auditory and visual stimuli.	Sports activities focus on auditory stimulation by encouraging the elderly to recall memories related to specific sports, which aids in better information retrieval. Additionally, multisensory stimulation helps the elderly accurately perceive and simultaneously process stimuli from sound and visual inputs.
8 Shopping	(1) To stimulate cognitive skills related to executive functions. (2) To stimulate recall and memory.	Working memory, categorizing, and sequencing are integral to executive management functions. These are stimulated using everyday items commonly found in the lives of the elderly. The activity employs the principle of creating an enjoyable and happy atmosphere to facilitate better recollection and information retrieval. This approach helps prevent stress or anxiety when undertaking challenging activities or tasks.
9 Household	(1) To stimulate cognitive skills related to executive functions.	Categorizing and sequencing are integral parts of executive management

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Session	Objective	Key principles and activities in brief
	(2) To stimulate event/episodic memory.	functions. These are stimulated using everyday items commonly found in the lives of the elderly. These stimuli support better recall and information retrieval.
10 Team games	(1) To stimulate language skills by encouraging the elderly to express their own thoughts. (2) To promote participation by encouraging the elderly to engage in group discussions and listen to others' opinions. (3) To summarize and conclude the group program.	The team game activity is designed to encourage the elderly to participate in the group by listening to others' opinions, which fosters learning and allows them to express their own thoughts. Additionally, the elderly are invited to share their memorable experiences from participating in the group activities, serving as a review and recall of their involvement.

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System and Tablet-based application development

This section presents how to develop the application or system, including four steps: study and planning, analysis and design, coding, testing, and improvement.

Study and planning step

This step involves planning the application's development. In this phase, the developer gathers and studies various user requirements and relevant research documents, such as users' individual choices, likes, and dislikes when interacting with an application or system. These preferences help customize the user experience to better meet their needs and expectations. By the end of this step, the system specifications that users need will be determined.

System analysis and design step

This step takes the specifications from the planning phase and analyzes them to find relevant information about the system. It involves studying the operation steps of the existing system to analyze the information that needs to be stored. The developer creates diagrams showing the relationships

between data and the system, designs the system flowcharts to be developed, and uses this information in the system design phase. This phase also includes designing the user interface (UI), the data stored in the system (database), and the system's process workflows.

System/application coding step

In this step, the information obtained from the system analysis and design step is developed into a functional application. This step transforms the data from a document format into a tangible and functional system. The system includes a tablet application and a web application. The tablet application was developed using React Native and then built for the Android platform under Android Studio. For web applications, Visual Studio was utilized to develop the application program interface as well as a manual website. The developed system is then installed on tablet devices with Android version 12 and Windows Server version 2023.

Application testing phase

This step involves testing the developed application with internal and beta tests. Firstly, internal tests include unit and integration tests that ensure the application works correctly. Secondly, a beta version should be released to a group of users to get feedback and identify issues. Two older adults were asked to try using the tablet application and get feedback and issues on improvement.

Application improvement step

In this step, experts' feedback and suggestions are summarized to determine further requirements and improve the system to meet user needs better. The questionnaire described in the next section is used.

Measurement

A questionnaire was applied to gather expert opinions on multi-component cognitive stimulation programs for older Adults with MCI. Each question was evaluated by rating, including 10 sessions. Each section contained four factors: the CMCS program content, the application's format and layout, a graphical application related to the CMCS program, and individual factors that were questioned.

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For more details, (1) the CMCS program content was described by objectives, activities, clarity, or understates, times, and theory and others that related to the concepts of the program (2) the application's format and layout were demonstrated by colors (ex., background, menu, text colors), and font(ex. size and family), position (ex. image, text, icon position), overall representation. (3) The association between graphics and the program was explained by how they related to objectives, activities, clarity, and understates of graphics. (4) individual factors were detailed by age, cognitive impairment, use of words, text, or sentence, and Thai cultural context. The four attributes of the questions and answers were rated on a 4-point scale, for example, 1 = not relevant/not clear/incomplete/meaningless: 4 = highly relevant/clear/complete/meaningful.

For measurement, the content validity index (CVI) was applied to evaluate the content validity. A content validity index was computed at the item (I-CVI) and scale (S-CVI) levels for each of the four qualities. The I-CVI was computed by dividing the total number of experts by the number of experts who gave a score of three or four. The I-CVI should not be less than 0.78 when there are more than five experts (Polit & Beck, 2006). Furthermore, the proportion of items on one scale that the experts rated as valid (ratings of 3 or 4) (universal agreement by experts = S-CVI/UA) and the average proportion of items on one scale rated 3 or 4 (average agreement by experts = S-CVI/Ave) were the two indices that were calculated to calculate the S-CVI. The S-CVI/UA is sensitive to the number of experts involved; the likelihood of producing a low S-CVI increases with the number of experts participating. Polit and Beck propose displaying both indices but choose the more moderate S-CVI/Ave. For both the S-CVI/UA and the S-CVI-Ave, 0.8 is the acceptable threshold; averages up to 0.9 are considered outstanding. In this study, five experts were required to give their evaluations. The experts worked in various fields, such as clinical psychology, psychiatry, gerontological nursing, and computer science.

Results

This study used a tablet and web-based architecture to develop a program. The system is separated into three layers: 1) Front-end layer, provided to participating users, represented by the Android tablet, as shown in Figure 27 Example screens of tablet application. 2) The application layer consists of business logic and is

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preserved to requests from the front-end layer, as demonstrated in Figure 26 Logical data model diagram. 3) A persistent layer is used for datastore and retrieving, as illustrated in

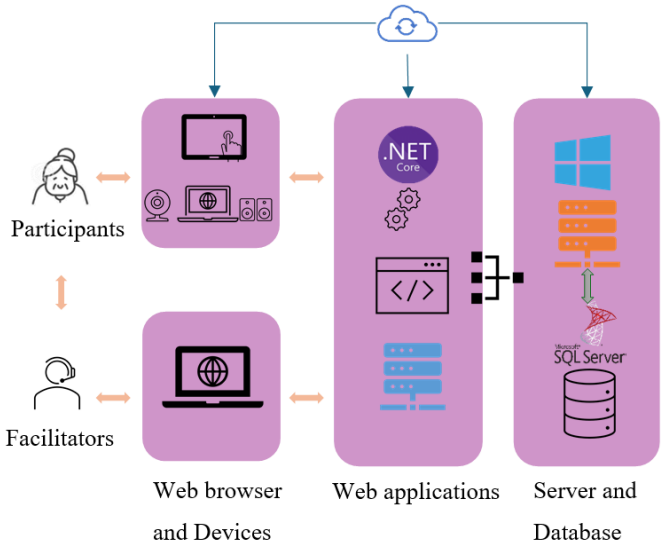

Figure 25 System architecture

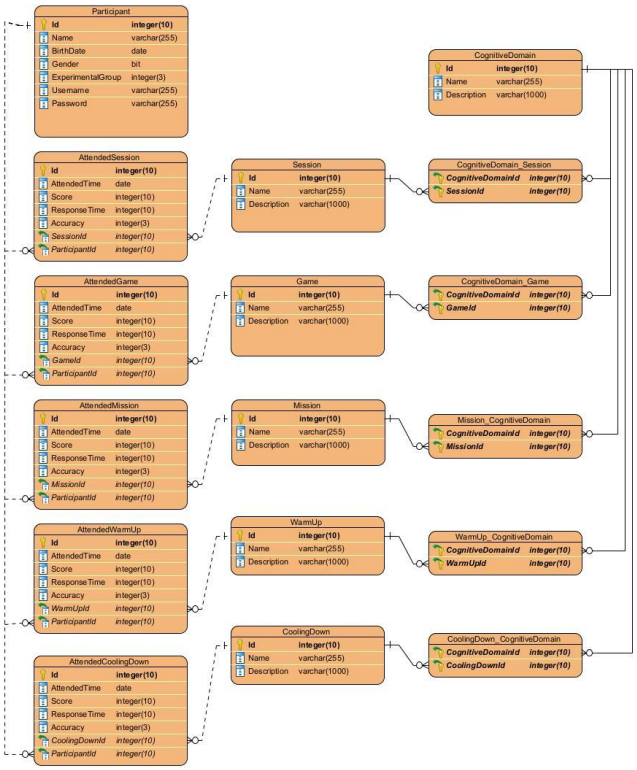

Figure 26 Logical data model diagram

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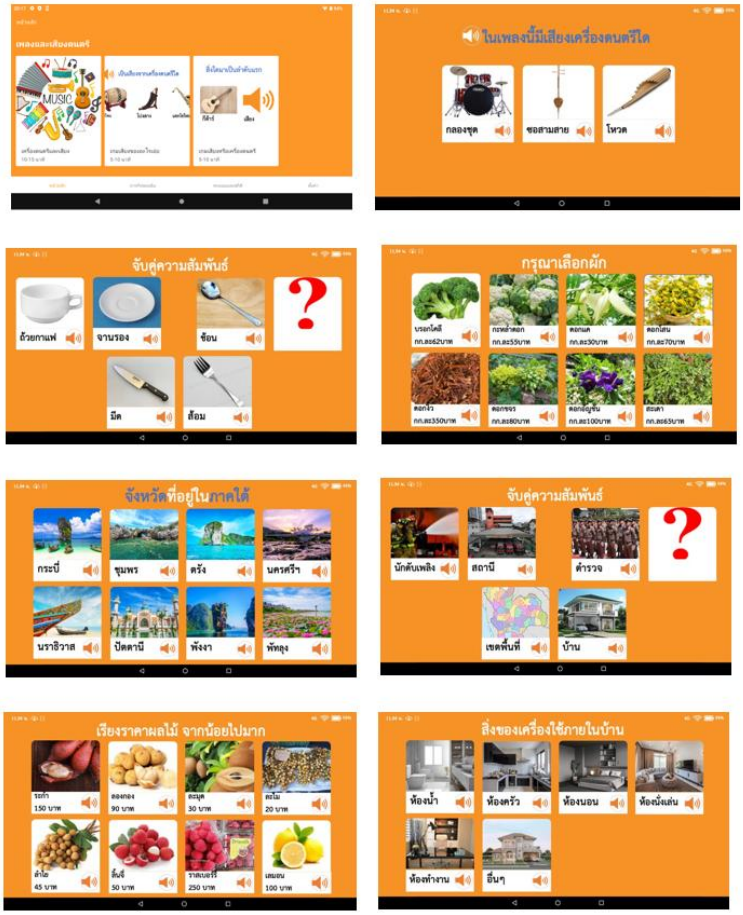

Figure 27 Example screens of tablet application

The Content Validity Index (CVI) was assessed based on five experts' evaluations to determine the items' relevance across multiple sessions. The overall Average Item CVI was found to be .90, indicating that the experts deemed 90% of the items relevant, reflecting strong content validity. The Scale-Level CVI/Average (S-CVI/Ave) also scored .90, underscoring the high content validity of the scale as a whole. When analyzed by session, the average item CVI scores were as follows in Table 12. These results indicate that all sessions exhibit high levels of content validity, with average item CVI scores ranging from .85 to .95. This high level of agreement among the experts supports the relevance and validity of the items included in each session. Overall, the findings demonstrate that the items across all sessions are generally well-validated and relevant, supporting the use of this scale for its intended purpose.

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Table 12 The average item CVI scores

Session	Theme	CVI
Session 1	Orientation and Physical Activity	.95
Session 2	Music and Sound	.87
Session 3	Childhood	.87
Session 4	Food and Cooking	.85
Session 5	Travel	.91
Session 6	Occupations and Current Affairs	.91
Session 7	Sports and Individual Games	.91
Session 8	Shopping	.89
Session 9	Household	.92
Session 10	Team Games and Closing Group	.90

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General discussion

The study aimed to evaluate the validity of the developed CMCS program, including the intervention program manual and materials (ex., tablet application) for use. Our findings demonstrate the great content validity of the CMCS program. The overall high CVI scores in this evaluation indicated that the items are generally relevant and well-validated by the expert panel. It indicated that the program related to the principles of CST and multisensory integration techniques. This study is designed based on group-based CST and multisensory stimulation approaches. CST has been shown to improve cognitive function and quality of life in individuals with dementia or MCI (Gomez-Soria et al., 2020; Spector et al., 2003). The program includes various activity sessions encompassing different areas such as life history, current affairs, creative tasks, games, and cognitive challenges (Aguirre et al., 2014; Yates et al., 2017). The belief that continuous participation in various mental activities improves cognitive and social functioning underpins cognitive stimulation treatments (Eckroth-Bucher & Siberski, 2009). In addition, This study also adapted to create 15 fundamental principles of individual CST, including mental stimulation, reminiscence, learning, and communication stimulation, employing a person-centered approach (Aguirre et al., 2014; Yates et al., 2017).

The present study introduces a comprehensive cognitive intervention program designed to address cognitive functions in older adults with MCI. The proposed program is tailored to target both cognitive domains and multisensory integration. This study's contribution lies in its novel approach to combining CST and multisensory integration training to address those cognitive deficits associated with MCI. Including tablet-based interventions and interactive sessions adds a technological dimension to traditional cognitive interventions, potentially enhancing engagement and outcomes.

Piloting the CMCS program

Aims

The pilot study aims to evaluate the effects of the tablet-group-based MCST program on cognition and emotions in older adults with MCI. This study hypothesizes that the intervention positively affects cognition and emotions in older adults with MCI after the intervention.

Methods

Design

This study investigates the efficacy of tablet- and group-based MCST program developed by the researchers, employing a one-group pretest–posttest design. Participants were randomly assigned to three subgroups, and dependent variables were measured both before and after the implementation of the program.

Participants

Thirty older adults participated as volunteers in the experiment. Participants ranged from 60 to 75 years of age (Mage = 66.14, SDage = 4.72) with normal or corrected vision, no color blindness or weakness, and no history of mental illness or neuropathy. Thai native speakers were capable of reading and comprehending writing. Participant characteristics are shown in Table 13. All participants were assessed using Thai version of Montreal Cognitive Assessment (MoCA-T) to assess cognitive impairment (Hemrungrojn et al., 2021), the subjective memory complaint scale to assess complaints of defective memory (Choe et al., 2018), the Chula Index Scale and ADL to assess normal activities of daily living

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(Jitapunkul et al., 1994), and CDR to assess the absence of dementia (Morris, 1997). These assessments are established screening tools as criteria for detecting MCI (Petersen et al., 2014).

Table 13 Characteristics of participants in piloting

		Frequency	Percent
Sex	Male	6	20.00
	Female	24	80.00
Occupation	Farmer	13	43.30
	Freelancer	3	10.00
	Seller	3	10.00
	Retired government officer	4	13.30
	Unemployed	7	23.30
Diseases	Diabetes	7	23.30
	Hypertension	12	40.00
	Other	6	20.00
Vision	Glasses	17	56.70
	No Glasses	13	43.30

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Instruments

Cognition was measured by the Thai version of Montreal Cognitive Assessment (MoCA-T). The MoCA-T version 8 is the most frequently used screening test, and it was produced as a quick screening tool for MCI and dementia in its early phases. The visuospatial (5 points), naming (3 points), attention (6 points), language (3 points), abstract (2 points), memory (5 points), and orientation (6 points) abilities are assessed on this exam. When an assessment was completed, all scores were totaled out of a possible overall of 30. Higher scores indicated more significant cognitive function. The internal consistency of the MoCA-T was excellent (Cronbach alpha = .91) (Hemrungrojn et al., 2021).

Depression was measured by The Thai Geriatric Depression Scale—15 (TGDS) (Wongpakaran et al., 2013). The TGDS Scale-15 is a structured self-report scale that assesses depression symptoms over the previous week. The scale contains 15 items, with responses chosen as agreeing or disagreeing.

The scale has a cut-off point for depression, which is 0–5 for no depression, 6–10 for suggestive of depression, and 11–15 for depression (Shiekh, 1986). The Cronbach's alpha coefficient of The TGDS Scale-15 was .83, which showed high internal consistency (Wongpakaran et al., 2013).

State Anxiety was measured by the State-Trait Anxiety Inventory Form (STAI) - state form (Y-1) in the Thai version. The STAI-state has the 20-item and has been validated by Darawan Thapinta (Thapinta, 1991). Participants were asked how often, during the last two weeks, they have been bothered by each of the 30 questions of generalized anxiety disorder. Response options are "not at all," "for several days," "more than half the time," and "nearly every day," scored as 0, 1, 2, and 3, respectively. Therefore, the scores range from 0 to 80, with scores of ≥20, ≥40, and ≥60 representing mild, moderate, and severe anxiety symptom levels, respectively. The Cronbach's alpha coefficient of the Thai STAI-state was .90, which showed high internal consistency (Thapinta, 1991)

Quality of life was measured by the Older People's Quality of Life Questionnaire (OPQoL-Brief) in the Thai version will assess participants' quality of life (Phanasathit, 2017). The OPQoL-Brief consists of 13 questions that are scored strongly agree = 1, agree = 2, disagree = 4, strongly disagree = 5. The items are added together to get a total OPQoL-Brief score, and then positive items are reverse coded, such that higher scores imply better QoL. The entire sum score varies from 13 to 65. The Cronbach's alpha coefficient of OPQoL-Brief was 0.94, and the consistency from the two-week test-retest reliability analyzed based on the ICC was .75, showing that the first and the second questionnaire response with a two-week interval were highly stability (Phanasathit, 2017).

Data analysis

Because the sample size in this study was not large enough to permit the assumption of normality on the study variables, the nonparametric test was used. The Wilcoxon signed-rank test was used to examine the effects of the tablet- and group-based MCST on cognition, emotions, and quality of life. The rank-biserial correlation coefficient (r_B) was considered as an effect size and is interpreted the same as *r* coefficient, such as trivial (<.10), small (.10), moderate (.30), and large (.50) (Tomczak & Tomczak, 2014).

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Results

In the Wilcoxon Signed Ranks Test, the participants showed significantly improved cognition (MoCA-total: $p < .01$), depression as measured by the TDGS ($p < .01$), and state anxiety as measured by the STAI-state ($p < .01$) but not in the quality of life as measured by the OPQoL-Brief ($p = .19$). Moreover, effect sizes among significant measures were large (r_B: .85-1.00) (see Table 14). Thus, Hypothesis 1 was supported.

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Table 14 Assessment results for older adults with MCI who completed both pre- and post-tests

Measure	Pre-test (N=30)		Post-test (N=30)		Wilcoxon Signed Ranks Test		
	Mean	SD	Mean	SD	*Z*	*p*	r_B
MoCA-T	19.50	2.13	23.13	2.71	4.70	<.01	1.00
TDGS-15	3.53	1.89	2.40	1.10	2.99	<.01	.85
STAI-state	43.37	5.40	37.30	5.87	3.96	<.01	.87
OPQoL-Brief	52.47	10.83	56.00	5.97	1.33	.19	.28

Phase 2 Investigation into the effect of the computerized multicomponent cognitive stimulation program on cognitive functions in older adults with MCI

Data analysis of participant characteristics

This section presents the demographic characteristics of participants categorized into three groups: MCST, CST, and Control. The distribution of participants across various characteristics such as gender, diseases, vision, marital status, and job type is outlined, along with the corresponding percentages and statistical comparisons. Gender distribution did not significantly differ among the groups ($\chi^2 = 1.24$, $p = .54$). Similarly, there were no significant differences observed in the prevalence of diabetes ($\chi^2 = 2.42$, $p = .29$), cardiovascular issues ($\chi^2 = 2.32$, $p = .31$), or other non-communicable diseases ($\chi^2 = 1.48$, $p = .48$) among the groups. Vision status also showed no significant differences across the groups ($\chi^2 = 0.09$, $p = .96$). Marital status, however, exhibited some variations among the groups ($\chi^2 = 7.18$, $p = .13$), with the control group having a higher proportion of married individuals

compared to MCST and CST groups. Employment status showed no significance (p = .11), with the CST group having a higher proportion of work or employed individuals compared to the other groups. See Table 15 for details.

The demographic analysis reveals that the MCST, CST, and control groups were generally well-matched in terms of gender, disease prevalence, and vision status, ensuring comparability across these variables. While there were some variations in marital status and employment status, these differences were not statistically significant. Therefore, the demographic characteristics of the participants do not significantly confound the outcomes of the study, allowing for a fair comparison of the interventions' effects across the groups.

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Table 15 Characteristics of the participants (categorical data)

Characteristic	MCST n=31		CST n=31		Control n=31		Group Comparison	
	n	%	n	%	n	%	χ^2	p
Gender							1.24	.54
Male	5	16	5	16	8	26		
Female	26	84	26	84	23	74		
Diseases								
Diabetes	7	23	9	29	4	13	2.42	.29
Cardiovascular	13	42	8	26	13	42	2.32	.31
Other NCDs	7	23	5	16	9	29	1.48	.48
Vision							0.09	.96
Glasses needed	18	58	18	58	19	61		
Normal vision	13	42	13	42	12	39		
Marital status							7.18	.13
Single	6	19	10	32	4	13		
Married	17	55	16	52	24	77		
Widowed	8	26	5	16	3	10		
Job							4.49	.11
Unemployed/retired	18	58	10	32	16	52		

Characteristic	MCST n=31		CST n=31		Control n=31		Group Comparison	
	n	%	n	%	n	%	x^2	*p*
Employed/working	13	42	21	68	15	48		

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The characteristics of participants from three groups (MCST, CST, and Control) are summarized (see Table 16). According to the lack of a normal distribution in the age variable (W = .96, p < .01), the Kruskal-Wallis test was employed to assess the age variable between the three groups. The mean ages across groups were relatively similar, with no statistically significant difference found (p = .44). In contrast, the distribution and variance data, along with other variables, were observed to follow a normal distribution and exhibited equal variance. Subsequently, a one-way ANOVA was conducted to ascertain the mean disparities in demographic and psychological scores across the three groups. The findings indicate that there was no significant variation in schooling years among the groups (p = .26). Similarly, measures of depression, anxiety, global cognition, and quality of life yielded no statistically significant differences among the groups (p > .05 for all comparisons).

These results show that demographic and psychological characteristics, global cognition, and quality of life do not differ significantly among the groups, indicating a balanced distribution across experimental conditions. See Table 15 and Figure 28 for more information.

Table 16 Characteristics of the participants (interval/ratio scale)

Characteristic	MCST n=31		CST n=31		Control n=31		Group Comparison	
	M	*SD*	*M*	*SD*	*M*	*SD*	$F \mid x^2$	*p*
Age	66.90	4.19	68.40	5.14	67.70	4.95	1.63[k]	.44
Schooling years	11.50	4.95	10.70	4.97	9.42	5.48	1.35	.26
Depression	2.32	2.20	2.23	1.76	2.13	2.11	0.14	.71
Anxiety	36.80	7.38	38.90	6.12	38.50	6.62	0.97	.33
Global cognition	21.50	2.23	20.80	2.53	20.7	2.11	0.94	.39

Note: k: The Krukull Wallis test was utilized for group comparison. F is the value of the statistic for group comparison using the ANOVA.

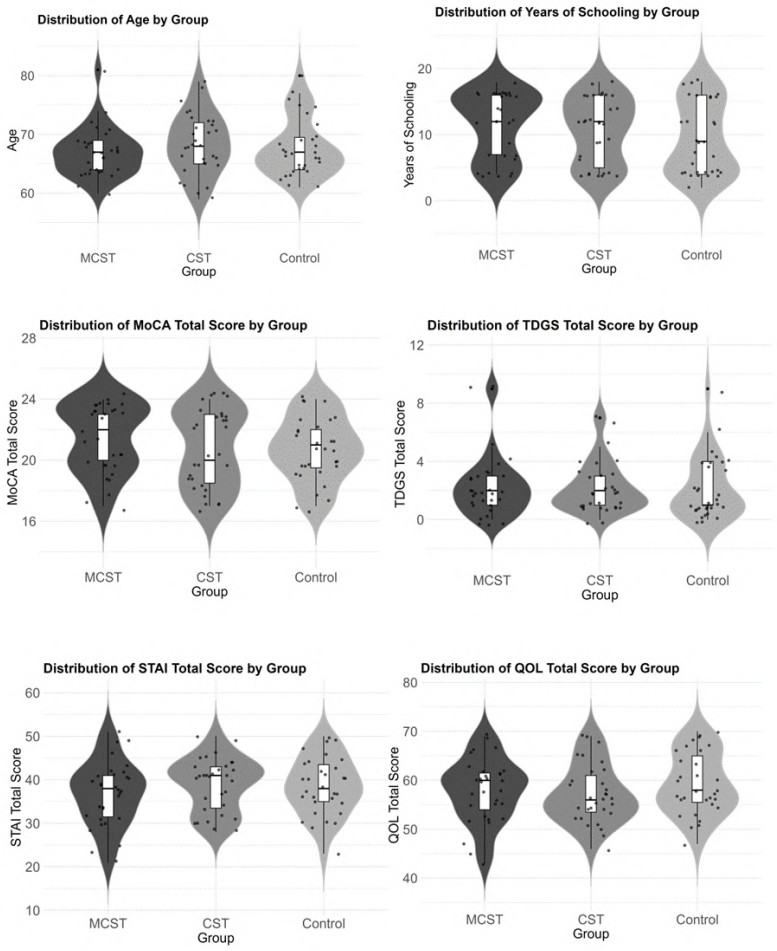

Figure 28 Violin plots of characteristic distribution

Data analysis of standardized and computer-based neuropsychological tests

Paper-based tests on global cognition, emotions, and quality of life

This section presents the characteristics of global cognitive, emotions, and quality of life variables across three different groups: the MCST group, CST group, and the control group. See Table 17 for overall information.

For the Montreal Cognitive Assessment (MoCA) scores, notable differences were observed between the groups. At the pre-test stage, the MCST group had the highest mean score (M = 21.50), followed by the CST group (M = 20.80), and the control group (M = 20.60). However, at the post-test stage, significant

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improvements were seen in the MCST group (M = 34.90), whereas the CST group (M = 23.70) and the control group (M = 20.40) showed comparatively smaller gains.

Regarding the TDGS test, no substantial differences were observed between the groups at the pre-test stage. However, at the post-test stage, the MCST group demonstrated a low mean score (M = 1.13), while the CST group (M = 1.39) and the control group (M = 2.43) showed high scores.

In terms of State-Trait Anxiety Inventory (STAI) scores, there were minor variations between the groups at both pre-test and post-test stages. The CST group consistently had slightly higher mean scores compared to the MCST and control groups.

For Quality of Life (QOL) assessments, there were marginal differences between the groups at both pre-test and post-test stages. The scores remained relatively stable across all groups, with slight fluctuations observed in the post-test scores.

Table 17 Characteristics of the global cognitive, emotions, and quality of life variables

Variables	Test	MCST			CST			Control		
		n	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
MoCA	Pre	31	21.50	2.23	31	20.80	2.53	30	20.60	2.06
	Post	31	24.90	2.29	31	23.74	2.16	30	20.43	2.45
TDGS	Pre	31	2.32	2.20	31	2.23	1.76	30	2.07	2.12
	Post	31	1.13	1.41	31	1.39	1.67	30	2.43	2.67
STAI	Pre	31	36.80	7.38	30	39.00	6.21	30	38.30	6.62
	Post	31	36.29	6.67	30	36.87	5.62	30	40.67	6.55
QOL	Pre	31	57.90	6.54	30	57.30	6.00	30	59.50	6.24
	Post	31	58.48	5.88	30	55.30	5.53	30	58.13	5.62

Analysis of assumptions

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In the normality, MoCA, STAI, and QOL have p-values greater than .05 (ranging from .74 to .99), indicating that these variables are normally distributed. TDGS has a p-value less than .05, indicating a departure from normality.

In the homoscedasticity, TDGS has a p-value less than .05 (specifically, <.01), suggesting heteroscedasticity. MoCA, STAI, and QOL have p-values greater than .05, indicating homogeneity of variance.

In the homogeneity of regression slope (Parallelism), all variables have p-values greater than .05, suggesting that the regression slopes are parallel across groups.

In summary, for the MoCA, STAI, and QOL variables, the assumptions of normality, homogeneity of variance, and homogeneity of regression slope are met. However, the TDGS variable deviates from normality and shows evidence of heteroscedasticity, indicating that the ANCOVA results are generally robust (see Table 84).

Analysis of group comparisons

ANCOVA was applied to analyze outcome variables by examining various paper-based tests that evaluate global cognition, emotions, and quality of life (QOL) variables. The groups under scrutiny encompass three distinct categories: the MCST, CST, and control groups. Post-test scores were the independent variable, while pre-test scores were incorporated as covariates. See Table 18 for overall information and Figure 29 for illustrations.

Regarding the Thai version of Montreal Cognitive Assessment (MoCA-T), significant differences were observed among the three groups *(F(*2,88*)* = 34.75, $p < .01$) with a moderate effect size (partial $\omega^2 = 0.42$). Post-hoc comparisons on MoCA-T revealed significant differences between the MCST and control groups *(t(*88*)* = 7.87, $p < .01$), with a large effect size (Cohen's $d = 2.03$). Similarly, significant differences were observed between the CST and control groups (t(88*)* = 6.36, $p < .01$) with a substantial effect size (Cohen's $d = 1.63$).

Significant differences in TDGS were found between the MCST and control groups ($p < .01$) and between the CST and control groups ($p < .01$), both with moderate to large effect sizes (Cohen's d = -0.99 and -0.78, respectively). Post-hoc analysis indicated a significant difference in STAI between the

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MCST and control groups (p = .01), with a moderate effect size (Cohen's d = -0.72). Moreover, significant differences were observed between the CST and control groups (p < .01) with a substantial effect size (Cohen's d = -0.87). The TDGS indicated significant differences among groups (p < .01), with a large effect size (partial ω^2 = .41). Pre-test scores significantly influenced post-test scores (p < .01) but with a smaller effect size (partial ω^2 = .08).

State-Trait Anxiety Inventory (STAI) scores differed significantly among groups (p < .01), with a substantial effect size (partial ω^2 = 0.37). Pre-test scores significantly impacted post-test scores (p < .01) with a modest effect size (partial ω^2 = 0.09). Quality of Life (QOL) scores did not significantly differ among groups (p = .95), with a negligible effect size (partial ω^2 < 0.01). However, pre-test scores significantly influenced post-test scores (p < .01) with a large effect size (partial ω^2 = 0.48).

The ANCOVA results demonstrate that the interventions (MCST and CST) had significant and important impacts on global cognition and emotional measures (TDGS and STAI), with both interventions leading to improvements over the control group. However, the interventions did not significantly affect the quality of life measures. The substantial effect sizes in cognition and emotional measures underscore the effectiveness of the MCST and CST interventions in enhancing cognitive function and reducing anxiety and depressive symptoms. The findings suggest that these interventions can be beneficial in improving specific aspects of cognitive and emotional health.

Table 18 ANCOVA of the paper-based tests on global cognition, emotions, and quality of life variables

		df	*SS*	*MS*	*F*	*p*	ω_p^2
MoCA							
	Pre-test	1	174.58	174.58	44.19	<.01	0.32
	Group	2	274.52	137.26	34.75	<.01	0.42
	Residuals	88	347.63	3.95			
	Post-hoc	*df*	*DM*	*SE*	*t*	*p*	*d*

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	MCST-CST	88	0.81	0.51	1.60	0.11	0.41
	MCST-Control	88	4.05	0.52	7.87	<.01	2.03
	CST-Control	88	3.24	0.51	6.36	<.01	1.63
TDGS							
	Pre-test	1	149.40	149.40	67.93	<.01	0.42
	Group	2	36.23	18.12	8.24	<.01	0.14
	Residuals	88	193.54	2.20			
	Post-hoc	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	88	-0.32	0.38	-0.85	.40	-0.22
	MCST-Control	88	-1.47	0.38	-3.87	<.01	-0.99
	CST-Control	88	-1.15	0.38	-3.03	<.01	-0.78
STAI							
	Pre-test	1	1,470.24	147.24	62.05	<.01	0.40
	Group	2	306.65	153.33	6.47	<.01	0.11
	Residuals	87	2,061.56	23.70			
	Post-hoc	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	87	0.71	1.26	0.57	1	0.15
	MCST-Control	87	-3.50	1.25	-2.80	.01	-0.72
	CST-Control	87	-4.22	1.26	-3.35	<.01	-0.87
QOL							
	Pre-test	1	1,331.53	1,331.53	78.69	<.01	0.48
	Group	2	39.75	19.87	1.18	.31	<0.01
	Residuals	87	1,472.10	16.92			

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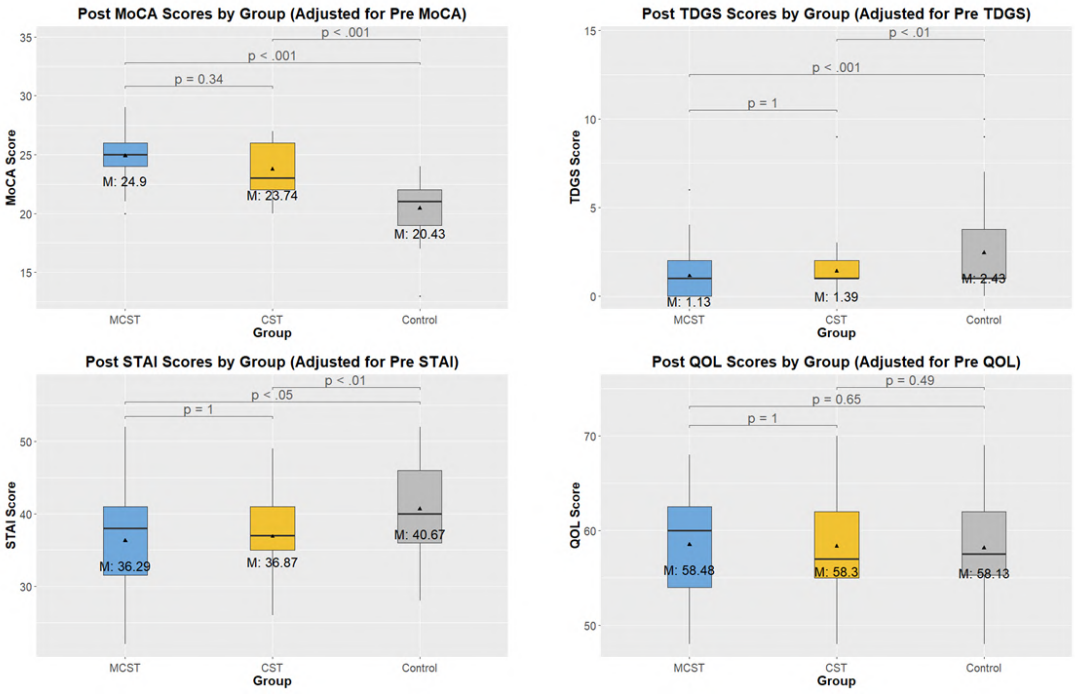

Figure 29 Box plots of standardized neuropsychological tests showing post hoc comparisons

Paired associates learning tasks (PAL)

This section provides the characteristics of variables in the Paired Associates Learning (PAL) tasks across three different groups: MCST, CST, and control (Table 19).

Corrected score differences were observed between the groups for the Verbal Paired Associates Learning (VPAL) task. At the pre-test stage, the control group had the highest mean score (M = 10.60), followed by the CST group (M = 9.52), and the MCST group (M = 9.16). However, at the post-test stage, both the MCST group (M = 10.70) and the CST group (M = 10.80) showed improvements, whereas the control group (M = 10.00) exhibited minimal change.

There were notable variations between the groups regarding the Object Paired Associates Learning (OPAL) task. Similar to VPAL, at the pre-test stage, the control group had the highest mean score (M = 7.37), followed by the CST group (M = 6.83), and the MCST group (M = 6.48). However, at the post-test stage, increasing scores were observed in both the MCST group (M = 7.87) and the CST group (M = 6.53), while the control group (M = 6.70) showed relatively smaller gains.

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Table 19 Characteristics of the variables in the paired associates learning tasks

Variables	*test*	MCST			CST			Control		
		n	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
VPAL	Pre	31	9.16	2.34	31	9.52	2.82	27	10.60	1.42
	Post	31	10.70	1.72	31	10.80	1.96	27	10.00	2.51
OPAL	Pre	31	6.48	2.39	30	6.83	2.51	27	7.37	2.39
	Post	31	7.87	2.14	30	6.53	2.36	27	6.70	2.00

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Analysis of assumptions

Correct variable – The Shapiro-Wilk test was performed and showed that the distribution of the Correct variable departed significantly from normality (W=0.71,p<.01). The variances of the Correct variable are equal across the three groups (Bartlett's *K-squared* = 4.20, $F = 2$, $p = .12$). Lastly, the slopes of the regression lines are homogeneous across the groups ($F = 2.66$, $p = .08$) (see Table 84). Overall, these results provide evidence supporting the homogeneity of variance, liearity, and homogeneity of regression slopes assumptions. However, the assumption of normality was not met, indicating that the ANCOVA results are generally robust despite this violation.

Analysis of group comparisons

For the correct variable in the verbal associates learning task (VPAL), we performed ANCOVA with the VPAL variable as the dependent variable and the intervention condition as a factor or dependent variable with pre-test scores as a covariate (see Table 26 and Figure 30). Results show a main significant effect related to the intervention condition *(F(*2,85)=6.61, p<.01), with a large effect size (*partial ω²=.10*), while statistically controlled for the effects of the covariate. The post-hoc comparisons revealed significant differences in performance between the MCST and control groups, as well as between the MCST and CST groups. No significant difference was found between the MCST and CST groups *(t(*85*)* = 0.23, *p* = .82), indicating similar performance. However, both the MCST-Control and CST-control groups showed significantly higher scores compared to the control group

*(t(*85*)* = 3.29, *p* < .01 for MCST-Control; t(85)= 3.12, *p* < .01 for CST-Control), with large effect sizes (Cohen's *d* = 0.84-0.89).

For the non-verbal associates learning task (OPAL), we performed ANCOVA with the OPAL variable as the dependent variable and the intervention condition as a factor or dependent variable with pre-test scores as covariate. Results show a main significant effect related to the intervention condition *(F(*2,84*)* = 7.14, p<.01), with a large effect size (partial ω^2=.11), while statistically controlled for the effects of the covariate. The post-hoc comparisons revealed significant differences in performance between the MCST and control groups, as well as between the MCST and CST groups. Significant differences were observed between the MCST and CST groups *(t(*84*)* = 3.21, *p* < .01) and between the MCST and control groups *(t(*84*)* = 3.29, *p* < .01). Again, large effect sizes were found for both comparisons (Cohen's *d* = 0.82-0.88). However, no significant difference was detected between the CST and control groups *(t(*84*)* = 0.19, *p* = .85), suggesting comparable performance between these two groups.

Overall, these results indicate that both the MCST and CST interventions were effective in improving performance on the paired associates learning tasks compared to the control group. However, no significant difference in performance was observed between the MCST and CST groups, suggesting similar efficacy of the two interventions in enhancing cognitive function in the context of paired associates learning.

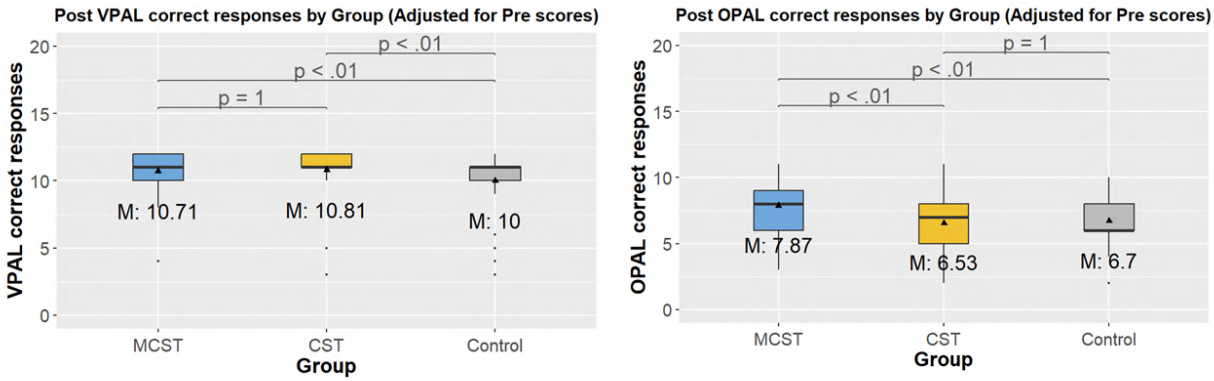

Figure 30 Box plots of VPAL-correct responses showing post hoc comparisons

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Verbal fluency tasks (VFT)

Table 20 presents the characteristics of variables in the Verbal Fluency Tasks (VFT) across three groups: the MCST group, the CST group, and the control group.

There were discernible differences between groups for the letter fluency task involving the letter 'Kor'. At the pre-test stage, the CST group exhibited the highest mean score (M = 8.73), followed by the MCST group (M = 8.33), and the control group (M = 7.39). After the intervention, both the CST (M = 10.80) and MCST (M = 9.67) groups showed improvements, while the control group (M = 9.14) also displayed an increase in mean score.

Similarly, in the letter fluency task involving the letter 'Or', differences were observed among the groups. At the pre-test stage, the CST group had the highest mean score (M = 7.16), followed by the MCST group (M = 7.00), and the control group (M = 6.39). After the intervention, both the CST (M = 8.61) and MCST (M = 8.83) groups demonstrated improvements, whereas the control group (M = 6.43) showed a slight increase in mean score.

Variations were evident among the groups regarding category fluency tasks, such as Animal and Fruit. In the Animal category, the MCST group had the highest mean score (M = 17.80) at the pre-test stage, followed by the CST group (M = 16.00), and the control group (M = 16.50). After the intervention, both the MCST (M = 19.10) and CST (M = 18.60) groups exhibited improvements, while the control group (M = 18.00) also showed a slight increase in mean score.

Similarly, in the Fruit category, the CST group had the highest mean score (M = 15.30) at the pre-test stage, followed by the MCST group (M = 14.80), and the control group (M = 13.70). After the intervention, both the CST (M = 15.50) and MCST (M = 15.60) groups demonstrated improvements, while the control group (M = 15.80) showed a minor increase in mean score.

Table 20 Characteristics of the variables in the verbal fluency task

		MCST			CST			Control		
Variables	*test*	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*

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Variables	*test*	MCST			CST			Control		
		n	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Letter										
'Kor'	Pre	30	8.33	4.43	30	8.73	3.69	28	7.39	4.19
	Post	30	9.67	4.85	30	10.80	4.72	28	9.14	5.50
'Or'	Pre	30	7.00	3.87	31	7.16	3.49	28	6.39	3.64
	Post	30	8.83	4.30	31	8.61	3.65	28	6.43	3.73
Category										
Animal	Pre	30	17.80	5.29	30	16.00	5.76	28	16.50	6.11
	Post	30	19.10	4.88	30	18.60	5.90	28	18.00	5.45
Fruit	Pre	29	14.80	4.19	31	15.30	4.54	28	13.70	5.12
	Post	29	15.60	5.07	31	15.50	4.85	28	15.80	4.78

Analysis of assumptions

The assumptions of normality, homoscedasticity, and parallelism were assessed for 'Kor' and 'Or' variables in the latter category, as well as for the Animal and Fruit categories (see Table 84). For the 'Kor' variable, normality was violated ($p < .01$), while homoscedasticity ($p = .69$) and parallelism ($p = .26$) assumptions were met. Similarly, for 'Or', the normality assumption was met ($p = .35$), while homoscedasticity ($p = .63$) and parallelism ($p = .33$) were also supported.

In the category analysis, both Animal and Fruit variables met the normality assumption ($p = .04$ and $p = .98$, respectively). However, for homoscedasticity, the Animal category violated the assumption ($p = .60$), while the Fruit category supported it ($p = .95$). Additionally, both categories showed no violation of the parallelism assumption ($p = .62$ and $p = .69$, respectively).

Overall, while normality was violated for the Kor variable in the latter category, and homoscedasticity was violated for the Animal category, the assumptions of homoscedasticity and parallelism were generally supported for the variables assessed, indicating that the ANCOVA results are generally robust despite these violations (see Table 84).

Analysis of group comparisons

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This section presents the results of ANCOVA for verbal fluency tasks, explicitly focusing on letters Kor, Or, and categories of animals and fruits. Post-test scores served as the independent variable, with pre-test scores as a covariate (see Table 26 and Figure 31).

For the task involving the letter 'Kor', no significant differences were found among groups (p = .70), with a moderate effect size (partial ω^2 < .01). In contrast, for the task involving the letter 'Or', significant differences were observed among groups *(F(*2,85*)* = 3.70, *p* = .03), with a small effect size (partial ω^2 = 0.06), when controlling for the covariate *(F(*1,85*)* = 74.41, p<.01). Post-hoc analyses have shown no significant difference in the correct score between MCST and CST groups *(t(*85*)* = 0.45, *p*=1) with a medium effect size (Cohen's *d* = 0.45) as well as between CST and control groups *(t(85)*=2.12, *p* = .11) with a negligible effect size (Cohen's *d* = 2.14). Constantly, other pairwise have shown a significance between MCST and control groups *(t(*85*)* = 3.29, *p* = .04) with a large effect size (Cohen's *d* = 2.56).

When considering the category of animals, no significant differences were detected among groups (p = .68), with a moderate effect size (partial ω^2 = 0.25). Pre-test scores significantly influenced post-test scores (p < .01) with a negligible effect size (partial ω^2 <.01). Similarly, for the category of fruits, no significant differences were found among groups (p = .68), with a tiny effect size (partial ω^2 < .01). Pre-test scores significantly influenced post-test scores (p < .01) with a negligible effect size (partial ω^2 = 0.16).

Overall, the letter 'Or' task showed significant differences among groups, particularly between the intervention group (MCST) and the control group, indicating the effectiveness of the interventions. However, there were no significant differences between CST and the control group as well as between the intervention groups themselves. The findings suggest that the interventions had a varying impact on verbal fluency tasks, with notable improvements observed in the letter 'Or' task but not in the other tasks.

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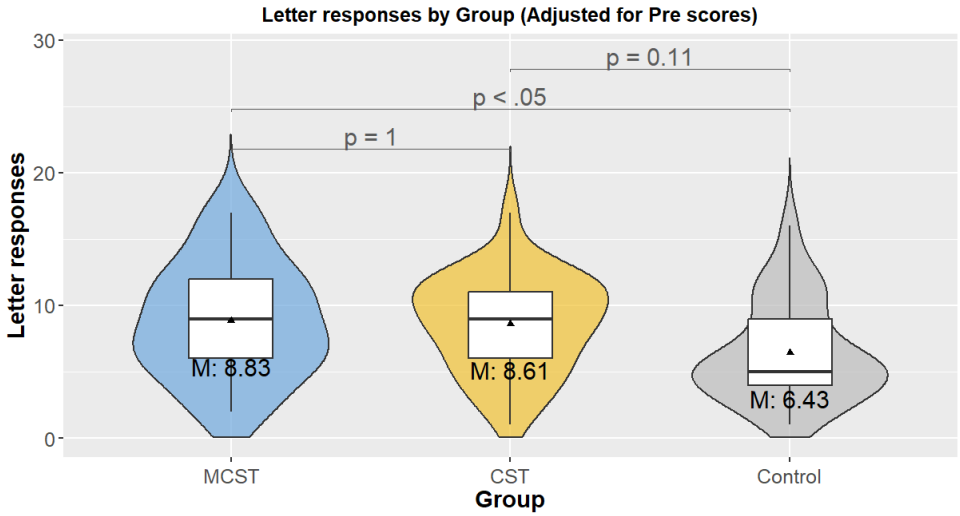

Figure 31 Violin and box plot of Verbal fluency tasks-'Or' showing post hoc comparisons

Corsi block-tapping task

This section presents the characteristics of variables in the Corsi block-tapping task across three conditions: the MCST group, the CST group, and the control group. The data includes performance on the task before (Pre) and after (Post) the intervention (see Table 21), specifically focusing on the span variable, which reflects participants' ability to remember and reproduce sequences of spatial locations.

Before the intervention (Pre-test), the mean span score for the MCST group was 4.10, with a standard deviation of 0.94. The CST group exhibited a slightly higher mean span score of 4.45, with a similar standard deviation of 0.93. The control group had a mean span score comparable to the MCST group, also at 4.10, with a slightly higher standard deviation of 1.16.

After the intervention (Post-test), there were noticeable improvements in span scores across all groups. The MCST group showed a significant increase in mean span score to 5.19, with a reduced standard deviation of 0.54. Similarly, the CST group demonstrated an improvement in mean span score to 4.87, with a standard deviation of 0.76. The control group also exhibited a slight increase in mean span score to 4.07, with a standard deviation of 1.01.

Table 21 Characteristics of the variable in the Corsi block-tapping task

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Variables	*test*	MCST			CST			Control		
		n	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Span	Pre	31	4.10	0.94	31	4.45	0.93	30	4.10	1.16
	Post	31	5.19	0.54	31	4.87	0.76	30	4.07	1.01

Analysis of assumptions

The assumption testing for the Corsi block-tapping task is presented in Table 84, evaluating Normality, Homoscedasticity, and Parallelism. The normality test indicates $W = 0.98$, suggesting a normal distribution ($p = .19$). The homoscedasticity test shows *K-squared* = 7.21, indicating homogeneity of variances ($p = .01$). The parallelism test reveals $F = 2.74$, indicating no violation of the assumption of homogeneity of regression slope ($p = .07$) (see Table 84).

The assumption testing for the ANCOVA on the Corsi block-tapping task shows that while the assumptions of normality and parallelism are satisfied, the assumption of homoscedasticity is violated. This indicates that the variances are not equal across groups, which may affect the robustness of the ANCOVA results.

Analysis of group comparisons

The results of ANCOVA for the span variable in the Corsi block-tapping task, examining group comparisons. The effect of group membership on Span performance was significant $(F(2,88) = 21.34, p < .01)$, with a medium effect size (partial $\omega^2 = 0.31$), when controlling the covariate $(F(1,88) = 36.65, p < .01)$, with a medium effect size (partial $\omega^2 = 0.28$) (see Table 26 and Figure 32).

Significant differences were observed between the groups in the post hoc comparisons of SPAN scores. Specifically, the comparison between the MCST and CST groups revealed a significant difference $(t(88) = 2.71, p < .01)$, with the MCST group exhibiting a mean SPAN score higher by 0.47 units compared to the CST group, suggesting a moderate effect (Cohen's $d = 0.70$). When comparing the MCST and control groups, a highly significant difference was found, with the MCST group showing a notably higher mean SPAN score of 1.13 units than the control group $(t(88) = 6.51, p < .01)$. This substantial difference indicates a lage effect size

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(Cohen's d = 1.67). Similarly, a highly significant difference was observed between the CST and control groups, with the CST group exhibiting a mean SPAN score higher by 0.66 units compared to the control group ($t(88)$ = 3.75, p < .01), indicating a large effect size (Cohen's d = 0.97).

The findings demonstrate that the interventions had a significant and meaningful impact on span performance in the Corsi block-tapping task, with the MCST intervention showing the greatest effectiveness. Pre-test performance also played a significant role in determining outcomes, emphasizing the importance of considering initial abilities when evaluating the effectiveness of interventions.

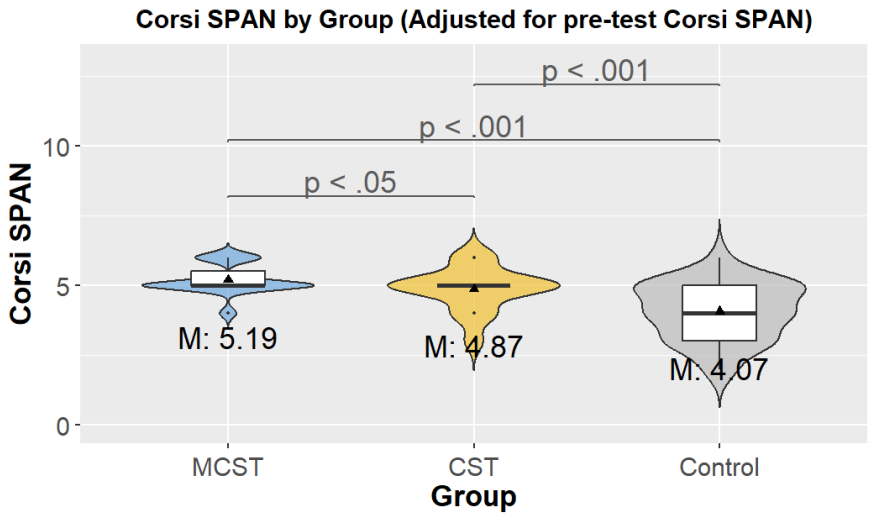

Figure 32 Violin and box plot of Span scores in Corsi block-tapping task showing post hoc comparisons

Mental rotation task

This section outlines the characteristics of the variable in the Metal Rotation Task, categorized into three conditions: MCST, CST, and Control, with data for Pre and Post-test. The statistics illustrate the mean performance and variability in the correct responses across different conditions and testing phases in the Metal Rotation Task.

Before the intervention (Pre-test), the mean number of correct responses for the MCST group was 28.90, with a standard deviation of 7.08. The CST

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group exhibited a slightly higher mean number of correct responses at 31.30, with a larger standard deviation of 10.60. The control group had a mean number of correct responses slightly lower than the MCST group, at 26.50, with a standard deviation of 6.81 (see Table 22).

After the intervention (Post-test), there were changes in the mean number of correct responses across all groups. The MCST group showed an increase in the mean number of correct responses to 31.50, with a standard deviation of 8.72. Conversely, the CST group demonstrated a decrease in the mean number of correct responses to 28.20, with a similar standard deviation of 8.72. The control group exhibited a slight increase in the mean number of correct responses to 28.00, with a standard deviation of 5.95.

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Table 22 Characteristics of the variable in the metal rotation task

Variables	*test*	MCST			CST			Control		
		n	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Correct	Pre	30	28.90	7.08	30	31.30	10.60	27	26.50	6.81
	Post	30	31.50	8.72	30	28.20	8.72	27	28.00	5.95

Analysis of assumptions

The analysis of assumptions for the Metal Rotation task is summarized in Table 84, evaluating Normality, Homoscedasticity, and Parallelism. The normality test indicates $W = 0.92$, suggesting a non-normal distribution ($p < .01$). The homoscedasticity test shows *K-squared* = 4.35, indicating relatively homogeneous variances ($p = .11$). The Parallelism test reveals $F = 1.10$, indicating no violation of the assumption of homogeneity of regression slope ($p = .21$) (see Table 84).

While the normality assumption is violated, the assumptions of homoscedasticity and parallelism are satisfied for the ANCOVA conducted on the Metal Rotation Task. This suggests that, despite the non-normal distribution of the data, the equality of variances and the consistent relationship between the covariate and the dependent variable across groups support the robustness of the ANCOVA results.

Analysis of group comparisons

This section presents the results of ANCOVA for the Correct response variable in the Metal Rotation Task, analyzing group comparisons. The effect of group membership on Correct responses was not statistically significant *(F(*2,83*)* = 2.33, *p* = .10), with a small effect size (partial $\omega^2 = 0.03$). Therefore, interventions does not appear to be a significant factor influencing correct responses in this task (see Table 26).

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Wisconsin card sorting test

The section presents the demographic characteristics of participants' performance on the Wisconsin Card Sorting Test (WCST) across three groups: the MCST group, the CST group, and the control group. Variables analyzed include percent errors, perseverative errors, non-perseverative errors, conceptual level responses, categories completed, trials to complete the first, and failure to maintain the set (see Table 23).

For percent errors, there were slight reductions observed in all groups from pre to post-test. At the pre-test stage, the MCST group had the highest mean percent errors (M = 52.70), followed by the CST group (M = 51.20), and the control group (M = 54.10). After the intervention, similar reductions were observed across all groups, with the MCST group showing the lowest mean percent errors (M = 49.40), followed by the CST group (M = 47.50), and the control group (M = 54.60).

In terms of perseverative errors, both the MCST and CST groups showed decreases from pre to post-test, while the control group exhibited a slight increase. At the pre-test stage, the MCST group had the highest mean perseverative errors (M = 13.00), followed by the CST group (M = 11.10), and the control group (M = 12.60). After the intervention, the MCST group displayed the lowest mean perseverative errors (M = 11.50), followed by the CST group (M = 9.65), and the control group (M = 13.70).

Non-perseverative errors showed relatively stable performance across all groups from pre to post-test. At the pre-test stage, the MCST group had the lowest mean non-perseverative errors (M = 35.60), followed by the CST group (M = 36.50), and the control group (M = 37.20). After the intervention, similar patterns were observed, with the MCST group maintaining the lowest mean non-perseverative

errors (M = 35.30), followed by the CST group (M = 34.60), and the control group (M = 36.90).

Conceptual level responses increased across all groups from pre to post-test. At the pre-test stage, the CST group had the highest mean conceptual level responses (M = 16.20), followed by the MCST group (M = 15.90), and the control group (M = 14.50). After the intervention, the CST group continued to exhibit the highest mean conceptual level responses (M = 18.90), followed by the MCST group (M = 18.10), and the control group (M = 14.40).

Categories completed and trials to complete the first showed slight increases in all groups from pre to post-test. Failure to maintain the set remained relatively stable across all groups across both testing periods.

Overall, the interventions (MCST and CST) led to notable improvements in several key features of the Wisconsin Card Sorting Test (WCST), particularly in reducing percent errors and perseverative errors, and increasing conceptual level responses.

Table 23 Characteristics of the variables in the Wisconsin card sorting test

	MCST			CST			Control		
test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Percent errors									
Pre	29	52.70	10.50	31	51.20	12.70	27	54.10	11.90
Post	29	49.40	14.50	31	47.50	14.00	27	54.60	10.40
Perseverative errors									
Pre	29	13.00	6.49	31	11.10	6.57	27	12.60	7.23
Post	29	11.50	7.36	31	9.65	7.74	27	13.70	7.95
Non-perseverative errors									
Pre	29	35.60	5.73	31	36.50	7.71	27	37.20	5.97
Post	29	35.30	8.59	31	34.60	6.85	27	36.90	4.80
Conceptual level responses									
Pre	29	15.90	6.31	31	16.20	8.31	27	14.50	6.92
Post	29	18.10	9.49	31	18.90	9.11	27	14.40	5.66

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	MCST			CST			Control		
test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Categories completed									
Pre	29	2.140	1.640	31	2.260	2.240	27	1.590	1.370
Post	29	2.760	2.440	31	2.900	2.530	27	1.670	1.210
Trials to complete the first									
Pre	29	28.90	30.50	31	37.40	38.30	27	41.90	37.90
Post	29	25.50	31.20	31	26.80	28.40	27	35.30	35.40
Failure to maintain the set									
Pre	29	13.20	2.25	31	14.00	2.03	27	13.90	1.86
Post	29	12.80	2.59	31	13.40	2.89	27	13.40	2.72

Analysis of assumptions

Table 84 presents the results of assumption testing for various variables measured in the Wisconsin Card Sorting Test (WCST). The assumptions tested include normality, homoscedasticity (homogeneity of variance), and homogeneity of regression slope.

Percent errors, non-perseverative errors, conceptual level responses, and failure to maintain set all have p-values greater than 0.05 (ranging from 0.76 to 0.99), suggesting that these variables are normally distributed. In other words, perseverative errors, categories completed, and trials to complete first have p-values less than 0.05, indicating a departure from normality. Moreover, almost all variables have p-values greater than 0.05, indicating homogeneity of variance. However, categories completed have a p-value less than 0.05 (specifically, <0.01), suggesting heteroscedasticity. Furthermore, all variables have p-values greater than 0.05, suggesting that the regression slopes are parallel across groups.

In summary, normality, variance, and regression slope homogeneity assumptions are met for most variables measured in the Wisconsin card sorting test. However, perseverative errors and categories deviate from normality, and categories completed show heteroscedasticity.

Analysis of group comparisons

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Table 17 presents the results of ANCOVA for the WCST, with pre-test scores as covariates and group (MCST, CST, and Control) as the independent variable. ANCOVA tests revealed no significant differences among the MCST, CST, and control groups for all analyzed variables (all $p > .05$). Effect sizes (partial ω^2) were generally small, indicating minimal variance explained by group differences after controlling for pre-test scores. These findings suggest that the intervention did not significantly influence performance on the WCST variables when controlling for pre-test performance (see Table 26).

Reaction time tasks

This section presents characteristics of variables in reaction time tasks, categorized into simple reaction and choice reactions. Each category includes Pre and Post-test data for three conditions: MCST, CST, and Control.

For the simple reaction time task, there was a slight increase in mean reaction time from pre to post-test across all groups. At the pre-test stage, the MCST group had a mean reaction time of 0.42 seconds, which remained relatively stable at 0.48 seconds post-test. Similarly, the CST group showed a mean reaction time of 0.42 seconds pre-test and 0.44 seconds post-test, while the control group exhibited a mean reaction time of 0.43 seconds pre-test and 0.43 seconds post-test.

In the choice reaction time task, there was a slight decrease in mean reaction time from pre to post-test across all groups. At the pre-test stage, the MCST group had a mean reaction time of 0.88 seconds, which decreased to 0.75 seconds post-test. Likewise, the CST group showed a mean reaction time of 0.90 seconds pre-test and 0.81 seconds post-test, while the control group exhibited a mean reaction time of 0.87 seconds pre-test and 0.78 seconds post-test.

Table 24 Characteristics of the variables in the reaction time tasks

	MCST			CST			Control		
test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Simple reaction									
Pre	31	0.42	0.11	31	0.42	0.10	28	0.43	0.09
Post	31	0.48	0.16	31	0.44	0.13	28	0.43	0.13

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	MCST			CST			Control		
test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Choice reaction									
Pre	31	0.88	0.38	30	0.90	0.40	27	0.87	0.48
Post	31	0.75	0.22	30	0.81	0.34	27	0.78	0.32

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Analysis of assumptions

The assumption testing for variables in the reaction time task is presented in Table 84, evaluating Normality, Homoscedasticity, and Parallelism. For the simple reaction task, the normality test indicates $W = 0.92$, suggesting normal distribution ($p < .01$). The homoscedasticity test shows *K-squared* = 2.16, indicating homogeneity of variances ($p = .34$). The parallelism test reveals $F = 2.12$, indicating no violation of the assumption of parallelism ($p = .13$). For the choice reaction task, normality test indicates $W = 0.72$, suggesting normal distribution ($p < .01$). The homoscedasticity test shows *K-squared* = 5.71, indicating homogeneity of variances ($p = .06$). Parallelism test reveals $F = 2.50$, indicating no violation of the assumption of parallelism ($p = .09$) (see Table 84).

While both the simple and choice reaction time tasks exhibit deviations from normality, the assumptions of homoscedasticity and parallelism are generally satisfied. This suggests that, despite the non-normal distribution of reaction times, the analyses remain robust with respect to the equality of variances and the homogeneity of regression slopes across groups.

Analysis of group comparisons

This section presents the results of ANCOVA for the reaction time tasks, analyzing the simple and choice reaction time tasks separately (see Table 26). For the simple reaction task, the effect of groups on reaction time was insignificant *(F(*2,86*)* = 1.89, $p = .16$) with a small effect size (partial $\omega^2 = 0.02$). For the choice reaction time task, the group did not have a significant effect on reaction time *(F(*2,84*)* = 0.27, $p = .77$) without effect size (partial $\omega^2 < .01$).

The ANCOVA results indicate that there were no significant effects of group condition on reaction times for either the simple reaction time task or the choice reaction time task. The small and negligible effect sizes suggest that any

differences in reaction times between groups are minimal and not meaningful. Therefore, the interventions or conditions applied to the groups did not significantly impact participants' performance in these reaction time tasks.

Sound-induced flash illusion task

The section is provided outlines the characteristics of variables in the Sound-induced Flash Illusion (SIFI)task across three conditions: MCST, CST, and Control, with data for both Pre and Post-test assessments.

Before the intervention (Pre-test), the mean number of correct responses varied across the three groups. The MCST group had a mean of 13.70 correct responses, with a standard deviation of 10.30. In contrast, the CST group exhibited a lower mean of 10.40 correct responses, with a smaller standard deviation of 5.88. The control group's mean was comparable to the MCST group at 14.70, with a similar standard deviation of 10.70. After the intervention (Post-test), notable changes in the mean number of correct responses were observed. The MCST group showed a substantial increase in the mean number of correct responses to 23.00, with a standard deviation of 13.00. Conversely, the CST group demonstrated a decrease in the mean number of correct responses to 8.31, with a smaller standard deviation of 5.83. The control group's mean remained relatively stable at 12.30, with a standard deviation of 12.30.

Regarding reaction time (RT), variables were included 2 conditions, 1 beep 2 flash and 2 beep and 1 flash. RT for 1 beep and 2 flashes: All groups showed a decrease in reaction time post-intervention. The CST group showed the most improvement in reaction time. RT for 2 flashes and 1 beep: All groups showed a decrease in reaction time post-intervention. The CST group again showed the most significant improvement in reaction time.

Table 25 Characteristics of the variables in the sound-induced flash illusion task

	MCST			CST			Control		
test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Correct response									
Pre	31	13.70	10.30	29	10.40	5.88	26	14.70	10.70

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	MCST			CST			Control		
test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Post	31	23.00	13.00	29	8.31	5.83	26	12.30	12.30
RT 1 beep 2 flash									
Pre	31	748	326	29	725	425	26	661	258
Post	31	686	204	29	559	192	26	608	236
RT 2 flash 1 beep									
Pre	31	766	391	29	755	321	26	763	322
Post	31	737	187	29	618	148	26	651	183

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Analysis of assumptions

The analysis of assumptions for the SIFI task is summarized in Table 84, evaluating Normality, Homoscedasticity, and Parallelism for three variables.

For Correct responses, normality test indicates $W = 0.95$, suggesting normal distribution ($p < .01$). Homoscedasticity test shows *K-squared* = 17.76, indicating unequal variances ($p < .01$). Parallelism test reveals $F = 2.05$, indicating no violation of the assumption of parallelism ($p = .14$).

For Response time (1 beep 2 flash), normality test indicates $W = 0.97$, suggesting normal distribution ($p = .07$). Homoscedasticity test shows *K-squared* = 1.21, indicating relatively equal variances ($p = .55$). Parallelism test reveals $F = 1.39$, indicating no violation of the assumption of homogeneity of regression slope ($p = .07$).

For Response time (2 beep 1 flash), normality test indicates $W = 0.95$, suggesting non-normal distribution ($p < .01$). Homoscedasticity test shows *K-squared* = 1.21, indicating relatively equal variances ($p = .42$). Parallelism test reveals $F = 2.72$, indicating no violation of the assumption of homogeneity of regression slope ($p = .07$).

Overall, while some assumptions are violated (particularly normality for correct responses and response time with 2 beeps and 1 flash), the assumptions of homoscedasticity and parallelism hold for most variables, indicating that the ANCOVA results are generally robust despite these violations.

Analysis of group comparisons

This section provided ANCOVA results concerning SIFI task, with analyses conducted separately for Correct responses and Response time (see Table 26).

The effect of group condition on correct responses was statistically significant *(F(*2,82*)* = 15.92, $p < .01$), with a large effect size (partial ω^2 = 0.26) when controlling the covariate *(F(*1,82*)* = 33.12, $p < .01$). Post hoc comparisons of the SIFI demonstrate significant differences in correct responses between groups. Both the MCST and CST groups exhibit significantly higher correct response rates compared to the control group *(t(*82*)* = 5.12, $p<.01$ and $t(82)=4.45$, $p < .01$, respectively), with the effect size, measured by Cohen's d, are 1.34 and 1.18, suggesting large effects. However, there is no significant difference in Correct responses between the CST and control groups *(t(*82*)* = -0.56, p =.58) (see Figure 33).

The effect of group condition on response time (RT) in the condition of 1 beep 2 flashes was statistically significant *(F(*82,2*)* = 3.12, p =.05), with a small effect size (partial ω^2 = 0.05). However, the effect of group condition on response time (RT) in the condition of 2 beeps 1 flash was statistically significant *(F(*1,82*)* = 4.24, p = .02), with a moderate effect size (partial ω^2 = 0.07) when controlling the covariate *(F(*1,82*)* = 14.93, $p < .01$). Post hoc comparisons of the SIFI demonstrate significant differences in correct responses between groups. Both the MCST group exhibit significantly higher RT compared to the CST group *(t(*82*)* = 2.81, p = .02), with the moderate effect size, measured by Cohen's *d* is 0.73, suggesting a moderate effect. However, the control group is no significant difference in RT both of the MCST group *(t(*82*)* = 1.99, p = .15), with a moderate effect size (Cohen's d = 0.53) and CST group *(t(*82*)* = -0.73, p = 1) , with a small effect size (Cohen's d = -0.20).

The analyses revealed significant differences in correct response rates and response times across different group conditions. Both MCST and CST interventions significantly improved correct response rates compared to the control group, with large effect sizes. In terms of response times for the 2 beep 1 flash condition, the MCST group showed significantly higher response times than the CST

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group, with a moderate effect size. However, the control group did not differ significantly from either intervention group in response times. These results suggest that both MCST and CST interventions are effective in enhancing performance in the SIFI task, with MCST showing a notable impact on correct responses and response times.

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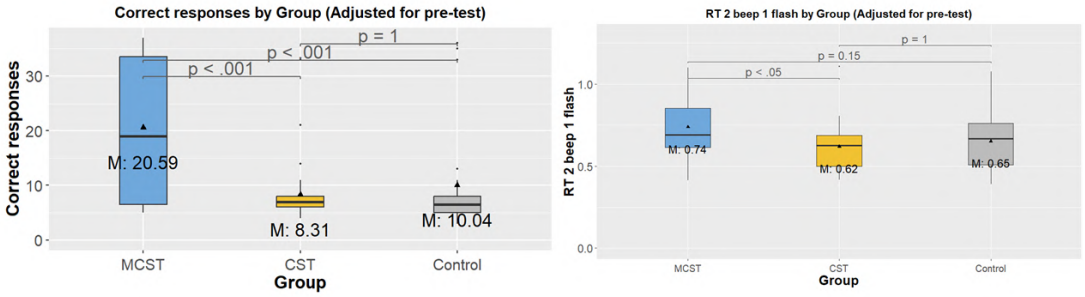

Figure 33 Box plot of Correct responses and Reaction time (RT) in the SIFI task showing post hoc comparisons

Table 26 ANCOVA of cognitive functions from computer-based neuropsychological tests

		df	*SS*	*MS*	*F*	*p*	ω_p^2
Verbal - Paired associates learning tasks							
Correct	Pre-test	1	107.16	107.158	38.83	<.01	0.11
Response	Group	2	36.47	18.23	6.61	<.01	0.30
	Residuals	85	234.55	2.759			
	Contrast	*df*	DM	SE	*t*	*p*	*d*
	MCST-CST	85	0.10	0.42	0.23	1	0.06
	MCST-Control	85	1.48	0.45	3.29	<.01	0.89
	CST-Control	85	1.39	0.45	3.12	<.01	0.84
Nonverbal - Paired associates learning tasks							
Correct	Pre-test	1	105.36	105.36	31.44	<.01	0.26
Response	Group	2	47.83	23.92	7.14	<.01	0.12
	Residuals	84	281.53	3.35			
	Contrast	df	DM	SE	*t*	*p*	*d*
	MCST-CST	84	1.51	0.47	3.21	<.01	0.82

		df	*SS*	*MS*	*F*	*p*	ω_p^2
	MCST-Control	84	1.60	0.49	3.29	<.01	0.88
	CST-Control	84	0.09	0.49	0.19	1	0.05
Verbal fluency tasks							
Letter							
'Kor'	Pre-test	1	1,002.87	1,002.87	71.76	<.01	0.45
	Group	2	10.12	6.06	0.36	.70	<.01
	Residuals	84	1,173.87	13.97			
'Or'	Pre-test	1	615.47	615.47	71.41	<.01	0.44
	Group	2	63.86	31.93	3.70	.03	0.06
	Residuals	85	732.67	8.62			
	Contrast	df	DM	SE	*t*	*p*	*d*
	MCST-CST	85	0.33	0.75	0.45	1	0.45
	MCST-Control	85	1.98	0.77	2.56	.04	2.56
	CST-Control	85	1.64	0.77	2.14	.11	2.14
Category							
Animal	Pre-test	1	642.54	642.54	28.90	<.01	0.24
	Group	2	9.40	4.70	0.21	.81	<.01
	Residuals	84	1,867.65	22.23			
Fruit	Pre-test	1	360.56	360.56	18.15	<.01	0.16
	Group	2	15.42	7.71	0.39	.68	<.01
	Residuals	84	1,668.65	19.86			
Corsi block-tapping task							
Span	Pre-test	1	16.79	16.79	36.65	<.01	0.28
	Group	2	19.55	9.77	21.34	<.01	0.31
	Residuals	88	40.32	0.46			
	Contrast	df	DM	SE	*t*	*p*	*d*
	MCST-CST	88	0.47	0.17	2.71	.02	0.70
	MCST-Control	88	1.13	0.17	6.51	<.01	1.67
	CST-Control	88	0.66	0.18	3.75	<.01	0.97
Mental rotation task							
Correct	Pre-test	1	171.00	171.02	3.35	.07	0.03
Reponse	Group	2	237.50	118.75	2.33	.10	0.03
	Residuals	83	4234.90	51.02			

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
Percent errors							
	Pre-test	1	36.50	36.51	0.21	.65	0.00
	Group	2	736.80	368.39	2.10	.13	0.03
	Residuals	83		175.83			
			14,593.60				
Perseverative errors							
	Pre-test	1	55.90	55.86	0.94	.33	0.00
	Group	2	214.90	107.46	1.81	.17	0.02
	Residuals	83	4,919.00	59.27			
Non perseverative errors							
	Pre-test	1	8.10	8.11	0.17	.68	0.00
	Group	2	83.90	41.96	0.86	.43	0.00
	Residuals	83	4,059.50	48.91			
Conceptual level responses							
	Pre-test	1	13.30	13.31	0.19	.66	0.00
	Group	2	321.10	160.57	2.28	.11	0.03
	Residuals	83	5,847.00	70.45			
Categories completed							
	Pre-test	1	0.65	0.65	0.14	.71	0.00
	Group	2	25.01	12.50	2.61	.08	0.04
	Residuals	83	398.02	4.80			
Trials to complete the first							
	Pre-test	1	2,092.00	2,092.23	2.11	.15	0.01
	Group	2	1,188.00	593.89	0.60	.55	0.00
	Residuals	83		992.33			
			82,363.00				
Failure to maintain the set							
	Pre-test	1	3.12	3.12	0.41	.52	0.00
	Group	2	8.52	4.26	0.56	.57	0.01
	Residuals	83	627.22	7.56			
Simple reaction							
RT	Pre-test	1	0.38	0.38	25.13	<.01	0.21
	Group	2	0.06	0.03	1.89	.16	0.02

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	86	1.29	0.02			
Choice reaction							
RT	Pre-test	1	2.25	2.25	36.14	.00	0.28
	Group	2	0.03	0.02	0.27	.77	<.01
	Residuals	84	5.23	0.06			
Sound-induced flash illusion task							
Correct Response							
	Pre-test	1	2,993.70	2,993.74	33.12	<.01	0.27
	Group	2	2,877.90	1,438.93	15.92	<.01	0.26
	Residuals	82	7,412.00	90.39			
	Contrast	df	DM	SE	*t*	*p*	*d*
	MCST-CST	82	12.72	2.48	5.12	<.01	1.34
	MCST-Control	82	11.26	2.53	4.45	<.01	1.18
	CST-Control	82	-1.46	2.61	-0.56	1	-0.15
RT 1 beep 2 flashes							
	Pre-test	1	0.84	0.84	24.07	.01	0.21
	Group	2	0.22	0.11	3.12	.05	0.05
	Residuals	82	2.85	0.03			
RT 2 beeps 1 flash							
	Pre-test	1	0.39	0.39	14.93	.01	0.14
	Group	2	0.22	0.11	4.24	.02	0.07
	Residuals	82	2.13	0.03			
	Contrast	*df*	DM	SE	*t*	*p*	*d*
	MCST-CST	82	0.11	0.04	2.81	.02	0.73
	MCST-Control	82	0.09	0.04	1.99	.15	0.53
	CST-Control	82	-0.03	0.04	-0.73	1	-0.20

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Overall result of neuropsychological analysis

The paper-based tests revealed complementary findings regarding global cognition, emotional states, and quality of life. The MCST group exhibited significant enhancements in global cognition and reductions in depressive and anxiety symptoms, outstanding both CST and control groups. The CST intervention also showed

improvements in these emotional measures, although to a lesser extent than MCST. However, neither intervention significantly influenced overall quality of life. Moreover, the results from the ANCOVA analysis of computer-based tests indicate that the MCST intervention demonstrated notable benefits in enhancing memory, visuospatial abilities, and multisensory integration, outperforming both the CST and control groups in these domains. The CST group also showed moderate improvements compared to the control group, particularly in visuospatial and multisensory integration tasks, though its effects were less pronounced than those of the MCST intervention. Thus, Hypothesis 2 is partially confirmed. However, this hypothesis does not extend to other aspects, as neither MCST nor CST interventions had significant effects on tasks assessing executive functions, verbal fluency, or reaction times. Therefore, this hypothesis cannot be fully applied.

Data analysis of EEG frequency bands

This section outlines analysis of relative power spectrum bands in findings from resting state and computerized neuropsychological tests included eyes closed and open tasks, paired associates learning tasks, verbal fluentcy task, Corsi block-tapping task, mental rotation task, Wisconsin card sorting test, simple and choice reaction time task, and sound-induced flash illusion task, respectively.

EEG - Eyes closed resting-state

Analysis of the relative power characteristics

The analysis of the relative spectral power of band frequencies in the eyes closed resting-state task revealed notable differences among the MCST, CST, and control groups across various brain regions and frequency bands.

In the delta band, relative spectral power consistently decreased from pre- to post-test assessments across all groups and brain regions. Specifically, the MCST group decreased from pre- to post-test in all regions except for the frontal lobe (FL), where the decrease was less pronounced (Pre: M = 72.88%, Post: M = 61.10%). Similarly, the CST and control groups exhibited reductions in delta band power post-test, with the most significant changes observed in the parietal and occipital regions.

The theta band had mixed findings across groups and brain regions. While the MCST group generally showed increases in theta band power from

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pre to post-test, particularly in frontal and occipital regions (Pre: M = 7.53%, Post: M = 10.91%), the CST and control groups exhibited more varied patterns of change. The frontal and central regions showed modest increases in theta band power post-test for the CST and control groups, while the parietal and occipital regions displayed more inconsistent changes.

Moving to the alpha band, both lower and upper alpha frequencies demonstrated intriguing patterns of change across groups and brain regions. Generally, there were increases in alpha band power from pre to post-test, with the most prominent changes observed in the parietal and occipital regions for both lower and upper alpha frequencies (Lower Alpha Pre: M = 7.82%, Post: M = 10.88%). However, the MCST group showed more pronounced increases compared to the CST and control groups, particularly in the parietal and occipital lobes.

In the beta band, the analysis revealed mixed results across groups and brain regions. While there were some increases in beta band power from pre to post-test, especially in the frontal and central regions (Beta Pre: M = 7.53%, Post: M = 11.29%), these changes were less consistent compared to other frequency bands. The MCST group displayed more variable changes in beta band power compared to the CST and control groups, suggesting differential modulation of beta band activity in response to the sound-induced flash illusion task.

Table 27 Characteristic of relative spectral power (%) of band frequencies in eyes closed resting-state task

		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Delta										
FL	Pre	31	72.88	16.42	30	70.13	17.83	28	62.30	19.48
	Post	31	61.10	18.39	30	63.14	19.92	28	66.41	18.1th e 9
FM	Pre	31	80.52	18.43	30	71.05	23.91	28	60.89	23.53
	Post	31	60.50	26.78	30	59.17	25.98	28	67.79	23.45
CL	Pre	31	77.59	17.75	30	73.30	22.28	28	65.93	19.55

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	31	62.59	19.50	30	60.41	22.47	28	68.00	21.06
CM	Pre	31	80.62	20.18	30	76.00	23.52	28	69.96	20.54
	Post	31	64.06	22.09	30	67.31	23.98	28	72.99	22.76
PL	Pre	31	79.68	16.53	30	75.83	19.28	28	70.24	20.47
	Post	31	64.63	20.36	30	67.22	23.17	28	69.72	19.56
PM	Pre	31	83.80	15.35	30	77.04	22.56	28	70.34	24.20
	Post	31	69.39	24.17	30	70.35	26.42	28	73.28	23.15
OL	Pre	31	84.23	14.42	30	78.74	19.84	28	76.84	17.34
	Post	31	69.73	23.56	30	73.56	23.52	28	75.65	16.31
OM	Pre	31	82.49	18.21	30	78.90	23.01	28	72.23	21.09
	Post	31	66.24	23.71	30	70.78	24.31	28	73.28	17.74
LTL	Pre	31	74.35	15.89	30	72.19	16.44	28	62.65	16.91
	Post	31	60.73	17.42	30	59.19	21.47	28	64.29	19.92
RTL	Pre	31	75.40	15.21	30	72.40	15.59	28	66.65	18.12
	Post	31	65.11	18.78	30	64.41	18.05	28	67.26	16.06
LTPJ	Pre	31	75.46	19.18	30	71.78	22.04	28	64.50	19.30
	Post	31	60.58	21.73	30	59.85	25.40	28	65.00	21.54
RTPJ	Pre	31	81.60	15.95	30	75.60	22.03	28	72.46	20.68
	Post	31	67.40	25.37	30	71.99	25.17	28	69.70	23.51
Theta										
FL	Pre	31	7.53	3.99	30	8.36	3.80	28	8.60	3.04
	Post	31	10.91	6.46	30	10.01	4.48	28	9.13	2.82
FM	Pre	31	6.13	4.83	30	7.87	4.67	28	8.96	4.10
	Post	31	10.96	7.78	30	10.31	5.93	28	8.60	3.93
CL	Pre	31	6.30	4.14	30	7.23	4.28	28	7.79	2.69
	Post	31	9.90	5.25	30	9.74	4.73	28	7.97	3.57
CM	Pre	31	5.39	4.60	30	6.72	4.81	28	7.69	3.69
	Post	31	10.33	7.20	30	8.57	5.20	28	7.03	4.35
PL	Pre	31	5.28	3.46	30	6.32	3.78	28	6.32	2.59

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		MCST			CST			Control	
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	31	8.41	4.64	30	7.39	3.91	28	6.93	2.76
PM	Pre	31	4.77	3.90	30	5.81	3.86	28	5.92	3.18
	Post	31	6.98	3.41	30	7.52	5.77	28	6.45	2.77
OL	Pre	31	4.66	3.21	30	5.51	3.73	28	5.22	2.09
	Post	31	8.51	7.03	30	6.56	4.56	28	6.35	2.93
OM	Pre	31	4.91	4.13	30	5.25	3.97	28	6.01	3.08
	Post	31	9.43	6.96	30	7.52	5.30	28	6.36	3.06
LTL	Pre	31	7.07	3.62	30	7.94	3.95	28	8.74	2.66
	Post	31	10.30	5.06	30	9.97	4.40	28	9.34	3.32
RTL	Pre	31	7.10	3.98	30	8.01	3.67	28	7.97	3.07
	Post	31	9.48	4.11	30	9.29	4.12	28	8.63	2.78
LTPJ	Pre	31	6.55	4.18	30	7.22	4.46	28	7.80	3.35
	Post	31	9.41	5.08	30	8.61	4.49	28	8.09	3.03
RTPJ	Pre	31	5.28	3.70	30	6.47	4.50	28	6.02	3.15
	Post	31	9.27	7.81	30	6.70	4.32	28	7.09	3.60
Lower Alpha										
FL	Pre	31	7.82	8.60	30	8.26	8.17	28	10.76	10.04
	Post	31	10.88	11.15	30	9.24	8.07	28	9.62	8.19
FM	Pre	31	5.28	8.04	30	8.64	11.57	28	11.66	10.96
	Post	31	13.30	16.46	30	11.44	11.14	28	10.69	11.64
CL	Pre	31	5.66	7.63	30	6.75	8.87	28	8.78	9.80
	Post	31	9.75	9.54	30	9.12	7.76	28	8.61	8.84
CM	Pre	31	5.96	10.38	30	6.87	10.32	28	8.23	10.40
	Post	31	9.94	10.35	30	8.67	9.31	28	8.14	10.22
PL	Pre	31	5.76	7.24	30	6.39	8.85	28	8.16	8.48
	Post	31	10.11	11.36	30	8.11	7.66	28	8.39	7.91
PM	Pre	31	4.44	7.14	30	6.32	9.60	28	8.26	10.29
	Post	31	8.64	13.28	30	7.15	8.58	28	7.55	8.68
OL	Pre	31	5.40	8.86	30	6.57	9.24	28	6.80	8.01

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		MCST			CST			Control	
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	31	11.72	17.02	30	8.06	10.35	28	7.75	8.47
OM	Pre	31	6.58	11.36	30	6.87	11.03	28	8.53	10.65
	Post	31	12.84	17.90	30	8.73	10.85	28	8.94	9.31
LTL	Pre	31	6.97	7.04	30	6.80	6.10	28	9.48	7.70
	Post	31	10.22	9.68	30	10.12	7.63	28	9.58	8.58
RTL	Pre	31	6.01	6.19	30	6.57	6.35	28	7.99	6.60
	Post	31	9.78	10.67	30	8.33	6.46	28	8.38	6.96
LTPJ	Pre	31	6.64	7.62	30	7.53	8.83	28	10.54	9.47
	Post	31	11.77	12.52	30	11.55	10.08	28	10.76	10.35
RTPJ	Pre	31	5.08	7.72	30	6.46	8.96	28	7.21	7.59
	Post	31	10.10	14.18	30	7.86	9.54	28	9.12	10.45
Upper Alpha										
FL	Pre	31	4.23	3.51	30	4.04	2.86	28	5.70	4.21
	Post	31	5.82	5.15	30	6.21	5.12	28	5.62	4.38
FM	Pre	31	2.91	3.34	30	3.88	3.50	28	6.10	4.69
	Post	31	5.17	4.68	30	7.07	6.55	28	5.11	4.40
CL	Pre	31	3.67	3.77	30	3.93	3.45	28	5.19	3.81
	Post	31	5.79	4.28	30	7.21	5.73	28	5.59	4.52
CM	Pre	31	3.27	4.53	30	3.58	3.70	28	4.31	3.77
	Post	31	5.63	5.47	30	5.82	5.69	28	4.69	4.54
PL	Pre	31	3.90	4.17	30	4.26	3.99	28	5.66	5.77
	Post	31	6.86	6.49	30	8.03	8.73	28	6.65	6.01
PM	Pre	31	3.16	4.56	30	3.74	4.98	28	6.51	8.95
	Post	31	6.73	9.13	30	7.43	10.33	28	6.81	10.21
OL	Pre	31	2.60	3.05	30	3.53	4.14	28	4.26	5.10
	Post	31	3.98	3.07	30	5.60	6.98	28	4.72	4.19
OM	Pre	31	2.67	3.44	30	3.43	4.90	28	5.22	6.13
	Post	31	4.68	3.56	30	5.86	6.92	28	5.39	4.86
LTL	Pre	31	4.14	3.27	30	4.26	3.15	28	5.92	3.98

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	31	6.42	5.00	30	7.45	5.16	28	6.00	4.74
RTL	Pre	31	4.10	3.19	30	4.18	2.93	28	5.40	4.01
	Post	31	5.70	4.36	30	6.40	4.89	28	5.54	3.85
LTPJ	Pre	31	4.58	4.74	30	4.97	4.68	28	6.27	4.63
	Post	31	6.95	5.76	30	8.65	7.22	28	6.86	6.17
RTPJ	Pre	31	2.90	2.84	30	4.25	4.94	28	5.01	5.10
	Post	31	5.66	7.92	30	6.27	8.33	28	5.64	5.63
Full Alpha										
FL	Pre	31	12.05	10.29	30	12.30	10.23	28	16.47	12.96
	Post	31	16.70	12.84	30	15.45	11.86	28	15.24	11.33
FM	Pre	31	8.20	10.09	30	12.52	14.20	28	17.77	14.26
	Post	31	18.47	18.99	30	18.50	16.05	28	15.80	15.30
CL	Pre	31	9.33	10.44	30	10.68	11.75	28	13.97	12.35
	Post	31	15.54	12.86	30	16.33	12.73	28	14.20	12.42
CM	Pre	31	9.23	13.44	30	10.45	13.38	28	12.54	13.05
	Post	31	15.57	14.29	30	14.50	13.96	28	12.82	13.65
PL	Pre	31	9.66	10.61	30	10.65	11.99	28	13.82	12.49
	Post	31	16.97	15.08	30	16.13	14.80	28	15.03	12.34
PM	Pre	31	7.60	9.68	30	10.06	13.65	28	14.78	16.73
	Post	31	15.38	18.54	30	14.57	16.64	28	14.36	17.20
OL	Pre	31	8.00	10.81	30	10.11	12.47	28	11.06	11.81
	Post	31	15.71	18.85	30	13.67	16.22	28	12.46	11.36
OM	Pre	31	9.24	13.58	30	10.30	14.91	28	13.75	13.89
	Post	31	17.52	19.57	30	14.59	16.52	28	14.33	12.72
LTL	Pre	31	11.11	9.34	30	11.06	8.88	28	15.40	10.26
	Post	31	16.64	12.18	30	17.57	12.01	28	15.58	12.31
RTL	Pre	31	10.10	8.52	30	10.76	8.89	28	13.39	9.60
	Post	31	15.48	13.34	30	14.73	10.56	28	13.92	9.57
LTPJ	Pre	31	11.22	11.34	30	12.50	12.59	28	16.81	12.21

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	31	18.71	15.80	30	20.20	16.35	28	17.63	14.46
RTPJ	Pre	31	7.97	9.63	30	10.71	13.06	28	12.23	11.43
	Post	31	15.76	18.31	30	14.13	16.73	28	14.76	14.67
Beta										
FL	Pre	31	7.53	5.40	30	9.21	6.89	28	12.64	9.53
	Post	31	11.29	7.50	30	11.41	7.38	28	9.22	7.16
FM	Pre	31	5.15	5.93	30	8.56	8.42	28	12.39	10.43
	Post	31	10.08	8.53	30	12.02	9.16	28	7.81	7.56
CL	Pre	31	6.79	5.70	30	8.79	8.24	28	12.32	9.18
	Post	31	11.98	8.08	30	13.51	9.20	28	9.83	8.60
CM	Pre	31	4.76	5.12	30	6.84	7.76	28	9.81	9.70
	Post	31	10.04	8.24	30	9.63	7.70	28	7.16	7.95
PL	Pre	31	5.38	4.72	30	7.20	6.47	28	9.62	10.12
	Post	31	9.99	7.07	30	9.26	7.08	28	8.32	8.32
PM	Pre	31	3.83	4.56	30	7.09	8.34	28	8.96	10.80
	Post	31	8.25	8.18	30	7.56	7.53	28	5.91	6.78
OL	Pre	31	3.11	2.74	30	5.64	5.67	28	6.89	8.89
	Post	31	6.06	4.92	30	6.22	5.58	28	5.54	5.96
OM	Pre	31	3.36	3.67	30	5.55	6.83	28	8.01	10.25
	Post	31	6.81	5.29	30	7.10	6.18	28	6.03	6.23
LTL	Pre	31	7.47	4.90	30	8.81	6.59	28	13.21	8.44
	Post	31	12.32	7.54	30	13.28	9.73	28	10.79	8.32
RTL	Pre	31	7.39	4.93	30	8.83	5.83	28	11.99	8.73
	Post	31	9.93	6.15	30	11.56	8.35	28	10.19	6.96
LTPJ	Pre	31	6.77	5.59	30	8.51	7.36	28	10.89	8.45
	Post	31	11.30	7.79	30	11.34	9.19	28	9.28	8.51
RTPJ	Pre	31	5.14	4.83	30	7.23	6.92	28	9.29	10.19
	Post	31	7.57	5.98	30	7.18	6.50	28	8.45	8.75

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Analysis of assumptions

In the assessment of assumptions for relative spectral power bands in the eyes-closed resting state, distinct patterns emerged across different frequency bands. In the delta band, normality assumptions were consistently violated across all variables (W range = 0.87 - 0.94, all $p < .01$), indicating potential deviations from a normal distribution. However, homoscedasticity, except for CL, LTL, and RTL (K-squared range = 0.20 - 4.42, all $p > .05$), and parallelism were generally supported (F range = 0.01 - 2.21, all $p > .05$), suggesting relatively consistent variances and slopes among groups.

Moving to the theta band, normality assumptions were largely violated (W range = 0.69 - 0.97, all $p < .01$), except for LTL and RTL, while homoscedasticity was mostly upheld (K-squared range = 0.03 - 19.85, all $p > .05$), except for CL and PM. Nevertheless, parallelism was generally supported (F range = 0.06 - 2.77, all $p > .05$), indicating comparable slopes across groups.

Shifting to the lower alpha band, violations of normality were widespread (W range = 0.69 - 0.97, all $p < .01$), while homoscedasticity was generally met (K-squared range = 0.01 - 15.08, all $p > .05$), except for PL and RTL. Parallelism was generally supported across variables (F range = 0.01 - 21.34, all $p > .05$).

In the upper alpha band, normality violations were common (W range = 0.68 - 0.89, all $p < .01$), though homoscedasticity was generally observed (K-squared range = 0.02 - 20.00, all $p > .05$), except for FL and FM. Parallelism was generally upheld (F range = 0.03 - 5.38, all $p > .05$).

In the full alpha band, normality assumptions were violated for most variables (W range = 0.78 - 0.91, all $p < .01$), except for LTL and RTL, while homoscedasticity was generally supported (K-squared range = 0.02 - 19.50, all $p > .05$), aside from OL, OM, and RTPJ. Parallelism was generally met (F range = 0.01 - 5.79, all $p > .05$).

Lastly, in the beta band, normality assumptions were largely violated (W range = 0.69 - 0.92, all $p < .01$), except for LTL and RTL, while homoscedasticity was generally observed (K-squared range = 0.06 - 4.64, all $p > .05$), except for CM and LTPJ. Parallelism was generally supported (F range = 0.02 - 3.92, all $p > .05$).

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Analysis of group comparisons

This section presents the results of the analysis for various parameters during the eyes-closed resting-state condition. The ANCOVA revealed significant effects of group condition on various frequency bands during eyes closed resting-state EEG measurements. See Table 28 and Figure 35, for more detail and illustrations. However, the results of the ANCOVA could not be interpretedfor the specified ROIs due to violations of the regression slope homogeneity assumption. Therefore, separate regression analyses for each group are presented in the following section for the affected ROIs: lower alpha (FL, LTL, LTPJ, OL, OM, PL, PM, RLTL), Upper alpha (OL, OM), full alpha (FL, LTPJ, OL, OM, PM), and beta (RTPJ). The following are the ANCOVA results for ROIs that met the assumption.

The delta band analysis across different regions of interest (ROI) revealed no significant effects of the group condition. In the frontal lobe (FL), the effect of group condition was not statistically significant, with a small effect size *(F(*2, 85*)* = 2.52, *p* = .09, partial $\omega^2 = 0.03$). Similar results were found in central electrode locations (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), and occipital midline (OM), with small effect sizes (all p > .05). No post-hoc analyses were conducted due to the lack of significant main effects.

In the theta band, the occipital midline (OM) presented a significant effect of group condition with a small effect size *(F(*2, 85*)* = 3.38, *p* = .04, partial $\omega^2 = 0.05$). Post-hoc comparisons indicated that the MCST group differed significantly from the control group with a moderate effect size *(t(*85*)* = 2.58, *p* = .03, Cohen's *d* = 0.68). However, no significant differences were found between the MCST and CST groups *(t(*85*)* = 1.53, *p* = .39, Cohen's *d* = 0.39) or between the CST and control groups *(t(*85*)* = 1.08, *p* = .85, Cohen's *d* = 0.28). The central midline (CM) also showed a significant effect with a small effect size *(F(*2, 85*)* = 3.12, *p* = .05, partial $\omega^2 = 0.05$). Post-hoc comparisons were not reported due to lack of significant pairwise differences.

The lower alpha band analysis indicated no significant group effects in most regions. In the frontal midline (FM), the group effect was not significant with a small effect size *(F(*2, 85*)* = 1.08, *p* = .34, partial $\omega^2 < .01$). Similar results were observed in The central left (CL) and central midline (CM) regions (CL:

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$F(2, 85) = 0.44$, $p = .65$, partial $\omega^2 < .01$; CM: $F(2, 85) = 0.38$, $p = .69$, partial $\omega^2 < .01$). No post-hoc analyses were conducted due to the lack of significant main effects.

In the upper alpha band, the left temporal lobe (LTL) presented a significant group effect with a small effect size ($F(2, 85) = 3.31$, $p = .04$, partial $\omega^2 = 0.05$). Post-hoc comparisons indicated that the CST group differed significantly from the control group with a moderate effect size ($t(85) = 2.54$, $p = .04$, Cohen's $d = 0.68$). The MCST group did not significantly differ from the CST group ($t(85) = -0.89$, $p = 1$, Cohen's $d = -0.23$) or from the control group ($t(85) = 1.70$, $p = .28$, Cohen's $d = 0.45$).

The full alpha band analysis indicated no significant group effects in most regions. For example, the frontal midline (FM)**,** central left (CL)**,** and central midline (CM) regions (FM: $F(2, 85) = 0.78$, $p = .46$, partial $\omega^2 < .01$; CL: $F(2, 85) = 0.62$, $p = .54$, partial $\omega^2 < .01$; CM: $F(2, 85) = 0.45$, $p = .64$, partial $\omega^2 < .01$).

The beta band analysis revealed significant group effects in several regions. The frontal midline (FM) showed a significant effect with a moderate effect size ($F(2, 85) = 3.61$, $p = .03$, partial $\omega^2 = 0.06$). Post-hoc comparisons indicated that the CST group differed significantly from the control group with a moderate effect size ($t(85) = 2.55$, $p = .04$, Cohen's $d = 0.68$). The MCST group did not significantly differ from the CST group ($t(85) = -0.39$, $p = 1$, Cohen's $d = -0.10$) or from the control group ($t(85) = 2.10$, $p = .12$, Cohen's $d = 0.58$). Similarly, central electrode locations (CL) and the central midline (CM) presented significant group effects with moderate effect sizes (CL: $F(2, 85) = 3.04$, $p = .05$, partial $\omega^2 = 0.04$; CM: $F(2, 85) = 2.85$, $p = .06$, partial $\omega^2 = 0.04$). Post-hoc analyses for these regions were not reported due to lack of significant pairwise differences.

Overall, the ANCOVA results indicate varying effects of group conditions across different EEG bands and regions. While most regions did not show significant group effects, notable exceptions include the occipital midline in the theta band and several regions in the beta band. Effect sizes were generally small, with a few moderate effects observed. These findings suggest specific localized changes in brain activity related to the group conditions, particularly in both lower and higher frequency bands such as theta and beta.

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Table 28 ANCOVA of the eyes closed resting-state

ROI		*df*	*SS*	*MS*	*F*	*p*	ω_p^2
Delta							
FL	Pre-test	1	0.471	0.471	16.14	<.01	0.15
	Group	2	0.147	0.073	2.52	.09	0.03
	Residuals	85	2.483	0.029			
FM	Pre-test	1	0.124	0.124	1.96	.17	0.01
	Group	2	0.228	0.114	1.81	.17	0.02
	Residuals	85	5.367	0.063			
CL	Pre-test	1	0.199	0.199	4.78	.03	0.04
	Group	2	0.155	0.077	1.86	.16	0.02
	Residuals	85	3.536	0.042			
CM	Pre-test	1	0.078	0.078	1.51	.22	0.01
	Group	2	0.168	0.084	1.62	.20	0.01
	Residuals	85	4.404	0.052			
PL	Pre-test	1	0.545	0.545	14.48	<.01	0.13
	Group	2	0.124	0.062	1.65	.20	0.01
	Residuals	85	3.201	0.038			
PM	Pre-test	1	1.000	1.000	20.89	<.01	0.18
	Group	2	0.178	0.089	1.85	.16	0.02
	Residuals	85	4.070	0.048			
OL	Pre-test	1	0.821	0.821	22.83	<.01	0.20
	Group	2	0.162	0.081	2.25	.11	0.03
	Residuals	85	3.058	0.036			
OM	Pre-test	1	0.959	0.959	25.96	<.01	0.22
	Group	2	0.226	0.113	3.06	.05	0.04
	Residuals	85	3.141	0.037			
LTL	Pre-test	1	0.368	0.368	11.02	<.01	0.10
	Group	2	0.147	0.074	2.20	.12	0.03
	Residuals	85	2.842	0.033			
RTL	Pre-test	1	0.268	0.268	9.52	<.01	0.09

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ROI		*df*	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	0.049	0.024	0.87	.42	<.01
	Residuals	85	2.395	0.028			
LTPJ	Pre-test	1	0.382	0.382	7.96	<.01	0.07
	Group	2	0.120	0.060	1.25	.29	0.01
	Residuals	85	4.083	0.048			
RTPJ	Pre-test	1	0.302	0.302	5.22	.02	0.05
	Group	2	0.070	0.035	0.61	.55	<.01
	Residuals	85	4.921	0.058			
Theta							
FL	Pre-test	1	0.009	0.009	4.13	.05	0.03
	Group	2	0.007	0.003	1.44	.24	0.01
	Residuals	85	0.194	0.002			
FM	Pre-test	1	0.007	0.007	2.03	.16	0.01
	Group	2	0.014	0.007	1.85	.16	0.02
	Residuals	85	0.312	0.004			
CL	Pre-test	1	0.009	0.009	4.24	.04	0.04
	Group	2	0.009	0.005	2.24	.11	0.03
	Residuals	85	0.171	0.002			
CM	Pre-test	1	0.003	0.003	1.05	.31	<.01
	Group	2	0.020	0.010	3.12	.05	0.05
	Residuals	85	0.277	0.003			
PL	Pre-test	1	0.002	0.002	1.67	.2	0.01
	Group	2	0.004	0.002	1.48	.23	0.01
	Residuals	85	0.126	0.001			
PM	Pre-test	1	0.003	0.003	1.71	.19	0.01
	Group	2	0.002	0.001	0.51	.60	<.01
	Residuals	85	0.149	0.002			
OL	Pre-test	1	0.012	0.012	4.86	.03	0.04
	Group	2	0.011	0.006	2.16	.12	0.03
	Residuals	85	0.217	0.003			

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ROI		*df*	*SS*	*MS*	*F*	*p*	ω_p^2
OM	Pre-test	1	0.017	0.017	6.28	.01	0.06
	Group	2	0.018	0.009	3.38	.04	0.05
	Residuals	85	0.231	0.003			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	85	0.020	0.013	1.53	.39	0.39
	MCST-Control	85	0.035	0.014	2.58	.03	0.68
	CST-Control	85	0.015	0.014	1.08	.85	0.28
LTL	Pre-test	1	0.005	0.005	2.81	.10	0.02
	Group	2	0.003	0.001	0.74	.48	<.01
	Residuals	85	0.156	0.002			
RTL	Pre-test	1	0.007	0.007	5.52	.02	0.05
	Group	2	0.002	0.001	0.65	.53	<.01
	Residuals	85	0.113	0.001			
LTPJ	Pre-test	1	0.003	0.003	1.38	.24	<.01
	Group	2	0.003	0.002	0.91	.41	<.01
	Residuals	85	0.157	0.002			
RTPJ	Pre-test	1	0.003	0.003	0.87	.35	<.01
	Group	2	0.013	0.007	2.12	.13	0.02
	Residuals	85	0.268	0.003			
Lower Alpha							
FL*	Pre-test	1	0.219	0.219	36.20	<.01	0.28
	Group	2	0.013	0.007	1.08	.34	<.01
	Residuals	85	0.515	0.006			
FM	Pre-test	1	0.097	0.097	5.80	.02	0.05
	Group	2	0.035	0.017	1.04	.36	0.00
	Residuals	85	1.418	0.017			
CL	Pre-test	1	0.056	0.056	7.88	<.01	0.07
	Group	2	0.006	0.003	0.44	.65	<.01
	Residuals	85	0.599	0.007			
CM	Pre-test	1	0.026	0.026	2.65	.11	0.02

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ROI		*df*	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	0.007	0.004	0.38	.69	<.01
	Residuals	85	0.827	0.010			
PL*	Pre-test	1	0.178	0.178	28.01	<.01	0.23
	Group	2	0.015	0.008	1.21	.30	<.01
	Residuals	85	0.540	0.006			
PM*	Pre-test	1	0.319	0.319	44.60	<.01	0.33
	Group	2	0.022	0.011	1.54	.22	0.01
	Residuals	85	0.608	0.007			
OL*	Pre-test	1	0.417	0.417	37.74	<.01	0.29
	Group	2	0.048	0.024	2.16	.12	0.03
	Residuals	85	0.939	0.011			
OM*	Pre-test	1	0.561	0.561	49.68	<.01	0.35
	Group	2	0.048	0.024	2.14	.12	0.03
	Residuals	85	0.960	0.011			
LTL*	Pre-test	1	0.189	0.189	35.77	<.01	0.28
	Group	2	0.011	0.005	1.00	.37	<.01
	Residuals	85	0.449	0.005			
RTL*	Pre-test	1	0.088	0.088	15.05	<.01	0.14
	Group	2	0.009	0.005	0.78	.46	<.01
	Residuals	85	0.500	0.006			
LTPJ*	Pre-test	1	0.119	0.119	10.90	<.01	0.10
	Group	2	0.012	0.006	0.53	.59	<.01
	Residuals	85	0.926	0.011			
RTPJ	Pre-test	1	0.119	0.119	9.76	<.01	0.09
	Group	2	0.013	0.007	0.54	.58	<.01
	Residuals	85	1.037	0.012			
Upper Alpha							
FL	Pre-test	1	0.063	0.063	38.30	<.01	0.30
	Group	2	0.005	0.003	1.61	.21	0.01
	Residuals	85	0.140	0.002			

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ROI		*df*	*SS*	*MS*	*F*	*p*	ω_p^2
FM	Pre-test	1	0.014	0.014	5.13	.03	0.04
	Group	2	0.011	0.005	2.02	.14	0.02
	Residuals	85	0.225	0.003			
CL	Pre-test	1	0.034	0.034	17.41	<.01	0.16
	Group	2	0.008	0.004	1.98	.14	0.02
	Residuals	85	0.168	0.002			
CM	Pre-test	1	0.019	0.019	7.59	<.01	0.07
	Group	2	0.004	0.002	0.71	.49	<.01
	Residuals	85	0.218	0.003			
PL	Pre-test	1	0.125	0.125	33.84	<.01	0.27
	Group	2	0.009	0.005	1.28	.28	0.01
	Residuals	85	0.314	0.004			
PM	Pre-test	1	0.265	0.265	40.21	<.01	0.31
	Group	2	0.017	0.008	1.26	.29	0.01
	Residuals	85	0.560	0.007			
OL*	Pre-test	1	0.096	0.096	67.61	<.01	0.43
	Group	2	0.003	0.002	1.11	.33	<.01
	Residuals	85	0.121	0.001			
OM*	Pre-test	1	0.085	0.085	46.68	<.01	0.34
	Group	2	0.004	0.002	1.03	.36	<.01
	Residuals	85	0.154	0.002			
LTL	Pre-test	1	0.061	0.061	36.16	<.01	0.28
	Group	2	0.011	0.006	3.31	.04	0.05
	Residuals	85	0.144	0.002			
	Contrast	*df*	DM	SE	*t*	*p*	*d*
	MCST-CST	85	-0.009	0.011	-0.89	1	-0.23
	MCST-Control	85	0.019	0.011	1.70	.28	0.45
	CST-Control	85	0.028	0.011	2.54	.04	0.68
RTL	Pre-test	1	0.028	0.028	17.81	<.01	0.16
	Group	2	0.003	0.002	1.06	.35	<.01

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ROI		*df*	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	85	0.136	0.002			
LTPJ	Pre-test	1	0.102	0.102	35.11	<.01	0.28
	Group	2	0.011	0.005	1.89	.16	0.02
	Residuals	85	0.247	0.003			
RTPJ	Pre-test	1	0.063	0.063	13.05	<.01	0.12
	Group	2	0.003	0.001	0.30	.74	<.01
	Residuals	85	0.410	0.005			
Full Alpha							
FL*	Pre-test	1	0.318	0.318	29.66	<.01	0.24
	Group	2	0.023	0.011	1.05	.35	<.01
	Residuals	85	0.913	0.011			
FM	Pre-test	1	0.087	0.087	3.17	.08	0.02
	Group	2	0.043	0.021	0.78	.46	<.01
	Residuals	85	2.345	0.028			
CL	Pre-test	1	0.123	0.123	8.36	<.01	0.08
	Group	2	0.018	0.009	0.62	.54	<.01
	Residuals	85	1.249	0.015			
CM	Pre-test	1	0.056	0.056	2.95	.09	0.02
	Group	2	0.017	0.009	0.45	.64	<.01
	Residuals	85	1.618	0.019			
PL	Pre-test	1	0.402	0.402	26.22	<.01	0.22
	Group	2	0.029	0.015	0.95	.39	<.01
	Residuals	85	1.303	0.015			
PM*	Pre-test	1	0.812	0.812	39.10	<.01	0.30
	Group	2	0.057	0.028	1.36	.26	0.01
	Residuals	85	1.766	0.021			
OL*	Pre-test	1	0.685	0.685	39.88	<.01	0.30
	Group	2	0.048	0.024	1.40	.25	0.01
	Residuals	85	1.460	0.017			
OM*	Pre-test	1	0.855	0.855	49.06	<.01	0.35

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ROI		*df*	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	0.061	0.030	1.75	.18	0.02
	Residuals	85	1.481	0.017			
LTL	Pre-test	1	0.339	0.339	31.99	<.01	0.26
	Group	2	0.039	0.019	1.82	.17	0.02
	Residuals	85	0.900	0.011			
RTL	Pre-test	1	0.145	0.145	13.04	<.01	0.12
	Group	2	0.014	0.007	0.64	.53	<.01
	Residuals	85	0.948	0.011			
LTPJ	Pre-test	1	0.291	0.291	13.97	<.01	0.13
*	Group	2	0.036	0.018	0.86	.43	<.01
	Residuals	85	1.772	0.021			
RTPJ	Pre-test	1	0.245	0.245	9.75	<.01	0.09
	Group	2	0.018	0.009	0.35	.70	<.01
	Residuals	85	2.139	0.025			
Beta							
FL	Pre-test	1	0.055	0.055	11.86	<.01	0.11
	Group	2	0.026	0.013	2.83	.06	0.04
	Residuals	85	0.393	0.005			
FM	Pre-test	1	0.046	0.046	7.09	<.01	0.06
	Group	2	0.047	0.023	3.61	.03	0.06
	Residuals	85	0.549	0.006			
	Contrast	*df*	DM	SE	*t*	*p*	*d*
	MCST-CST	85	-0.008	0.021	-0.39	1	-0.10
	MCST-Control	85	0.047	0.022	2.10	.12	0.58
	CST-Control	85	0.055	0.021	2.55	.04	0.68
CL	Pre-test	1	0.059	0.059	8.88	<.01	0.08
	Group	2	0.040	0.020	3.04	.05	0.04
	Residuals	85	0.562	0.007			
CM	Pre-test	1	0.047	0.047	8.22	<.01	0.08
	Group	2	0.032	0.016	2.85	.06	0.04

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ROI		*df*	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	85	0.481	0.006			
PL	Pre-test	1	0.081	0.081	17.82	<.01	0.16
	Group	2	0.018	0.009	1.97	.15	0.02
	Residuals	85	0.387	0.005			
PM	Pre-test	1	0.040	0.040	7.78	<.01	0.07
	Group	2	0.021	0.010	2.03	.14	0.02
	Residuals	85	0.437	0.005			
OL	Pre-test	1	0.059	0.059	25.69	<.01	0.22
	Group	2	0.007	0.003	1.46	.24	0.01
	Residuals	85	0.194	0.002			
OM	Pre-test	1	0.057	0.057	20.52	<.01	0.18
	Group	2	0.010	0.005	1.74	.18	0.02
	Residuals	85	0.235	0.003			
LTL	Pre-test	1	0.027	0.027	3.81	.05	0.03
	Group	2	0.023	0.012	1.67	.19	0.01
	Residuals	85	0.592	0.007			
RTL	Pre-test	1	0.071	0.071	16.39	<.01	0.15
	Group	2	0.011	0.006	1.28	.28	0.01
	Residuals	85	0.369	0.004			
LTPJ	Pre-test	1	0.078	0.078	12.52	<.01	0.11
	Group	2	0.024	0.012	1.90	.16	0.02
	Residuals	85	0.529	0.006			
RTPJ	Pre-test	1	0.084	0.084	20.29	<.01	0.18
*	Group	2	0.002	0.001	0.29	.75	<.01
	Residuals	85	0.352	0.004			

*A significant interaction effect

Analysis of regression

This analysis evaluates the relationships between pre-test and post-test values for the three groups (MCST, CST, and control) during the eyes-closed

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resting-state condition. The the relative powers for specific frequency bands analyzed include lower alpha, upper alpha, full alpha, and beta, across various brain regions (see Table 29).

The results for the relative lower alpha indicate that the MCST group consistently demonstrates strong predictive relationships across all regions. For example, in the FL region, MCST has a significant regression slope (β_1 = 1.07, p < .001) with a high R^2_{adj} = 0.67, indicating a robust explanatory relationship between pre-test and post-test values. The CST group shows moderate predictive power in the same region (β_1 = 0.45, p = .01, R^2_{adj} = .18), while the control group displays a weak and marginally significant relationship ($\beta 1$ = 0.27, p = .09, R^2_{adj} = .07) (see Figure 34).

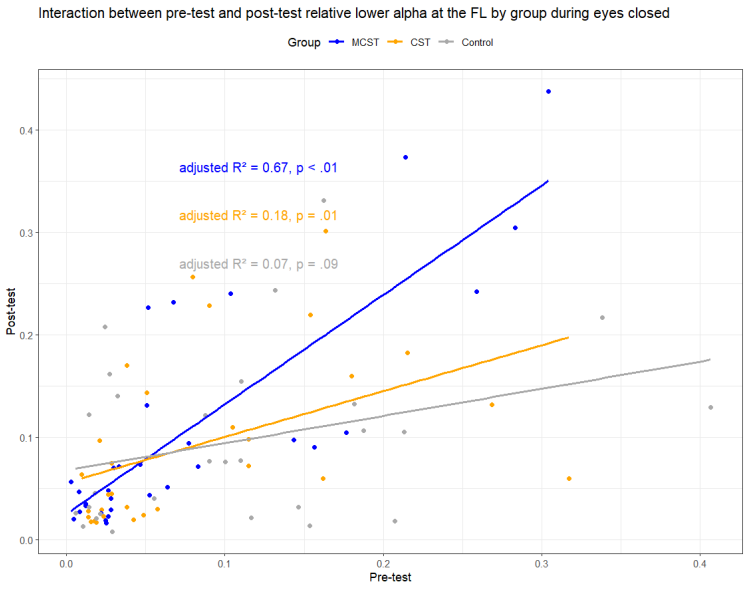

Figure 34 A scatter plot and the regression lines are shows interaction between pre-test and post-test relative lower alpha in the frontal lobe area (FL) by group during eyes closed

Similar trends are observed in the OL and OM regions. MCST consistently exhibits steep slopes and high R^2_{adj} values (e.g., OL: β_1 = 1.53, p < .001, R^2_{adj} = .62; OM: β_1 = 1.28, p < .001, R^2_{adj} = .65). CST demonstrates moderate but significant relationships (e.g., OL: β_1= 0.58, p < .001, R^2_{adj} = .24), while the control

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group exhibits weaker relationships, with non-significant results in several regions (e.g., OL: β_1 = 0.19, p = .37, R^2_{adj} = −0.01). The PM region reveals a particularly strong effect for MCST (β_1 = 1.72, p < .001, R^2_{adj} = .85), highlighting the intervention's effectiveness. CST (β_1 = 0.37, p = .02, R^2_{adj} = .14) and control (β_1 = 0.44, p < .001, R^2_{adj} = .24) show weaker but significant relationships. For the LTL region, MCST again demonstrates strong predictive power (β_1 = 1.13, p < .001, R^2_{adj} = .66), with CST (β_1 = 0.53, p = .02, R^2_{adj} = .15) and control (β_1 = 0.40, p = .06, R^2 = .09) exhibiting weaker results.

In the relative upper alpha, the MCST group shows significant predictive relationships but with lower R^2_{adj} values compared to lower alpha. For example, in the OL region, MCST achieves a slope of β_1 = 0.58, p < .001, R^2_{adj} = .31. Interestingly, CST outperforms MCST in this region, with a steeper slope (β_1= 1.24, p < .001, R^2_{adj} = .52), suggesting a more substantial intervention effect. The control group shows moderate predictive power (β_1 = 0.59, p < .001, R^2_{adj} = .49). In the OM region, MCST demonstrates significant predictive power (β_1 = 0.52, p < .001, R^2_{adj} = 0.23), but CST again shows a stronger slope (β_1 = 1.03, p < .001, R^2_{adj} = .51). The control group shows a weaker but significant relationship (β_1 = 0.43, p < .001, R^2_{adj} = .26).

For the relative full alpha, MCST consistently demonstrates strong predictive power across all regions. For instance, in the FL region, MCST exhibits a significant relationship (β_1 = 0.97, p < .001, R^2_{adj} = .59). CST shows moderate predictive power (β_1 = 0.48, p = .02, R^2_{adj} = .14), while the control group demonstrates weaker results (β_1 = 0.33, p = .05, R^2_{adj} = 0.11). In the OM region, MCST remains strong (β_1 = 1.11, p < .001, R^2_{adj} = .57), with CST also showing significance (β_1 = 0.69, p < .001, R^2_{adj} = .36). The control group displays weaker but still significant relationships (β_1 = 0.36, p = 0.04, R^2_{adj} = .12).

In the relative beta, the MCST group continues to demonstrate significant predictive relationships but with lower R^2_{adj} values compared to the Alpha bands. For the RTPJ region, MCST shows moderate predictive power (β_1 = 0.54, p =

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0.01, R^2_{adj} = .16). The CST group fails to demonstrate significance (β_1 = 0.02, p = 0.91, R^2_{adj} =−0.04), indicating minimal intervention effect. The control group, however, shows a strong relationship (β_1 = 0.58, p < .001, R^2_{adj} = .43), suggesting some natural predictive capacity in this band.

Across all frequency bands and regions, the MCST group consistently exhibits the strongest and most significant predictive relationships between pre-test and post-test values, highlighting its effectiveness as an intervention. The CST group shows moderate predictive power, with occasional instances where it outperforms MCST (e.g., upper alpha at the OL region). The control group, on the other hand, generally demonstrates weaker or non-significant relationships, although some regions (e.g., Beta at the RTPJ) show moderate predictive power. These results suggest that MCST is the most effective intervention in influencing post-test outcomes, particularly in the lower alpha and full alpha bands. CST exhibits moderate effectiveness, while the control group shows limited natural predictive relationships.

Table 29 Regression analysis of the eyes closed resting-state

ROI	Model	Variable	*β*	*SE*	*t*	*p*
Lower Alpha						
FL	MCST	Constant	0.03	0.02	1.61	.12
		Pre-test	1.07	0.14	7.84	<.01
	CST	Constant	0.06	0.02	2.89	.01
		Pre-test	0.45	0.17	2.69	.01
	Control	Constant	0.07	0.02	3.06	.01
		Pre-test	0.27	0.15	1.75	.09
OL	MCST	Constant	0.03	0.02	1.57	.13
		Pre-test	1.53	0.22	7.04	<.01
	CST	Constant	0.04	0.02	2.10	.05
		Pre-test	0.58	0.18	3.18	.00
	Control	Constant	0.06	0.02	3.06	.01
		Pre-test	0.19	0.20	0.91	.37
OM	MCST	Constant	0.04	0.02	2.00	.05
		Pre-test	1.28	0.17	7.53	<.01
	CST	Constant	0.05	0.02	2.46	.02
		Pre-test	0.58	0.15	3.88	<.01
	Control	Constant	0.07	0.02	3.08	<.01
		Pre-test	0.25	0.16	1.50	.15

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ROI	Model	Variable	β	*SE*	*t*	*p*
PL	MCST	Constant	0.03	0.02	1.76	.09
		Pre-test	1.29	0.17	7.75	<.01
	CST	Constant	0.05	0.02	3.50	<.01
		Pre-test	0.43	0.14	2.99	.01
	Control	Constant	0.07	0.02	3.41	<.01
		Pre-test	0.15	0.18	0.82	.42
PM	MCST	Constant	0.01	0.01	0.92	.36
		Pre-test	1.72	0.13	13.02	<.01
	CST	Constant	0.05	0.02	2.75	.01
		Pre-test	0.37	0.15	2.43	.02
	Control	Constant	0.04	0.02	2.13	.04
		Pre-test	0.44	0.14	3.11	.00
LTL	MCST	Constant	0.02	0.01	1.65	.11
		Pre-test	1.13	0.15	7.70	<.01
	CST	Constant	0.07	0.02	3.35	<.01
		Pre-test	0.53	0.21	2.47	.02
	Control	Constant	0.06	0.02	2.35	.03
		Pre-test	0.40	0.20	1.94	.06
RTL	MCST	Constant	0.03	0.02	1.48	.15
		Pre-test	1.11	0.24	4.54	<.01
	CST	Constant	0.07	0.02	4.14	<.01
		Pre-test	0.19	0.19	1.00	.32
	Control	Constant	0.06	0.02	3.05	.01
		Pre-test	0.26	0.20	1.32	.20
LTPJ	MCST	Constant	0.04	0.02	1.91	.07
		Pre-test	1.13	0.22	5.14	<.01
	CST	Constant	0.08	0.02	3.58	<.01
		Pre-test	0.45	0.20	2.28	.03
	Control	Constant	0.11	0.03	3.76	<.01
		Pre-test	-0.05	0.21	-0.24	.81
Upper Alpha						
OL	MCST	Constant	0.02	0.01	4.10	<.01
		Pre-test	0.58	0.15	3.82	<.01
	CST	Constant	0.01	0.01	1.06	.30
		Pre-test	1.24	0.22	5.70	<.01
	Control	Constant	0.02	0.01	2.99	.01
		Pre-test	0.59	0.11	5.23	<.01
OM	MCST	Constant	0.03	0.01	4.60	<.01
		Pre-test	0.52	0.17	3.14	<.01
	CST	Constant	0.02	0.01	2.16	.04
		Pre-test	1.03	0.18	5.62	<.01
	Control	Constant	0.03	0.01	3.03	.01

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ROI	Model	Variable	*β*	*SE*	*t*	*p*
		Pre-test	0.43	0.13	3.28	<.01
Full Alpha						
FL	MCST	Constant	0.05	0.02	2.18	.04
		Pre-test	0.97	0.15	6.63	<.01
	CST	Constant	0.10	0.03	3.01	.01
		Pre-test	0.48	0.20	2.40	.02
	Control	Constant	0.10	0.03	2.97	.01
		Pre-test	0.33	0.16	2.06	.05
OL	MCST	Constant	0.05	0.03	1.86	.07
		Pre-test	1.29	0.22	5.92	<.01
	CST	Constant	0.06	0.03	1.91	.07
		Pre-test	0.75	0.20	3.71	<.01
	Control	Constant	0.09	0.03	3.06	.01
		Pre-test	0.35	0.18	1.97	.06
OM	MCST	Constant	0.07	0.03	2.62	.01
		Pre-test	1.11	0.17	6.45	<.01
	CST	Constant	0.08	0.03	2.55	.02
		Pre-test	0.69	0.16	4.18	<.01
	Control	Constant	0.09	0.03	2.94	.01
		Pre-test	0.36	0.17	2.16	.04
PM	MCST	Constant	0.04	0.03	1.45	.16
		Pre-test	1.52	0.22	6.98	<.01
	CST	Constant	0.10	0.04	2.77	.01
		Pre-test	0.46	0.21	2.18	.04
	Control	Constant	0.05	0.03	1.37	.18
		Pre-test	0.65	0.16	4.18	<.01
LTPJ	MCST	Constant	0.08	0.03	2.72	.01
		Pre-test	0.93	0.19	4.80	<.01
	CST	Constant	0.13	0.04	3.35	<.01
		Pre-test	0.58	0.22	2.65	.01
	Control	Constant	0.17	0.05	3.64	<.01
		Pre-test	0.01	0.23	0.05	.96
Beta						
RTPJ	MCST	Constant	0.05	0.01	3.31	<.01
		Pre-test	0.54	0.21	2.60	.01
	CST	Constant	0.07	0.02	3.99	<.01
		Pre-test	0.02	0.18	0.11	.91
	Control	Constant	0.03	0.02	1.81	.08
		Pre-test	0.58	0.12	4.67	<.01

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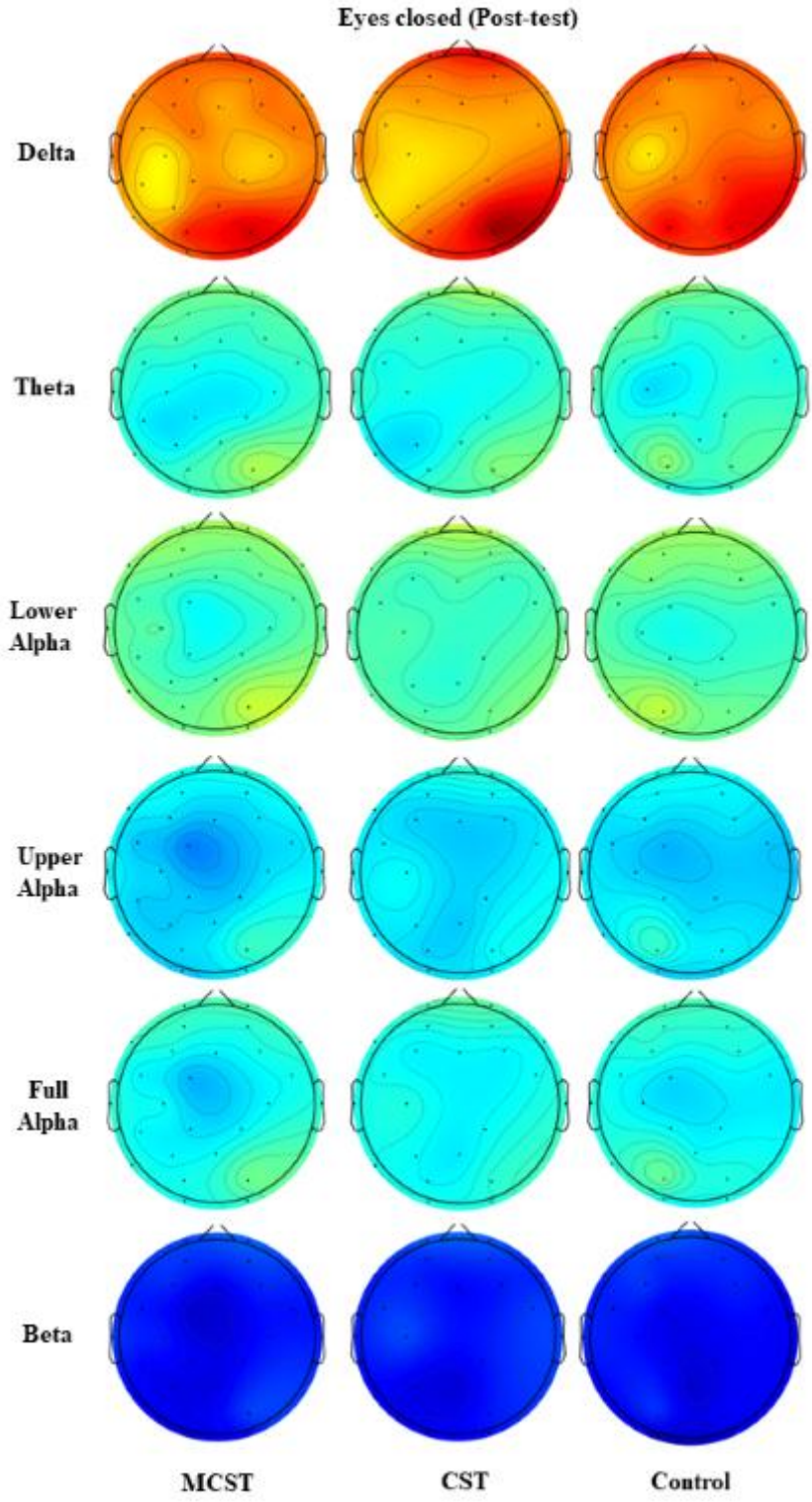

Figure 35 The topographic brain mapping of relative power during eyes closed at post-test

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EEG - Eyes open resting-state

Analysis of the relative power characteristics

The analysis of relative spectral power across different brain regions and frequency bands revealed distinct patterns of neural activity modulation in response to the eyes open resting-state task.

In the delta band, there were consistent decreases in relative spectral power from pre to post-test assessments across all groups and brain regions. Notably, the mean values (M) showed a significant decrease in delta band power post-test compared to pre-test across most brain regions for all groups, indicating a reduction in slow-wave activity during the eyes open resting-state task (e.g., from M = 80% pre-test to M = 70% post-test).

Moving to the theta band, mixed findings were observed. While some brain regions showed increases in theta band power post-test compared to pre-test, others displayed more variable changes. However, the overall trend indicated a slight increase in theta band power post-test, particularly in frontal and occipital regions, although the changes were less consistent compared to other frequency bands (e.g., from M = 7% pre-test to M = 9% post-test).

In the alpha band, both lower and upper alpha frequencies demonstrated notable increases in relative spectral power post-test compared to pre-test across various brain regions. Specifically, the mean values indicated a significant increase in alpha band power post-test, particularly in parietal and occipital regions, suggesting enhanced alpha activity during the eyes open resting-state task (e.g., from M = 2% pre-test to M = 5% post-test).

Regarding the full alpha band, similar trends were observed, with significant increases in relative spectral power post-test compared to pre-test across most brain regions. The mean values reflected a substantial increase in full alpha band power post-test, indicating widespread enhancement of alpha activity during the eyes open resting-state task (e.g., from M = 4% pre-test to M = 8% post-test).

Lastly, in the beta band, there were mixed results observed across groups and brain regions. While some regions showed increases in beta band power post-test compared to pre-test, others displayed more variable changes.

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Overall, the mean values showed modest increases in beta band power post-test, particularly in frontal and central regions, although the changes were less consistent compared to other frequency bands (e.g., from M = 8% pre-test to M = 10% post-test).

In summary, the analysis of relative spectral power across different brain regions and frequency bands during the eyes open resting-state task revealed distinct patterns of neural activity modulation. While there were consistent decreases in delta band power, increases were observed in theta, alpha, full alpha, and beta band power, with mean values reflecting the magnitude of these changes.

Table 30 Characteristic of relative spectral power (%) of band frequencies in eyes open resting-state

		MCST			CST			Control		
ROI	*test*	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Delta										
FL	Pre	31	81.51	9.18	29	75.43	14.67	28	72.38	13.25
	Post	31	72.01	11.47	29	75.00	12.24	28	72.33	14.37
FM	Pre	31	84.66	13.57	29	73.86	22.39	28	71.16	17.36
	Post	31	68.41	18.38	29	68.10	21.26	28	71.85	19.44
CL	Pre	31	82.37	13.57	29	75.48	19.43	28	72.28	16.20
	Post	31	66.75	14.65	29	67.31	19.52	28	69.46	17.59
CM	Pre	31	85.27	13.55	29	78.76	21.75	28	77.09	14.58
	Post	31	71.82	15.17	29	74.21	19.51	28	74.05	19.39
PL	Pre	31	86.07	10.44	29	80.29	18.22	28	79.09	14.32
	Post	31	74.56	15.11	29	75.79	19.24	28	76.29	15.04
PM	Pre	31	89.26	11.67	29	81.58	19.88	28	82.13	15.44
	Post	31	77.87	18.14	29	78.49	20.25	28	80.55	16.58
OL	Pre	31	90.18	7.47	29	83.12	16.69	28	85.66	13.01
	Post	31	80.82	15.92	29	82.39	14.69	28	83.64	12.35
OM	Pre	31	90.67	7.35	29	84.20	16.55	28	83.54	15.12
	Post	31	79.49	16.95	29	81.40	15.20	28	82.75	14.32

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		MCST			CST			Control		
ROI	*test*	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
LTL	Pre	31	80.55	12.25	29	74.55	16.90	28	71.46	12.78
	Post	31	66.12	14.50	29	67.44	18.48	28	68.82	15.90
RTL	Pre	31	80.42	10.75	29	73.64	15.76	28	73.39	13.01
	Post	31	70.33	14.55	29	74.25	15.32	28	72.65	12.37
LTPJ	Pre	31	83.51	12.54	29	78.79	18.97	28	73.74	12.71
	Post	31	69.84	17.95	29	70.34	21.49	28	71.15	17.54
RTPJ	Pre	31	84.75	11.64	29	77.12	21.24	28	80.99	13.52
	Post	31	72.99	19.86	29	80.19	17.71	28	76.88	17.26
Theta										
FL	Pre	31	7.55	2.77	29	8.35	3.08	28	8.37	2.43
	Post	31	9.48	2.84	29	8.95	3.04	28	8.98	2.87
FM	Pre	31	6.10	4.55	29	8.01	5.07	28	8.55	3.83
	Post	31	9.73	5.34	29	10.24	5.62	28	9.63	5.00
CL	Pre	31	6.29	4.11	29	6.66	4.12	28	7.20	2.46
	Post	31	9.16	3.36	29	8.69	4.62	28	8.28	3.31
CM	Pre	31	5.96	4.49	29	6.56	5.31	28	7.04	2.91
	Post	31	8.60	3.82	29	8.00	5.19	28	7.70	4.21
PL	Pre	31	5.22	3.21	29	5.95	4.10	28	6.01	2.37
	Post	31	7.70	3.23	29	6.93	3.82	28	6.95	2.91
PM	Pre	31	4.65	3.86	29	5.77	4.84	28	5.35	3.25
	Post	31	7.16	3.92	29	6.56	4.59	28	6.25	3.62
OL	Pre	31	4.35	2.62	29	5.52	4.05	28	4.84	2.65
	Post	31	6.36	3.41	29	6.16	3.38	28	6.09	3.28
OM	Pre	31	4.36	2.87	29	5.40	4.50	28	5.17	2.57
	Post	31	6.98	3.50	29	6.86	3.60	28	6.01	3.47
LTL	Pre	31	6.64	3.15	29	7.34	4.10	28	7.88	2.27
	Post	31	9.58	3.27	29	8.80	3.44	28	8.87	3.05
RTL	Pre	31	6.42	2.58	29	7.56	3.89	28	7.01	2.06
	Post	31	8.61	2.71	29	7.54	3.26	28	7.75	2.48

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ROI	*test*	MCST			CST			Control		
		n	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
LTPJ	Pre	31	6.08	3.85	29	6.28	5.09	28	7.44	2.59
	Post	31	8.68	3.69	29	8.13	3.64	28	8.25	3.08
RTPJ	Pre	31	5.56	3.43	29	6.42	4.44	28	5.54	2.35
	Post	31	8.25	4.22	29	6.03	3.49	28	6.65	3.65
Lower Alpha										
FL	Pre	31	1.74	1.19	29	2.98	2.43	28	2.97	2.09
	Post	31	3.64	3.97	29	3.18	2.90	28	3.31	3.18
FM	Pre	31	1.98	2.18	29	4.03	4.46	28	4.71	5.75
	Post	31	4.81	5.74	29	5.63	6.52	28	5.16	6.26
CL	Pre	31	2.19	1.98	29	3.42	3.52	28	3.98	4.17
	Post	31	4.94	4.21	29	5.04	4.59	28	4.94	5.01
CM	Pre	31	1.90	2.34	29	3.16	4.13	28	3.73	4.50
	Post	31	4.30	4.13	29	4.30	4.54	28	4.83	6.24
PL	Pre	31	1.83	1.66	29	3.52	4.76	28	3.18	3.11
	Post	31	4.75	6.13	29	4.34	5.16	28	3.91	3.69
PM	Pre	31	1.42	1.80	29	3.64	5.82	28	2.53	2.44
	Post	31	4.46	8.86	29	3.96	5.38	28	2.97	3.15
OL	Pre	31	1.25	1.18	29	2.89	4.80	28	1.95	1.67
	Post	31	3.83	6.53	29	3.17	4.24	28	2.78	4.43
OM	Pre	31	1.17	1.21	29	2.57	4.51	28	2.29	2.09
	Post	31	4.05	7.18	29	3.22	4.53	28	3.12	5.46
LTL	Pre	31	2.43	1.74	29	3.85	3.24	28	3.92	2.93
	Post	31	5.51	5.13	29	5.37	4.67	28	5.47	5.45
RTL	Pre	31	2.56	1.88	29	3.96	3.90	28	3.41	2.58
	Post	31	5.02	4.68	29	3.80	3.59	28	4.36	4.00
LTPJ	Pre	31	2.10	1.73	29	3.48	3.95	28	4.02	3.45
	Post	31	5.62	6.34	29	5.38	5.73	28	5.24	5.35
RTPJ	Pre	31	2.03	2.08	29	4.07	5.59	28	2.52	1.95
	Post	31	5.37	6.84	29	3.45	4.38	28	4.05	5.32

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Upper Alpha										
FL	Pre	31	1.78	1.49	29	2.56	2.16	28	2.82	1.67
	Post	31	2.61	1.62	29	2.60	1.83	28	3.02	2.50
FM	Pre	31	1.83	2.20	29	3.33	3.39	28	3.73	2.93
	Post	31	3.24	2.43	29	4.02	3.16	28	3.68	3.48
CL	Pre	31	2.28	2.16	29	3.28	2.92	28	3.79	2.96
	Post	31	4.17	2.59	29	4.77	3.30	28	4.69	3.95
CM	Pre	31	1.73	1.94	29	2.56	2.97	28	3.16	2.89
	Post	31	3.43	2.27	29	3.47	2.83	28	4.06	3.96
PL	Pre	31	1.96	1.83	29	3.03	3.51	28	3.27	2.59
	Post	31	3.65	2.71	29	4.05	4.01	28	3.72	2.81
PM	Pre	31	1.44	2.02	29	2.81	3.68	28	2.98	3.47
	Post	31	3.01	2.90	29	3.51	4.01	28	3.05	3.59
OL	Pre	31	1.22	1.25	29	2.57	3.32	28	1.89	1.81
	Post	31	2.60	2.55	29	2.55	2.87	28	2.35	2.62
OM	Pre	31	1.10	1.18	29	2.20	2.95	28	2.22	2.20
	Post	31	2.72	2.67	29	2.55	3.04	28	2.51	3.07
LTL	Pre	31	2.53	2.10	29	3.36	2.68	28	4.04	2.47
	Post	31	4.28	2.39	29	4.89	3.37	28	4.47	3.48
RTL	Pre	31	2.62	1.92	29	3.64	2.83	28	3.43	2.19
	Post	31	3.84	2.48	29	3.47	2.42	28	3.72	2.48
LTPJ	Pre	31	2.23	2.03	29	3.27	3.48	28	4.36	2.87
	Post	31	4.38	3.49	29	4.98	4.44	28	4.61	3.55
RTPJ	Pre	31	2.14	2.08	29	3.66	4.35	28	2.69	2.33
	Post	31	3.87	3.60	29	3.06	3.20	28	3.42	3.13
Full Alpha										
FL	Pre	31	3.51	2.62	29	5.53	4.46	28	5.79	3.31
	Post	31	6.25	5.31	29	5.79	4.48	28	6.33	5.50
FM	Pre	31	3.82	4.28	29	7.35	7.61	28	8.44	7.94
	Post	31	8.06	7.78	29	9.65	9.28	28	8.84	9.17
CL	Pre	31	4.47	4.08	29	6.70	6.26	28	7.77	6.68

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ROI	*test*	MCST			CST			Control		
		n	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	31	9.11	6.51	29	9.81	7.58	28	9.63	8.30
CM	Pre	31	3.63	4.21	29	5.71	6.84	28	6.89	7.06
	Post	31	7.73	5.97	29	7.77	7.15	28	8.89	9.32
PL	Pre	31	3.79	3.44	29	6.56	8.14	28	6.45	5.30
	Post	31	8.40	8.31	29	8.40	8.76	28	7.63	5.98
PM	Pre	31	2.86	3.79	29	6.45	9.32	28	5.50	5.17
	Post	31	7.47	11.26	29	7.47	9.00	28	6.02	6.56
OL	Pre	31	2.47	2.37	29	5.45	8.05	28	3.83	3.21
	Post	31	6.42	8.73	29	5.72	6.99	28	5.13	6.85
OM	Pre	31	2.27	2.32	29	4.77	7.41	28	4.51	4.02
	Post	31	6.77	9.45	29	5.76	7.46	28	5.64	8.30
LTL	Pre	31	4.96	3.75	29	7.22	5.78	28	7.96	5.04
	Post	31	9.79	7.24	29	10.26	7.68	28	9.94	8.38
RTL	Pre	31	5.18	3.55	29	7.60	6.56	28	6.85	4.57
	Post	31	8.86	6.77	29	7.27	5.76	28	8.08	5.89
LTPJ	Pre	31	4.34	3.66	29	6.75	7.27	28	8.38	5.78
	Post	31	9.99	9.27	29	10.37	9.77	28	9.86	8.27
RTPJ	Pre	31	4.18	3.98	29	7.73	9.78	28	5.22	4.06
	Post	31	9.24	9.77	29	6.51	7.31	28	7.47	7.94
Beta										
FL	Pre	31	7.43	6.54	29	10.69	9.81	28	13.47	10.68
	Post	31	12.25	8.83	29	10.27	7.18	28	12.36	9.72
FM	Pre	31	5.42	5.90	29	10.77	11.38	28	11.85	9.54
	Post	31	13.81	13.20	29	12.01	8.74	28	9.68	8.58
CL	Pre	31	6.88	6.24	29	11.16	10.13	28	12.76	9.70
	Post	31	14.98	9.77	29	14.18	9.97	28	12.63	9.56
CM	Pre	31	5.14	5.66	29	8.97	11.50	28	8.98	7.60
	Post	31	11.85	9.81	29	10.02	8.90	28	9.35	9.68
PL	Pre	31	4.92	4.38	29	7.20	7.82	28	8.45	8.69

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ROI	*test*	MCST			CST			Control		
		n	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	31	9.33	6.77	29	8.89	8.42	28	9.13	9.00
PM	Pre	31	3.23	4.53	29	6.20	7.42	28	7.02	8.63
	Post	31	7.49	7.32	29	7.47	8.53	28	7.17	9.12
OL	Pre	31	3.00	3.18	29	5.90	6.38	28	5.66	8.74
	Post	31	6.39	6.65	29	5.74	6.17	28	5.14	4.89
OM	Pre	31	2.69	3.07	29	5.63	7.22	28	6.78	10.67
	Post	31	6.76	6.96	29	5.97	6.26	28	5.61	5.33
LTL	Pre	31	7.85	6.64	29	10.89	8.83	28	12.71	7.61
	Post	31	14.51	8.60	29	13.50	9.38	28	12.37	7.54
RTL	Pre	31	7.98	5.84	29	11.19	7.75	28	12.75	8.49
	Post	31	12.20	7.49	29	10.94	8.35	28	11.53	6.34
LTPJ	Pre	31	6.07	6.27	29	8.19	8.35	28	10.45	7.23
	Post	31	11.49	7.49	29	11.16	9.58	28	10.74	9.74
RTPJ	Pre	31	5.52	5.19	29	8.74	8.88	28	8.26	8.99
	Post	31	9.51	8.71	29	7.27	8.53	28	9.01	9.13

Analysis of assumptions

In the assessment of assumptions for relative spectral power bands in the eyes closed resting-state within the delta band, it is notable that normality assumptions were generally violated (W range = 0.82 - 0.95, all $p < .01$), except for OL and OM. Homoscedasticity was largely supported (K-squared range = 0.62 - 2.36, all $p > .05$), except for PM and OL, while parallelism was generally met (F range = 0.03 - 1.79, all $p > .05$), except for PM and RTPJ.

For the theta band, normality assumptions were largely violated across variables (W range = 0.92 - 0.99, all $p < .05$), except for FL, while homoscedasticity was generally upheld (K-squared range = 0.04 - 4.16, all $p > .05$), except for RTL. Parallelism was generally supported (F range = 0.05 - 2.91, all $p > .05$), except for RTL.

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In the lower alpha band, , normality assumptions were frequently violated (W range = 0.52 - 0.81, all p < .01), while homoscedasticity was generally observed (K-squared range = 0.02 - 26.90, all p > .05), except for PM. Parallelism was generally met (F range = 0.06 - 2.09, all p > .05), except for PM, LTPJ, and RTPJ.

For the upper alpha band, normality violations were common (W range = 0.64 - 0.90, all p < .01), except for RTL, while homoscedasticity was generally observed (K-squared range = 0.02 - 8.86, all p > .05), except for CL and RTL. Parallelism was generally upheld (F range = 0.05 - 2.77, all p > .05), except for RTL.

In the full alpha band, normality assumptions were frequently violated (W range = 0.59 - 0.88, all *p* < .01), while homoscedasticity was generally supported (K-squared range = 0.04 - 7.70, all *p* > .05), except for PL and PM. Parallelism was generally met (F range = 0.04 - 1.46, all p > .05), except for PL and PM.

Lastly, in the beta band, normality assumptions were generally violated (W range = 0.77 - 0.94, all p < .01), except for LTL. Homoscedasticity was largely observed (K-squared range = 0.05 - 2.77, all p > .05), except for PM. Parallelism was generally supported (F range = 0.08 - 5.36, all p > .05), except for PM and RTL.

Analysis of group comparisons

This section presents the results of ANCOVA for various parameters during the eyes-open resting-state condition. However, the results of the ANCOVA could not be interpreted due to violations of the regression slope homogeneity assumption. Therefore, a separate regression analysis for each group is presented in the following section for the affected Beta at the right TPJ. The following are the ANCOVA results for ROIs that met the assumption.

Overall, all of relative bands no significant group effects were observed across any brain regions in the eyes-open resting-state condition. To summarize, these results suggest that both interventions such as MCST and CST do not have main effect on resting-state EEG during eyes open task. Please see Table 31 and Figure 37, for more information and illustrations. The analysis of the delta band

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across different regions did not reveal significant effects of the group condition. In the frontal lobe (FL), the effect of group condition was not statistically significant, with a small effect size *(F(*2, 84*)* = 0.91, *p* = .40, partial $\omega^2 < .01$). Similar results were found in the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), and occipital midline (OM), all showing non-significant effects with small effect sizes (all p > .05). Therefore, no post-hoc analyses were conducted for the delta band due to the lack of significant main effects.

In the theta band, none of the regions of interest (ROIs) showed significant group effects. For instance, the frontal lobe (FL) displayed a non-significant group effect with a small effect size *(F(*2, 84*)* = 0.61, *p* = .54, partial $\omega^2 <$ .01). The right temporal lobe (RTL) also exhibited a non-significant effect with a small effect size *(F(*2, 84*)* = 2.03, *p* = .14, partial $\omega^2 = 0.02$). Similarly, other regions such as the central midline (CM) and occipital midline (OM) showed non-significant group effects with small effect sizes (all *p* > .05). No post-hoc analyses were needed due to the absence of significant main effects.

The lower alpha band analysis indicated no significant group effects in the majority of regions. In the frontal lobe (FL), the effect was not significant, with a small effect size *(F(*2, 84*)* = 0.96, *p* = .39, partial $\omega^2 < .01$). Similar non-significant effects with small effect sizes were observed in the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), and occipital midline (OM) (all *p* > .05). Consequently, no post-hoc analyses were performed.

In the upper alpha band, no regions demonstrated significant group effects. For example, the frontal lobe (FL) had a non-significant group effect with a small effect size *(F(*2, 84*)* = 0.23, *p* = .79, partial $\omega^2 < .01$). Similarly, the occipital lobe (OL) and the occipital midline (OM) showed non-significant group effects with small effect sizes (OL: F(2, 84*)* = 0.57, *p* = .57, partial $\omega^2 < .01$; OM: F(2, 84*)* = 0.90, *p* = .41, partial $\omega^2 < .01$). Other regions like the left temporal lobe (LTL) and right temporal lobe (RTL) also did not show significant effects (all p > .05). No post-hoc analyses were required due to the lack of significant main effects.

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The beta band analysis revealed no significant group effects in the majority of regions. The frontal lobe (FL) showed a non-significant effect with a small effect size *(F(*2, 84*)* = 0.95, *p* = .39, partial $\omega^2 < .01$). Other regions such as the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), and right temporal lobe (RTL) also displayed non-significant group effects with small effect sizes (all *p* > .05). Therefore, no post-hoc analyses were performed for the beta band due to the absence of significant main effects.

Overall, the ANCOVA results for the eyes open resting-state EEG indicate that there were no significant effects of group conditions across the delta, theta, lower alpha, upper alpha, and beta bands in the various regions of interest. Effect sizes were generally small, indicating minimal influence of the group variable on the EEG spectral power in these bands. Consequently, no post-hoc analyses were necessary due to the lack of significant group effects.

Table 31 ANCOVA of the eyes open resting-state

		Df	*SS*	*MS*	*F*	*p*	ω^2
Delta							
FL	Pre-test	1	0.063	0.063	4.05	.05	0.03
	Group	2	0.028	0.014	0.91	.40	<.01
	Residuals	84	1.297	0.015			
FM	Pre-test	1	0.041	0.041	1.06	.31	<.01
	Group	2	0.043	0.022	0.56	.57	<.01
	Residuals	84	3.240	0.039			
CL	Pre-test	1	0.157	0.157	5.58	.02	0.05
	Group	2	0.043	0.022	0.77	.47	<.01
	Residuals	84	2.358	0.028			
CM	Pre-test	1	0.077	0.077	2.42	.12	0.02
	Group	2	0.027	0.013	0.42	.66	<.01
	Residuals	84	2.679	0.032			
PL	Pre-test	1	0.162	0.162	6.31	.01	0.06

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		Df	*SS*	*MS*	*F*	*p*	ω^2
	Group	2	0.024	0.012	0.48	.62	<.01
	Residuals	84	2.151	0.026			
PM	Pre-test	1	0.142	0.142	4.40	.04	0.04
	Group	2	0.031	0.015	0.48	.62	<.01
	Residuals	84	2.716	0.032			
OL	Pre-test	1	0.161	0.161	8.49	<.01	0.08
	Group	2	0.035	0.018	0.93	.40	<.01
	Residuals	84	1.592	0.019			
OM	Pre-test	1	0.172	0.172	7.80	<.01	0.07
	Group	2	0.052	0.026	1.18	.31	<.01
	Residuals	84	1.854	0.022			
LTL	Pre-test	1	0.078	0.078	3.04	.09	0.02
	Group	2	0.034	0.017	0.65	.52	<.01
	Residuals	84	2.168	0.026			
RTL	Pre-test	1	0.078	0.078	4.08	.05	0.03
	Group	2	0.050	0.025	1.31	.28	0.01
	Residuals	84	1.601	0.019			
LTPJ	Pre-test	1	0.208	0.208	6.13	.02	0.06
	Group	2	0.031	0.015	0.46	.64	<.01
	Residuals	84	2.853	0.034			
RTPJ	Pre-test	1	0.042	0.042	1.26	.27	<.01
	Group	2	0.106	0.053	1.59	.21	0.01
	Residuals	84	2.795	0.033			
Theta							
FL	Pre-test	1	0.003	0.003	4.19	.04	0.03
	Group	2	0.001	<.001	0.61	.54	<.01
	Residuals	84	0.068	0.001			
FM	Pre-test	1	0.003	0.003	0.97	.33	<.01
	Group	2	0.001	<.001	0.12	.89	<.01
	Residuals	84	0.238	0.003			

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		Df	*SS*	*MS*	*F*	*p*	ω^2
CL	Pre-test	1	0.004	0.004	2.48	.12	0.02
	Group	2	0.002	0.001	0.57	.57	<.01
	Residuals	84	0.119	0.001			
CM	Pre-test	1	0.001	0.001	0.63	.43	<.01
	Group	2	0.002	0.001	0.39	.68	<.01
	Residuals	84	0.165	0.002			
PL	Pre-test	1	0.002	0.002	1.38	.24	<.01
	Group	2	0.001	0.001	0.68	.51	<.01
	Residuals	84	0.093	0.001			
PM	Pre-test	1	0.003	0.003	1.72	.19	0.01
	Group	2	0.002	0.001	0.50	.61	<.01
	Residuals	84	0.137	0.002			
OL	Pre-test	1	0.003	0.003	2.31	.13	0.01
	Group	2	<.001	<.001	0.13	.88	<.01
	Residuals	84	0.093	0.001			
OM	Pre-test	1	0.003	0.003	2.65	.11	0.02
	Group	2	0.002	0.001	0.80	.45	<.01
	Residuals	84	0.102	0.001			
LTL	Pre-test	1	0.001	0.001	0.63	.43	<.01
	Group	2	0.001	0.001	0.65	.52	<.01
	Residuals	84	0.089	0.001			
RTL	Pre-test	1	0.005	0.005	6.22	.01	0.06
	Group	2	0.003	0.002	2.03	.14	0.02
	Residuals	84	0.063	0.001			
LTPJ	Pre-test	1	0.002	0.002	1.97	.16	0.01
	Group	2	0.001	<.001	0.29	.75	<.01
	Residuals	84	0.101	0.001			
RTPJ	Pre-test	1	0.002	0.002	1.10	.30	<.01
	Group	2	0.009	0.004	2.99	.06	0.04
	Residuals	84	0.121	0.001			

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		Df	*SS*	*MS*	*F*	*p*	ω^2
Lower Alpha							
FL	Pre-test	1	0.007	0.007	6.76	.01	0.06
	Group	2	0.002	0.001	0.96	.39	<.01
	Residuals	84	0.089	0.001			
FM	Pre-test	1	0.057	0.057	17.90	<.01	0.16
	Group	2	0.002	0.001	0.38	.68	0.00
	Residuals	84	0.266	0.003			
CL	Pre-test	1	0.016	0.016	8.37	<.01	0.08
	Group	2	0.001	<.001	0.21	.81	<.01
	Residuals	84	0.163	0.002			
CM	Pre-test	1	0.006	0.006	2.37	.13	0.02
	Group	2	<.001	<.001	0.05	.95	<.01
	Residuals	84	0.209	0.002			
PL	Pre-test	1	0.017	0.017	6.84	.01	0.06
	Group	2	0.003	0.002	0.68	.51	<.01
	Residuals	84	0.205	0.002			
PM	Pre-test	1	0.017	0.017	4.38	.04	0.04
	Group	2	0.006	0.003	0.74	.48	<.01
	Residuals	84	0.324	0.004			
OL	Pre-test	1	0.025	0.025	10.37	<.01	0.10
	Group	2	0.005	0.002	0.99	.37	<.01
	Residuals	84	0.203	0.002			
OM	Pre-test	1	0.038	0.038	12.82	<.01	0.12
	Group	2	0.007	0.003	1.11	.33	<.01
	Residuals	84	0.250	0.003			
LTL	Pre-test	1	0.025	0.025	11.05	<.01	0.10
	Group	2	0.002	0.001	0.46	.63	<.01
	Residuals	84	0.193	0.002			
RTL	Pre-test	1	0.013	0.013	8.39	<.01	0.08
	Group	2	0.005	0.003	1.67	.19	0.01

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		Df	*SS*	*MS*	*F*	*p*	ω^2
	Residuals	84	0.129	0.002			
LTPJ	Pre-test	1	0.014	0.014	4.44	.04	0.04
	Group	2	0.002	0.001	0.33	.72	<.01
	Residuals	84	0.274	0.003			
RTPJ	Pre-test	1	0.005	0.005	1.61	.21	0.01
	Group	2	0.009	0.004	1.41	.25	0.01
	Residuals	84	0.262	0.003			
Upper Alpha							
FL	Pre-test	1	0.002	0.002	6.18	.01	0.06
	Group	2	<.001	<.001	0.23	.79	<.01
	Residuals	84	0.032	<.001			
FM	Pre-test	1	0.005	0.005	5.40	.02	0.05
	Group	2	<.001	<.001	0.19	.82	<.01
	Residuals	84	0.074	0.001			
CL	Pre-test	1	0.016	0.016	18.04	<.01	0.16
	Group	2	<.001	<.001	0.10	.91	<.01
	Residuals	84	0.077	0.001			
CM	Pre-test	1	0.007	0.007	7.38	<.01	0.07
	Group	2	<.001	<.001	0.13	.88	<.01
	Residuals	84	0.074	0.001			
PL	Pre-test	1	0.009	0.009	9.91	<.01	0.09
	Group	2	<.001	<.001	0.19	.83	<.01
	Residuals	84	0.079	0.001			
PM	Pre-test	1	0.005	0.005	4.42	.04	0.04
	Group	2	<.001	<.001	0.16	.85	<.01
	Residuals	84	0.100	0.001			
OL	Pre-test	1	0.009	0.009	13.90	<.01	0.13
	Group	2	0.001	<.001	0.57	.57	<.01
	Residuals	84	0.052	0.001			
OM	Pre-test	1	0.012	0.012	17.42	<.01	0.16

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		Df	*SS*	*MS*	*F*	*p*	ω^2
	Group	2	0.001	0.001	0.90	.41	<.01
	Residuals	84	0.059	0.001			
LTL	Pre-test	1	0.011	0.011	12.86	<.01	0.12
	Group	2	0.001	<.001	0.48	.62	<.01
	Residuals	84	0.071	0.001			
RTL	Pre-test	1	0.005	0.005	10.04	<.01	0.09
	Group	2	0.001	<.001	0.74	.48	<.01
	Residuals	84	0.045	0.001			
LTPJ	Pre-test	1	0.015	0.015	11.26	<.01	0.10
	Group	2	0.001	0.001	0.48	.62	<.01
	Residuals	84	0.110	0.001			
RTPJ	Pre-test	1	0.002	0.002	1.72	.19	0.01
	Group	2	0.002	0.001	0.77	.47	<.01
	Residuals	84	0.091	0.001			
Full Alpha							
FL	Pre-test	1	0.015	0.015	5.96	.02	0.05
	Group	2	0.002	0.001	0.47	.62	<.01
	Residuals	84	0.206	0.002			
FM	Pre-test	1	0.078	0.078	11.37	<.01	0.11
	Group	2	0.003	0.002	0.22	.80	<.01
	Residuals	84	0.573	0.007			
CL	Pre-test	1	0.055	0.055	11.14	<.01	0.10
	Group	2	0.001	0.001	0.13	.88	<.01
	Residuals	84	0.418	0.005			
CM	Pre-test	1	0.020	0.020	3.59	.06	0.03
	Group	2	0.001	0.001	0.09	.91	<.01
	Residuals	84	0.466	0.006			
PL	Pre-test	1	0.044	0.044	7.95	<.01	0.07
	Group	2	0.005	0.002	0.44	.65	<.01
	Residuals	84	0.470	0.006			

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		Df	*SS*	*MS*	*F*	*p*	ω^2
PM	Pre-test	1	0.037	0.037	4.55	.04	0.04
	Group	2	0.008	0.004	0.48	.62	<.01
	Residuals	84	0.683	0.008			
OL	Pre-test	1	0.058	0.058	11.34	<.01	0.11
	Group	2	0.009	0.005	0.89	.41	<.01
	Residuals	84	0.428	0.005			
OM	Pre-test	1	0.086	0.086	14.06	<.01	0.13
	Group	2	0.014	0.007	1.11	.33	<.01
	Residuals	84	0.512	0.006			
LTL	Pre-test	1	0.059	0.059	11.09	<.01	0.10
	Group	2	0.003	0.002	0.29	.75	<.01
	Residuals	84	0.450	0.005			
RTL	Pre-test	1	0.027	0.027	7.78	<.01	0.07
	Group	2	0.009	0.005	1.35	.27	0.01
	Residuals	84	0.292	0.003			
LTPJ	Pre-test	1	0.050	0.050	6.42	.01	0.06
	Group	2	0.005	0.003	0.33	.72	<.01
	Residuals	84	0.655	0.008			
RTPJ	Pre-test	1	0.009	0.009	1.25	.27	<.01
	Group	2	0.017	0.009	1.21	.30	<.01
	Residuals	84	0.592	0.007			
Beta							
FL	Pre-test	1	0.059	0.059	8.63	<.01	0.08
	Group	2	0.013	0.006	0.95	.39	<.01
	Residuals	84	0.570	0.007			
FM	Pre-test	1	0.001	0.001	0.13	.72	<.01
	Group	2	0.031	0.015	1.39	.25	0.01
	Residuals	84	0.929	0.011			
CL	Pre-test	1	0.056	0.056	6.36	.01	0.06
	Group	2	0.025	0.013	1.44	.24	0.01

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		Df	*SS*	*MS*	*F*	*p*	ω^2
	Residuals	84	0.738	0.009			
CM	Pre-test	1	0.038	0.038	4.44	.04	0.04
	Group	2	0.021	0.010	1.21	.3	<.01
	Residuals	84	0.715	0.009			
PL	Pre-test	1	0.081	0.081	14.56	<.01	0.13
	Group	2	0.005	0.003	0.47	.63	<.01
	Residuals	84	0.469	0.006			
PM	Pre-test	1	0.048	0.048	7.46	<.01	0.07
	Group	2	0.004	0.002	0.31	.74	<.01
	Residuals	84	0.538	0.006			
OL	Pre-test	1	0.045	0.045	14.78	<.01	0.14
	Group	2	0.008	0.004	1.34	.27	0.01
	Residuals	84	0.254	0.003			
OM	Pre-test	1	0.038	0.038	10.96	<.01	0.10
	Group	2	0.008	0.004	1.24	.30	0.01
	Residuals	84	0.288	0.003			
LTL	Pre-test	1	0.033	0.033	4.75	.03	0.04
	Group	2	0.018	0.009	1.27	.29	0.01
	Residuals	84	0.579	0.007			
RTL	Pre-test	1	0.035	0.035	6.83	.01	0.06
	Group	2	0.009	0.004	0.86	.43	<.01
	Residuals	84	0.431	0.005			
LTPJ	Pre-test	1	0.087	0.087	12.54	<.01	0.12
	Group	2	0.011	0.005	0.76	.47	<.01
	Residuals	84	0.584	0.007			
RTPJ	Pre-test	1	0.034	0.034	4.57	.04	0.04
	Group	2	0.014	0.007	0.98	.38	<.01
	Residuals	84	0.617	0.007			

*A significant interaction effect

Analysis of regression

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For the relative beta during the eyes-open resting-state condition, the MCST group demonstrates strong predictive power in the RTPJ region (see Table 32). MCST exhibits a significant relationship (β_1 = 1.05, $p < 0.001$, R^2_{adj} = 0.37), indicating that pre-test scores strongly predict post-test outcomes. In contrast, CST shows no meaningful predictive power in this region ($\beta_1 = -0.04$, p = .81, $R^2_{adj} = -0.03$), suggesting that the intervention does not contribute to the relationship between pre-test and post-test scores. The control group displays a weak and non-significant relationship (β_1 = 0.32, p = .11, R^2_{adj} = 0.06), highlighting the limited natural association between pre-test and post-test values without intervention. These findings emphasize the effectiveness of the MCST intervention in enhancing beta band activity outcomes in the RTPJ region, whereas CST and the control group show minimal or no impact.

Table 32 Regression analysis of the eyes open resting-state

ROI	Model	Variable	*B*	*SE*	*t*	*p*
Beta						
RTPJ	MCST	Constant	0.04	0.02	2.04	.05
		Pre-test	1.05	0.24	4.31	<.01
	CST	Constant	0.08	0.02	3.36	<.01
		Pre-test	-0.04	0.18	-0.24	.81
	Control	Constant	0.06	0.02	2.80	.01
		Pre-test	0.32	0.19	1.66	.11

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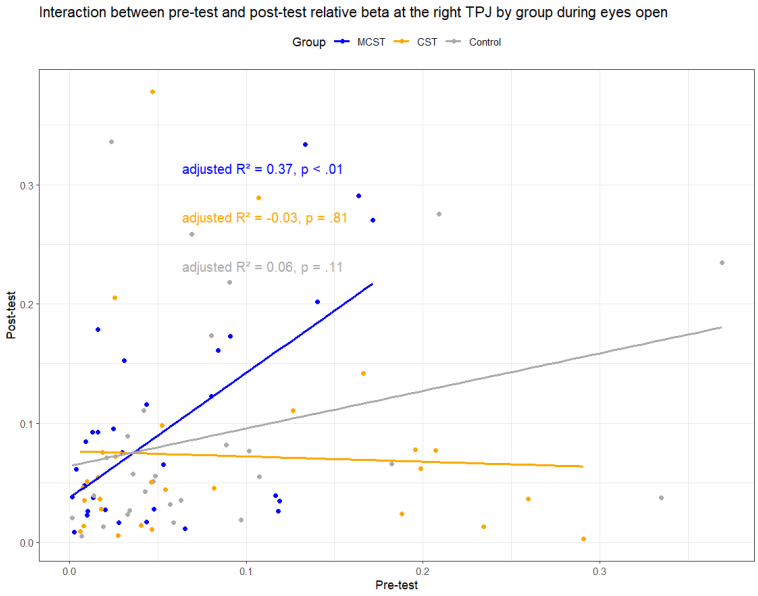

Figure 36 A scatter plot and the regression lines are shows interaction between pre-test and post-test relative beta in the right TPJ area (RTPJ) by group during eyes open

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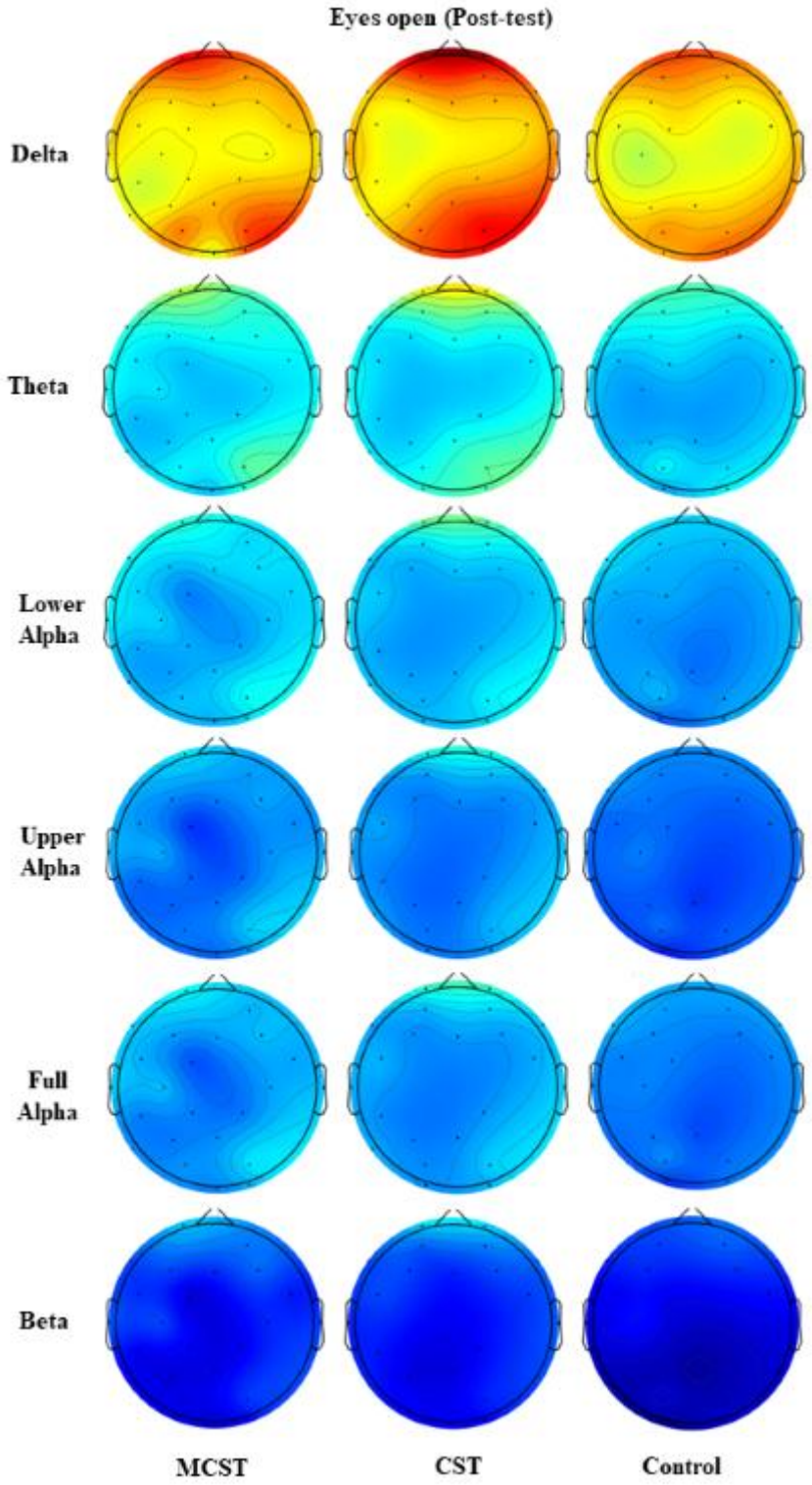

Figure 37 The topographic brain mapping of relative power during eyes open at post-test

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EEG - Verbal paired associates learning task

Analysis of the relative power characteristics

Across all brain regions, there was a consistent decrease in delta band power from pre to post-test assessments for all groups (see Table 33). Notably, the mean values (M) showed a significant decrease in delta band power post-test compared to pre-test across most brain regions, indicating a reduction in slow-wave activity during the verbal paired associates learning task. For example, in the frontal lobe (FL), delta band power decreased from M = 78.26% pre-test to M = 73.46% post-test.

In the theta band, there were mixed findings observed across brain regions. While some regions showed increases in theta band power post-test compared to pre-test, others displayed decreases. However, the overall trend indicated slight changes in theta band power post-test, with mean values reflecting these alterations. For instance, in the frontal midline (FM), theta band power increased from M = 6.16% pre-test to M = 8.61% post-test.

For the lower alpha band, both increases and decreases in relative spectral power were observed across brain regions. The mean values indicated significant changes in lower alpha band power post-test compared to pre-test, with some regions showing increases and others showing decreases. For instance, in central electrode locations (CL), lower alpha band power increased from M = 1.63% pre-test to M = 2.50% post-test.

Similar to the lower alpha band, the upper alpha band displayed mixed changes across brain regions. While some regions exhibited increases in upper alpha band power post-test compared to pre-test, others showed decreases. The mean values reflected these alterations in upper alpha band power. For example, in the parietal lobe (PL), upper alpha band power increased from M = 1.49% pre-test to M = 2.55% post-test.

In the full alpha band, there were significant increases in relative spectral power observed across most brain regions post-test compared to pre-test. The mean values indicated a substantial increase in full alpha band power post-test, suggesting widespread enhancement of alpha activity during the verbal paired

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associates learning task. For instance, in the occipital lobe (OL), full alpha band power increased from M = 2.18% pre-test to M = 2.94% post-test.

Across brain regions, the beta band showed mixed changes in relative spectral power from pre to post-test assessments. Some regions displayed increases in beta band power post-test, while others showed decreases. The mean values reflected these variable changes in beta band power. For example, in the frontal lobe (FL), beta band power increased from M = 8.53% pre-test to M = 12.89% post-test.

In summary, the analysis of relative spectral power across different brain regions and band frequencies during the verbal paired associates learning task revealed diverse patterns of neural activity modulation. While there were consistent decreases in delta band power and increases in full alpha band power, other bands showed mixed changes across brain regions.

Table 33 Characteristic of relative spectral power (%) of band frequencies in the verbal paired associates learning task

		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Delta										
FL	Pre	30	78.26	7.93	31	78.10	10.01	26	78.21	8.29
	Post	30	73.42	11.99	31	73.89	10.16	26	76.00	11.72
FM	Pre	30	84.10	12.50	31	78.22	15.75	26	79.54	12.20
	Post	30	77.49	15.06	31	72.91	17.28	26	78.89	11.83
CL	Pre	30	83.68	10.11	31	75.51	18.01	26	78.58	12.39
	Post	30	76.38	14.44	31	72.13	16.28	26	78.76	12.42
CM	Pre	30	88.09	10.19	31	80.07	18.77	26	80.89	13.73
	Post	30	80.93	16.48	31	75.86	18.05	26	83.41	12.65
PL	Pre	30	87.72	8.50	31	82.53	16.62	26	84.43	9.89
	Post	30	81.45	16.44	31	79.31	13.81	26	84.01	13.37
PM	Pre	30	90.29	8.55	31	83.77	18.63	26	87.82	9.01
	Post	30	83.91	16.64	31	82.38	14.75	26	85.85	14.11

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
OL	Pre	30	90.05	8.00	31	84.68	17.17	26	89.92	10.91
	Post	30	87.16	13.58	31	87.79	12.08	26	89.73	11.96
OM	Pre	30	91.18	8.56	31	85.45	17.83	26	89.21	12.36
	Post	30	86.81	14.20	31	87.44	12.20	26	90.05	12.80
LTL	Pre	30	80.66	9.45	31	75.54	15.49	26	77.14	9.38
	Post	30	76.30	12.18	31	73.43	13.76	26	77.99	12.43
RTL	Pre	30	82.57	7.64	31	76.38	16.21	26	80.08	10.99
	Post	30	77.26	12.99	31	77.12	12.79	26	78.84	11.93
LTPJ	Pre	30	82.77	11.51	31	78.68	18.20	26	78.88	13.43
	Post	30	78.68	17.02	31	77.02	15.85	26	81.22	12.83
RTPJ	Pre	30	87.33	9.27	31	79.52	19.40	26	87.40	10.34
	Post	30	79.53	19.09	31	79.39	15.61	26	84.74	13.54
Theta										
FL	Pre	30	9.55	3.40	31	9.09	2.94	26	9.25	2.14
	Post	30	8.94	2.09	31	9.73	2.54	26	8.64	2.82
FM	Pre	30	6.16	2.87	31	8.27	4.54	26	7.88	3.37
	Post	30	8.61	4.53	31	10.38	4.29	26	8.40	3.17
CL	Pre	30	6.25	3.22	31	7.20	2.78	26	7.39	3.27
	Post	30	7.76	2.76	31	9.19	3.65	26	7.09	2.22
CM	Pre	30	5.18	3.53	31	6.81	4.72	26	7.41	5.37
	Post	30	6.82	4.05	31	8.95	4.49	26	6.41	3.01
PL	Pre	30	5.30	2.65	31	5.90	3.12	26	6.41	3.42
	Post	30	6.34	3.38	31	7.49	3.07	26	6.02	2.87
PM	Pre	30	4.83	3.09	31	5.76	3.83	26	5.60	3.03
	Post	30	6.12	4.02	31	7.19	4.25	26	5.94	4.66
OL	Pre	30	5.20	3.55	31	5.74	4.02	26	5.42	6.30
	Post	30	5.67	4.32	31	5.82	4.26	26	4.54	2.71
OM	Pre	30	4.89	4.37	31	5.45	4.07	26	5.93	7.77
	Post	30	5.97	4.86	31	6.05	4.35	26	4.27	2.64

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
LTL	Pre	30	7.37	2.94	31	8.17	3.12	26	8.41	2.78
	Post	30	8.27	2.54	31	8.98	2.55	26	7.70	2.15
RTL	Pre	30	7.32	3.34	31	7.61	2.46	26	6.80	2.52
	Post	30	7.87	2.32	31	7.79	2.26	26	7.35	1.87
LTPJ	Pre	30	6.57	3.66	31	6.82	3.42	26	8.50	6.23
	Post	30	6.93	3.63	31	7.66	3.07	26	6.70	3.17
RTPJ	Pre	30	5.38	2.86	31	6.31	3.23	26	5.22	4.01
	Post	30	6.52	3.62	31	6.91	3.37	26	5.54	3.04
Lower Alpha										
FL	Pre	30	1.77	0.82	31	1.85	0.89	26	1.67	0.74
	Post	30	2.16	1.22	31	2.29	1.51	26	1.94	1.03
FM	Pre	30	1.59	1.35	31	2.43	2.05	26	1.94	1.26
	Post	30	2.39	1.89	31	3.32	3.42	26	2.35	1.49
CL	Pre	30	1.63	1.16	31	2.62	1.99	26	1.89	1.09
	Post	30	2.45	1.73	31	3.27	3.51	26	2.03	1.11
CM	Pre	30	1.26	1.30	31	2.41	2.60	26	1.84	1.38
	Post	30	2.15	2.06	31	3.18	4.00	26	1.77	1.37
PL	Pre	30	1.38	1.21	31	2.04	2.16	26	1.52	0.98
	Post	30	2.09	2.16	31	2.62	3.06	26	1.60	1.12
PM	Pre	30	1.14	1.34	31	1.95	2.53	26	1.24	0.93
	Post	30	1.90	2.42	31	2.32	3.02	26	1.46	1.35
OL	Pre	30	1.11	0.99	31	1.69	2.18	26	0.90	0.95
	Post	30	1.44	1.88	31	1.40	2.25	26	0.99	0.95
OM	Pre	30	0.91	1.00	31	1.44	1.93	26	0.91	0.86
	Post	30	1.45	1.94	31	1.38	2.12	26	0.90	0.94
LTL	Pre	30	1.95	1.05	31	2.51	1.75	26	2.07	0.93
	Post	30	2.46	1.76	31	2.59	1.93	26	2.14	1.13
RTL	Pre	30	1.77	0.90	31	2.41	1.81	26	1.64	0.86
	Post	30	2.52	2.01	31	2.39	2.44	26	2.04	1.07

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
LTPJ	Pre	30	1.85	1.47	31	2.42	2.43	26	1.98	1.23
	Post	30	2.36	2.36	31	2.47	2.62	26	1.90	1.40
RTPJ	Pre	30	1.38	1.20	31	2.30	2.50	26	1.08	0.76
	Post	30	2.54	3.17	31	2.50	3.55	26	1.56	1.35
Upper Alpha										
FL	Pre	30	1.89	1.35	31	1.86	1.11	26	1.85	1.34
	Post	30	2.40	1.64	31	2.35	1.31	26	2.03	1.06
FM	Pre	30	1.68	1.95	31	2.33	1.81	26	2.16	1.94
	Post	30	2.47	2.58	31	3.06	2.70	26	2.21	1.30
CL	Pre	30	1.92	1.60	31	2.97	2.60	26	2.47	1.89
	Post	30	2.80	2.61	31	3.42	2.79	26	2.37	1.55
CM	Pre	30	1.30	1.34	31	2.34	2.44	26	2.30	2.03
	Post	30	2.31	2.50	31	2.85	2.54	26	1.87	1.70
PL	Pre	30	1.49	1.45	31	2.36	2.85	26	1.87	1.61
	Post	30	2.52	3.20	31	2.78	2.69	26	1.87	1.77
PM	Pre	30	1.11	1.43	31	2.23	3.34	26	1.45	1.38
	Post	30	2.21	3.28	31	2.26	2.37	26	1.73	2.02
OL	Pre	30	1.07	1.03	31	1.80	2.53	26	1.04	1.24
	Post	30	1.52	2.12	31	1.42	2.00	26	1.05	1.41
OM	Pre	30	0.83	0.88	31	1.56	2.34	26	1.08	1.31
	Post	30	1.46	1.97	31	1.33	1.79	26	1.02	1.59
LTL	Pre	30	2.14	1.32	31	2.90	2.73	26	2.49	1.52
	Post	30	2.63	2.07	31	2.84	1.91	26	2.27	1.39
RTL	Pre	30	1.84	1.05	31	2.72	2.46	26	2.12	1.75
	Post	30	2.62	2.25	31	2.51	1.86	26	2.20	1.43
LTPJ	Pre	30	2.15	1.87	31	3.04	3.55	26	2.55	2.01
	Post	30	2.77	3.16	31	2.93	2.97	26	2.23	1.75
RTPJ	Pre	30	1.49	1.38	31	2.82	3.63	26	1.43	1.46
	Post	30	2.82	3.79	31	2.75	3.02	26	1.80	2.00

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Full Alpha										
FL	Pre	30	3.66	2.13	31	3.71	1.96	26	3.53	2.01
	Post	30	4.57	2.83	31	4.64	2.70	26	3.97	1.96
FM	Pre	30	3.28	3.25	31	4.76	3.80	26	4.10	3.06
	Post	30	4.86	4.36	31	6.38	5.74	26	4.57	2.67
CL	Pre	30	3.55	2.74	31	5.58	4.48	26	4.36	2.92
	Post	30	5.25	4.21	31	6.69	6.00	26	4.40	2.54
CM	Pre	30	2.56	2.62	31	4.75	4.92	26	4.13	3.34
	Post	30	4.46	4.46	31	6.03	6.17	26	3.65	2.96
PL	Pre	30	2.87	2.64	31	4.40	4.93	26	3.39	2.57
	Post	30	4.61	5.29	31	5.40	5.55	26	3.47	2.83
PM	Pre	30	2.24	2.74	31	4.18	5.82	26	2.69	2.30
	Post	30	4.12	5.64	31	4.58	5.28	26	3.19	3.33
OL	Pre	30	2.18	2.01	31	3.49	4.67	26	1.94	2.17
	Post	30	2.97	3.96	31	2.83	4.22	26	2.04	2.34
OM	Pre	30	1.74	1.86	31	3.00	4.24	26	2.00	2.14
	Post	30	2.91	3.88	31	2.71	3.88	26	1.91	2.51
LTL	Pre	30	4.09	2.33	31	5.41	4.41	26	4.56	2.40
	Post	30	5.09	3.78	31	5.43	3.70	26	4.41	2.35
RTL	Pre	30	3.61	1.92	31	5.13	4.21	26	3.76	2.55
	Post	30	5.14	4.23	31	4.90	4.15	26	4.24	2.30
LTPJ	Pre	30	4.00	3.30	31	5.46	5.86	26	4.53	3.19
	Post	30	5.13	5.47	31	5.40	5.52	26	4.12	3.05
RTPJ	Pre	30	2.87	2.55	31	5.12	6.07	26	2.51	2.19
	Post	30	5.36	6.91	31	5.25	6.35	26	3.35	3.18
Beta										
FL	Pre	30	8.53	7.32	31	9.10	7.43	26	9.01	6.35
	Post	30	13.07	9.04	31	11.73	8.24	26	11.39	9.87
FM	Pre	30	6.46	8.24	31	8.75	8.96	26	8.48	7.19
	Post	30	9.04	7.55	31	10.33	9.10	26	8.14	7.48
CL	Pre	30	6.52	5.61	31	11.71	12.04	26	9.67	7.55

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		MCST			CST			Control	
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	30	10.61	8.29	31	11.99	8.20	26	9.75	8.75
CM	Pre	30	4.17	4.78	31	8.36	10.62	26	7.56	7.23
	Post	30	7.80	8.48	31	9.17	8.58	26	6.53	7.97
PL	Pre	30	4.11	3.75	31	7.17	9.48	26	5.77	5.41
	Post	30	7.59	8.28	31	7.79	6.43	26	6.50	8.89
PM	Pre	30	2.64	3.17	31	6.30	10.00	26	3.89	4.35
	Post	30	5.85	7.41	31	5.86	6.47	26	5.02	7.46
OL	Pre	30	2.57	2.98	31	6.09	9.99	26	2.72	3.81
	Post	30	4.20	5.65	31	3.56	4.14	26	3.69	7.60
OM	Pre	30	2.19	2.88	31	6.09	12.01	26	2.87	4.20
	Post	30	4.32	5.90	31	3.80	4.76	26	3.77	8.36
LTL	Pre	30	7.88	5.69	31	10.88	9.59	26	9.89	5.62
	Post	30	10.34	7.78	31	12.16	10.30	26	9.90	9.62
RTL	Pre	30	6.49	4.55	31	10.88	11.13	26	9.36	6.82
	Post	30	9.74	7.64	31	10.19	8.61	26	9.58	9.22
LTPJ	Pre	30	6.65	5.98	31	9.04	9.91	26	8.09	6.61
	Post	30	9.27	8.84	31	9.92	9.69	26	7.95	7.93
RTPJ	Pre	30	4.42	4.59	31	9.05	11.33	26	4.86	5.62
	Post	30	8.59	9.71	31	8.45	7.32	26	6.36	8.86

Analysis of assumptions

In the verbal paired associates learning task, within the delta band, normality assumptions were generally violated (W range = 0.69 - 0.91, all $p < .01$), except for OL and OM. Homoscedasticity was mostly observed (K-squared range = 0.21 - 3.69, all $p > .05$), except for FM, CL, and CM, while parallelism was generally met (F range = 0.02 - 4.35, all $p > .05$), except for PM, RTL, and RTPJ.

For the theta band, normality assumptions were frequently violated (W range = 0.83 - 0.97, all $p < .05$), except for LTL. Homoscedasticity was generally observed (K-squared range = 0.59 - 9.35, all $p > .05$), except for OM.

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Parallelism was generally supported (F range = 0.12 - 4.27, all p > .05), except for RTL.

In the lower alpha band, , normality assumptions were frequently violated (W range = 0.58 - 0.77, all p < .01), except for OL. Homoscedasticity was generally observed (K-squared range = 3.58 - 34.78, all p > .05), except for RTL. Parallelism was generally met (F range = 0.03 - 1.98, all p > .05), except for RTL.

Within the upper alpha band, normality assumptions were commonly violated (W range = 0.60 - 0.86, all p < .01), except for OL and OM. Homoscedasticity was generally observed (K-squared range = 0.12 - 13.69, all p > .05), except for RTL. Parallelism was generally upheld (F range = 0.02 - 3.90, all p > .05), except for RTL.

For the full alpha band, normality assumptions were frequently violated (W range = 0.60 - 0.83, all p < .01), except for OL. Homoscedasticity was generally supported (K-squared range = 0.08 - 17.60, all p > .05), except for RTL. Parallelism was generally met (F range = 0.02 - 3.88, all p > .05), except for RTL.

Lastly, in the beta band, normality assumptions were frequently violated (W range = 0.59 - 0.89, all p < .01), except for OL. Homoscedasticity was mostly observed (K-squared range = 0.12 - 9.79, all p > .05), except for RTL. Parallelism was generally supported (F range = 0.06 - 7.38, all p > .05), except for RTL.

Analysis of group comparisons

This section presents the results of ANCOVA for various parameters during the verbal paired associates learning task. It shows significant group effects were found in central electrode locations (CL) and central midline (CM) in the relative theta band but not in other frequency bands (see Table 34 and Figure 40). However, the results of the ANCOVA could not be interpreted due to violations of the regression slope homogeneity assumption. Therefore, separate regression analyses for each group are presented in the following section for the affected ROIs: Delta (PM), Theta (CL, FM, LTPJ, OL), Upper alpha (CL, CM), and Beta (OL, PM). The following are the ANCOVA results for ROIs that met the assumption.

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The analysis of the delta band across different regions revealed no significant effects of the group condition. In the frontal lobe (FL), the group effect was not significant, with a small effect size *(F(*2, 83*)* = 0.43, *p* = .65, partial ω^2 < .01). Similar non-significant effects with small effect sizes were observed in the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all p > .05). Consequently, no post-hoc analyses were necessary for the delta band.

In the theta band, significant group effects were found in central midline (CM) with a small effect size (F(2, 83*)* = 3.79, *p* = .03, partial ω^2 = 0.06). Post-hoc comparisons indicated that the CST group was significantly different from the control group in the central midline *(t(*83*)*= 2.70, *p* = .03, Cohen's *d* = 0.72). However, no significant differences were found between the MCST and control groups or between the MCST and CST groups (all p > .05). Other regions such as the frontal lobe (FL) and occipital midline (OM) did not show significant group effects (all p > .05).

In the lower alpha band, , no significant group effects were found in any region. For example, the frontal lobe (FL) showed a non-significant group effect with a small effect size *(F(*2, 83*)* = 0.34, *p* = .71, partial ω^2 < .01). Similar results were observed in the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all p > .05). Therefore, no post-hoc analyses were conducted.

The upper alpha band analysis indicated no significant group effects across all regions. For instance, the frontal lobe (FL) exhibited a non-significant group effect with a small effect size *(F(*2, 83*)* = 0.62, *p* = .54, partial ω^2 < .01). The same non-significant effects were seen in the frontal midline (FM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction

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(LTPJ), and right temporal-parietal junction (RTPJ) (all p > .05). No post-hoc analyses were required due to the lack of significant main effects.

In the beta band, no significant group effects were observed across any regions. The frontal lobe (FL) showed a non-significant group effect with a small effect size *(F(*2, 83*)* = 0.35, *p* = .71, partial $\omega^2 < .01$). Similarly, the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) did not exhibit significant group effects (all p > .05). Thus, no post-hoc analyses were performed for the beta band.

Overall, the ANCOVA results for the verbal paired associates learning task indicated significant group effects in the theta band in the central midline, with a small effect size. Post-hoc comparisons revealed that the CST group significantly differed from the control group in both the central midline, with a moderate effect size. Other bands and regions did not show significant group effects, indicating minimal influence of the group variable on EEG spectral power during the learning task.

Table 34 ANCOVA of the verbal paired associates learning task

		df	*SS*	*MS*	*F*	*p*	ω_p^2
Delta							
FL	Pre-test	1	0.069	0.069	5.74	.02	0.05
	Group	2	0.010	0.005	0.43	.65	<.01
	Residuals	83	1.001	0.012			
FM	Pre-test	1	0.050	0.050	2.21	.14	0.01
	Group	2	0.049	0.024	1.08	.34	<.01
	Residuals	83	1.862	0.022			
CL	Pre-test	1	0.313	0.313	17.38	<.01	0.16
	Group	2	0.045	0.023	1.26	.29	0.01
	Residuals	83	1.493	0.018			
CM	Pre-test	1	0.388	0.388	18.08	<.01	0.16

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	0.080	0.040	1.85	.16	0.02
	Residuals	83	1.783	0.021			
PL	Pre-test	1	0.332	0.332	18.69	<.01	0.17
	Group	2	0.029	0.015	0.82	.44	<.01
	Residuals	83	1.473	0.018			
PM*	Pre-test	1	0.397	0.397	21.14	<.01	0.19
	Group	2	0.015	0.007	0.39	.68	<.01
	Residuals	83	1.559	0.019			
OL	Pre-test	1	0.310	0.310	25.35	<.01	0.22
	Group	2	0.017	0.009	0.70	.50	<.01
	Residuals	83	1.013	0.012			
OM	Pre-test	1	0.250	0.250	17.52	<.01	0.16
	Group	2	0.025	0.012	0.87	.42	<.01
	Residuals	83	1.183	0.014			
LTL	Pre-test	1	0.303	0.303	23.14	<.01	0.20
	Group	2	0.024	0.012	0.91	.41	<.01
	Residuals	83	1.088	0.013			
RTL	Pre-test	1	0.285	0.285	22.73	<.01	0.20
	Group	2	0.015	0.008	0.61	.55	<.01
	Residuals	83	1.040	0.013			
LTPJ	Pre-test	1	0.227	0.227	10.63	<.01	0.10
	Group	2	0.030	0.015	0.69	.50	<.01
	Residuals	83	1.773	0.021			
RTPJ	Pre-test	1	0.345	0.345	14.95	<.01	0.14
	Group	2	0.039	0.020	0.85	.43	<.01
	Residuals	83	1.913	0.023			
Theta							
FL	Pre-test	1	0.001	0.001	1.33	.25	<.01
	Group	2	0.002	0.001	1.61	.21	0.01
	Residuals	83	0.051	0.001			

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
FM*	Pre-test	1	0.003	0.003	1.58	.21	0.01
	Group	2	0.006	0.003	1.79	.17	0.02
	Residuals	83	0.138	0.002			
CL*	Pre-test	1	0.005	0.005	5.49	.02	0.05
	Group	2	0.007	0.003	3.93	.02	0.06
	Residuals	83	0.070	0.001			
CM	Pre-test	1	0.013	0.013	9.37	<.01	0.09
	Group	2	0.011	0.005	3.79	.03	0.06
	Residuals	83	0.118	0.001			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	83	-0.017	0.010	-1.73	.26	-0.45
	MCST-Control	83	0.010	0.010	0.98	.98	0.27
	CST-Control	83	0.027	0.010	2.70	.03	0.72
PL	Pre-test	1	0.007	0.007	7.26	<.01	0.07
	Group	2	0.004	0.002	2.10	.13	0.02
	Residuals	83	0.075	0.001			
PM	Pre-test	1	0.029	0.029	18.63	<.01	0.17
	Group	2	0.002	0.001	0.62	.54	<.01
	Residuals	83	0.127	0.002			
OL*	Pre-test	1	0.020	0.020	15.23	<.01	0.14
	Group	2	0.003	0.001	0.99	.37	<.01
	Residuals	83	0.108	0.001			
OM	Pre-test	1	0.014	0.014	9.08	<.01	0.08
	Group	2	0.007	0.003	2.20	.12	0.03
	Residuals	83	0.128	0.002			
LTL	Pre-test	1	<.001	<.001	0.21	.65	<.01
	Group	2	0.002	0.001	1.99	.14	0.02
	Residuals	83	0.050	0.001			
RTL	Pre-test	1	0.001	0.001	2.72	.1	0.02
	Group	2	<.001	<.001	0.32	.73	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	83	0.039	<.001			
LTPJ	Pre-test	1	<.001	<.001	0.15	.7	<.01
*	Group	2	0.002	0.001	0.73	.49	<.01
	Residuals	83	0.091	0.001			
RTPJ	Pre-test	1	0.007	0.007	6.36	.01	0.06
	Group	2	0.002	0.001	0.89	.41	<.01
	Residuals	83	0.089	0.001			
Lower Alpha							
FL	Pre-test	1	0.001	0.001	8.22	<.01	0.08
	Group	2	<.001	<.001	0.34	.71	<.01
	Residuals	83	0.013	<.001			
FM	Pre-test	1	0.003	0.003	4.46	.04	0.04
	Group	2	0.001	0.001	0.93	.40	<.01
	Residuals	83	0.049	0.001			
CL	Pre-test	1	0.008	0.008	16.47	<.01	0.15
	Group	2	0.001	<.001	0.90	.41	<.01
	Residuals	83	0.042	0.001			
CM	Pre-test	1	0.008	0.008	12.03	<.01	0.11
	Group	2	0.002	0.001	1.27	.29	0.01
	Residuals	83	0.058	0.001			
PL	Pre-test	1	0.007	0.007	16.19	<.01	0.15
	Group	2	0.001	<.001	0.88	.42	<.01
	Residuals	83	0.038	<.001			
PM	Pre-test	1	0.006	0.006	11.34	<.01	0.11
	Group	2	<.001	<.001	0.47	.63	<.01
	Residuals	83	0.044	0.001			
OL	Pre-test	1	0.009	0.009	39.65	<.01	0.31
	Group	2	<.001	<.001	0.67	.52	<.01
	Residuals	83	0.019	<.001			
OM	Pre-test	1	0.007	0.007	32.66	<.01	0.27

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	0.001	<.001	1.09	.34	<.01
	Residuals	83	0.019	<.001			
LTL	Pre-test	1	0.004	0.004	15.99	<.01	0.15
	Group	2	<.001	<.001	0.42	.66	<.01
	Residuals	83	0.020	<.001			
RTL	Pre-test	1	0.008	0.008	26.17	<.01	0.22
	Group	2	0.001	<.001	0.96	.39	<.01
	Residuals	83	0.025	<.001			
LTPJ	Pre-test	1	0.004	0.004	9.51	<.01	0.09
	Group	2	<.001	<.001	0.44	.65	<.01
	Residuals	83	0.037	<.001			
RTPJ	Pre-test	1	0.016	0.016	22.91	<.01	0.20
	Group	2	0.001	0.001	0.82	.45	<.01
	Residuals	83	0.056	0.001			
Upper Alpha							
FL	Pre-test	1	0.001	0.001	5.94	.02	0.05
	Group	2	<.001	<.001	0.62	.54	<.01
	Residuals	83	0.015	<.001			
FM	Pre-test	1	0.002	0.002	2.85	.09	0.02
	Group	2	0.001	<.001	0.88	.42	<.01
	Residuals	83	0.044	0.001			
CL*	Pre-test	1	0.012	0.012	25.20	<.01	0.22
	Group	2	0.001	0.001	1.13	.33	<.01
	Residuals	83	0.038	<.001			
CM*	Pre-test	1	0.009	0.009	20.44	<.01	0.18
	Group	2	0.002	0.001	1.91	.15	0.02
	Residuals	83	0.036	<.001			
PL	Pre-test	1	0.009	0.009	14.81	<.01	0.14
	Group	2	0.001	0.001	0.89	.41	<.01
	Residuals	83	0.050	0.001			

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
PM	Pre-test	1	0.009	0.009	14.64	<.01	0.14
	Group	2	0.001	<.001	0.51	.60	<.01
	Residuals	83	0.049	0.001			
OL	Pre-test	1	0.008	0.008	29.30	<.01	0.25
	Group	2	<.001	<.001	0.84	.44	<.01
	Residuals	83	0.022	<.001			
OM	Pre-test	1	0.005	0.005	21.15	<.01	0.19
	Group	2	0.001	<.001	1.04	.36	<.01
	Residuals	83	0.021	<.001			
LTL	Pre-test	1	0.007	0.007	25.01	<.01	0.22
	Group	2	<.001	<.001	0.76	.47	<.01
	Residuals	83	0.022	<.001			
RTL	Pre-test	1	0.006	0.006	22.16	<.01	0.20
	Group	2	0.001	<.001	0.97	.38	<.01
	Residuals	83	0.024	<.001			
LTPJ	Pre-test	1	0.007	0.007	10.17	<.01	0.10
	Group	2	0.001	<.001	0.52	.60	<.01
	Residuals	83	0.056	0.001			
RTPJ	Pre-test	1	0.015	0.015	18.99	<.01	0.17
	Group	2	0.002	0.001	1.01	.37	<.01
	Residuals	83	0.064	0.001			
Full Alpha							
FL	Pre-test	1	0.005	0.005	7.85	<.01	0.07
	Group	2	0.001	<.001	0.51	.60	<.01
	Residuals	83	0.050	0.001			
FM	Pre-test	1	0.009	0.009	4.52	.04	0.04
	Group	2	0.004	0.002	1.00	.37	<.01
	Residuals	83	0.164	0.002			
CL	Pre-test	1	0.036	0.036	21.12	<.01	0.19
	Group	2	0.004	0.002	1.14	.32	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	83	0.143	0.002			
CM	Pre-test	1	0.033	0.033	16.60	<.01	0.15
	Group	2	0.006	0.003	1.65	.20	0.01
	Residuals	83	0.163	0.002			
PL	Pre-test	1	0.030	0.030	15.27	<.01	0.14
	Group	2	0.004	0.002	0.92	.40	<.01
	Residuals	83	0.165	0.002			
PM	Pre-test	1	0.028	0.028	13.31	<.01	0.12
	Group	2	0.002	0.001	0.42	.66	<.01
	Residuals	83	0.176	0.002			
OL	Pre-test	1	0.033	0.033	33.85	<.01	0.27
	Group	2	0.001	0.001	0.77	.47	<.01
	Residuals	83	0.080	0.001			
OM	Pre-test	1	0.025	0.025	26.62	<.01	0.23
	Group	2	0.002	0.001	1.12	.33	<.01
	Residuals	83	0.079	0.001			
LTL	Pre-test	1	0.019	0.019	20.43	<.01	0.18
	Group	2	0.001	0.001	0.62	.54	<.01
	Residuals	83	0.078	0.001			
RTL	Pre-test	1	0.028	0.028	26.30	<.01	0.23
	Group	2	0.002	0.001	1.07	.35	<.01
	Residuals	83	0.088	0.001			
LTPJ	Pre-test	1	0.020	0.020	9.36	<.01	0.09
	Group	2	0.002	0.001	0.50	.61	<.01
	Residuals	83	0.181	0.002			
RTPJ	Pre-test	1	0.056	0.056	20.29	<.01	0.18
	Group	2	0.005	0.003	0.96	.39	<.01
	Residuals	83	0.230	0.003			
Beta							
FL	Pre-test	1	0.032	0.032	4.03	.05	0.03

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	0.005	0.003	0.35	.71	<.01
	Residuals	83	0.651	0.008			
FM	Pre-test	1	0.016	0.016	2.46	.12	0.02
	Group	2	0.007	0.003	0.50	.61	<.01
	Residuals	83	0.538	0.006			
CL	Pre-test	1	0.098	0.098	16.45	<.01	0.15
	Group	2	0.006	0.003	0.51	.60	<.01
	Residuals	83	0.496	0.006			
CM	Pre-test	1	0.107	0.107	18.56	<.01	0.17
	Group	2	0.012	0.006	1.04	.36	<.01
	Residuals	83	0.479	0.006			
PL	Pre-test	1	0.103	0.103	20.71	<.01	0.18
	Group	2	0.006	0.003	0.58	.56	<.01
	Residuals	83	0.414	0.005			
PM*	Pre-test	1	0.096	0.096	24.49	<.01	0.21
	Group	2	0.006	0.003	0.72	.49	<.01
	Residuals	83	0.324	0.004			
OL*	Pre-test	1	0.041	0.041	14.14	<.01	0.13
	Group	2	0.005	0.003	0.93	.40	<.01
	Residuals	83	0.242	0.003			
OM	Pre-test	1	0.040	0.040	10.91	<.01	0.10
	Group	2	0.004	0.002	0.55	.58	<.01
	Residuals	83	0.301	0.004			
LTL	Pre-test	1	0.178	0.178	26.78	<.01	0.23
	Group	2	0.005	0.003	0.38	.68	<.01
	Residuals	83	0.551	0.007			
RTL	Pre-test	1	0.131	0.131	23.12	<.01	0.20
	Group	2	0.005	0.003	0.46	.63	<.01
	Residuals	83	0.469	0.006			
LTPJ	Pre-test	1	0.115	0.115	17.45	<.01	0.16

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	0.006	0.003	0.45	.64	<.01
	Residuals	83	0.549	0.007			
RTPJ	Pre-test	1	0.072	0.072	10.72	<.01	0.10
	Group	2	0.009	0.004	0.67	.52	<.01
	Residuals	83	0.558	0.007			

*A significant interaction effect

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Analysis of regression

The following analysis explores the predictive relationships between pre-test and post-test relative powers for specific frequency bands (delta, theta, upper alpha, and beta) for different regions and groups, including MCST, CST, and control (see Table 35).

For the relative delta, in the PM region, the MCST group demonstrates no significant relationship between pre-test and post-test values (β_1 = 0.27, p = .46, R^2 = −.02), indicating minimal explanatory power. The CST group shows moderate predictive power (β_1 = 0.42, p < .001, adjusted R^2 = .25), suggesting that pre-test values explain 25% of the variance in post-test outcomes. The control group exhibits the strongest relationship (β_1 = 1.31, p < .001, adjusted R^2 = .69), indicating that 69% of the variance in post-test values is explained by pre-test values (see Figure 38).

Figure 38 A scatter plot and the regression lines are shows interaction between pre-test and post-test relative delta at the parietal midline (PM) by group during the VPAL task

For the relative theta, in the CL region, the MCST group does not demonstrate a significant relationship ($\beta_1 = -0.07$, $p = .66$, adjusted $R^2 = -.03$), while the CST group shows moderate predictive power ($\beta_1 = 0.64$, $p = .01$, adjusted $R^2 = .21$). The control group exhibits weak predictive power ($\beta_1 = 0.24$, $p = .08$, adjusted $R^2 = .09$). In the FM region, the MCST group shows no significant predictive relationship ($\beta_1 = -0.49$, $p = .09$, adjusted $R^2 = .06$), while the CST group demonstrates marginal significance ($\beta_1 = 0.31$, $p = .07$, adjusted $R^2 = .07$). The control group fails to show significance ($\beta_1 = 0.22$, $p = .25$, adjusted $R^2 = .02$). In the LTPJ region, the MCST group shows no significant relationship ($\beta_1 = 0.25$, $p = .17$, adjusted $R^2 = .03$), while the CST group demonstrates moderate predictive power ($\beta_1 = 0.33$, $p = .05$, adjusted $R^2 = .10$). The control group fails to demonstrate significance ($\beta_1 = -0.15$, $p = .16$, adjusted $R^2 = .04$). In the OL region, the MCST group shows moderate predictive power ($\beta_1 = 0.51$, $p = .02$, adjusted $R^2 = .15$), while the CST group demonstrates a stronger relationship ($\beta_1 = 0.62$, $p < .001$, adjusted $R^2 = .39$). The control group does not exhibit significant predictive power ($\beta_1 = 0.11$, $p = .20$, adjusted $R^2 = .03$) (see Figure 39).

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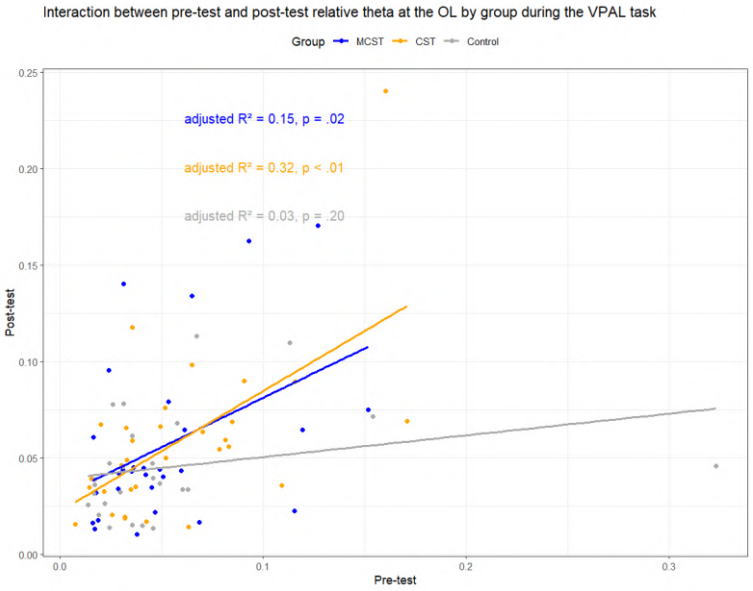

Figure 39 A scatter plot and the regression lines are shows interaction between pre-test and post-test relative theta at the occipital lobe (OL) by group during the VPAL task

For the relative upper alpha, in the CL region, the MCST group shows no significant relationship (β_1 = 0.00, p = .99, adjusted R^2 = −.04), while the CST group demonstrates strong predictive power (β_1 = 0.78, p < .001, adjusted R^2 = .51), with pre-test values explaining 51% of the variance in post-test outcomes. The control group exhibits moderate predictive power (β_1 = 0.48, p < .001, adjusted R^2 = .32). In the CM region, the MCST group does not demonstrate significance (β_1 = −0.06, p = .87, adjusted R^2 = −.03), while the CST group exhibits strong predictive power (β_1 = 0.76, p < .001, adjusted R^2 = .51). The control group shows weak predictive power (β_1 = 0.40, p = .01, adjusted R^2 = .20).

For the relative beta, in the OL region, the MCST group demonstrates marginal predictive power (β_1 = 0.65, p = .07, adjusted R^2 = .08), while the CST group shows moderate predictive power (β_1 = 0.22, p < .001, adjusted R^2 = .26). The control group demonstrates the strongest relationship (β_1 = 1.26, p < .001, adjusted R^2 = .38). In the PM region, the MCST group fails to show a significant relationship (β_1 = 0.33, p = .46, adjusted R^2 = −.02), while the CST group demonstrates marginal predictive power (β_1 = 0.39, p < .001, adjusted R^2 = .35). The

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control group shows the strongest relationship (β_1 = 1.39, p < .001, adjusted R^2 = .65), highlighting the natural predictive capacity in this region.

Across the verbal PAL task, the CST group demonstrates consistent and moderate predictive power in most and regions, particularly in the Delta PM and Upper alpha CL regions. The MCST group shows limited predictive power, with significance in only a few regions, such as the Theta OL and Beta OL. The control group consistently exhibits strong predictive relationships, particularly in the PM region across, suggesting a strong natural association between pre-test and post-test values. These results highlight the relative effectiveness of the CST intervention and the limited impact of the MCST intervention in the context of the verbal PAL task.

Table 35 Regression analysis of the verbal paired associates learning task

ROI	Model	Variable	β	*SE*	*t*	*p*
Delta						
PM	MCST	Constant	0.59	0.33	1.79	.08
		Pre-test	0.27	0.36	0.75	.46
	CST	Constant	0.47	0.11	4.43	<.01
		Pre-test	0.42	0.12	3.33	<.01
	Control	Constant	-0.29	0.15	-1.9	.07
		Pre-test	1.31	0.17	7.5	<.01
Theta						
FM	MCST	Constant	0.12	0.02	6.06	<.01
		Pre-test	-0.49	0.28	-1.74	.09
	CST	Constant	0.08	0.02	5.03	<.01
		Pre-test	0.31	0.17	1.85	.07
	Control	Constant	0.07	0.02	4.16	<.01
		Pre-test	0.22	0.19	1.19	.25
CL	MCST	Constant	0.08	0.01	7.26	<.01
		Pre-test	-0.07	0.16	-0.44	.66
	CST	Constant	0.05	0.02	2.78	.01
		Pre-test	0.64	0.21	3.01	.01
	Control	Constant	0.05	0.01	5.11	<.01
		Pre-test	0.24	0.13	1.85	.08
OL	MCST	Constant	0.03	0.01	2.30	.03
		Pre-test	0.51	0.21	2.46	.02
	CST	Constant	0.02	0.01	2.03	.05
		Pre-test	0.62	0.16	3.91	<.01

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ROI	Model	Variable	*β*	*SE*	*t*	*p*
	Control	Constant	0.04	0.01	5.64	<.01
		Pre-test	0.11	0.08	1.33	.20
LTPJ	MCST	Constant	0.05	0.01	3.87	<.01
		Pre-test	0.25	0.18	1.40	.17
	CST	Constant	0.05	0.01	4.60	<.01
		Pre-test	0.33	0.16	2.09	.05
	Control	Constant	0.08	0.01	7.61	<.01
		Pre-test	-0.15	0.10	-1.46	.16
Upper Alpha						
CL	MCST	Constant	0.03	0.01	3.66	<.01
		Pre-test	0.00	0.31	-0.01	.99
	CST	Constant	0.01	0.01	2.06	.05
		Pre-test	0.78	0.14	5.67	<.01
	Control	Constant	0.01	0.00	2.81	.01
		Pre-test	0.48	0.13	3.59	<.01
CM	MCST	Constant	0.02	0.01	3.66	<.01
		Pre-test	-0.06	0.35	-0.17	.87
	CST	Constant	0.01	0.00	2.40	.02
		Pre-test	0.76	0.13	5.71	<.01
	Control	Constant	0.01	0.00	2.08	.05
		Pre-test	0.40	0.15	2.70	.01
Beta						
OL	MCST	Constant	0.03	0.01	1.93	.06
		Pre-test	0.65	0.34	1.91	.07
	CST	Constant	0.02	0.01	2.94	.01
		Pre-test	0.22	0.06	3.43	<.01
	Control	Constant	0.00	0.01	0.18	.86
		Pre-test	1.26	0.31	4.01	<.01
PM	MCST	Constant	0.05	0.02	2.79	.01
		Pre-test	0.33	0.44	0.75	.46
	CST	Constant	0.03	0.01	3.03	.01
		Pre-test	0.39	0.10	4.14	<.01
	Control	Constant	0.00	0.01	-0.35	.73
		Pre-test	1.39	0.20	6.87	<.01

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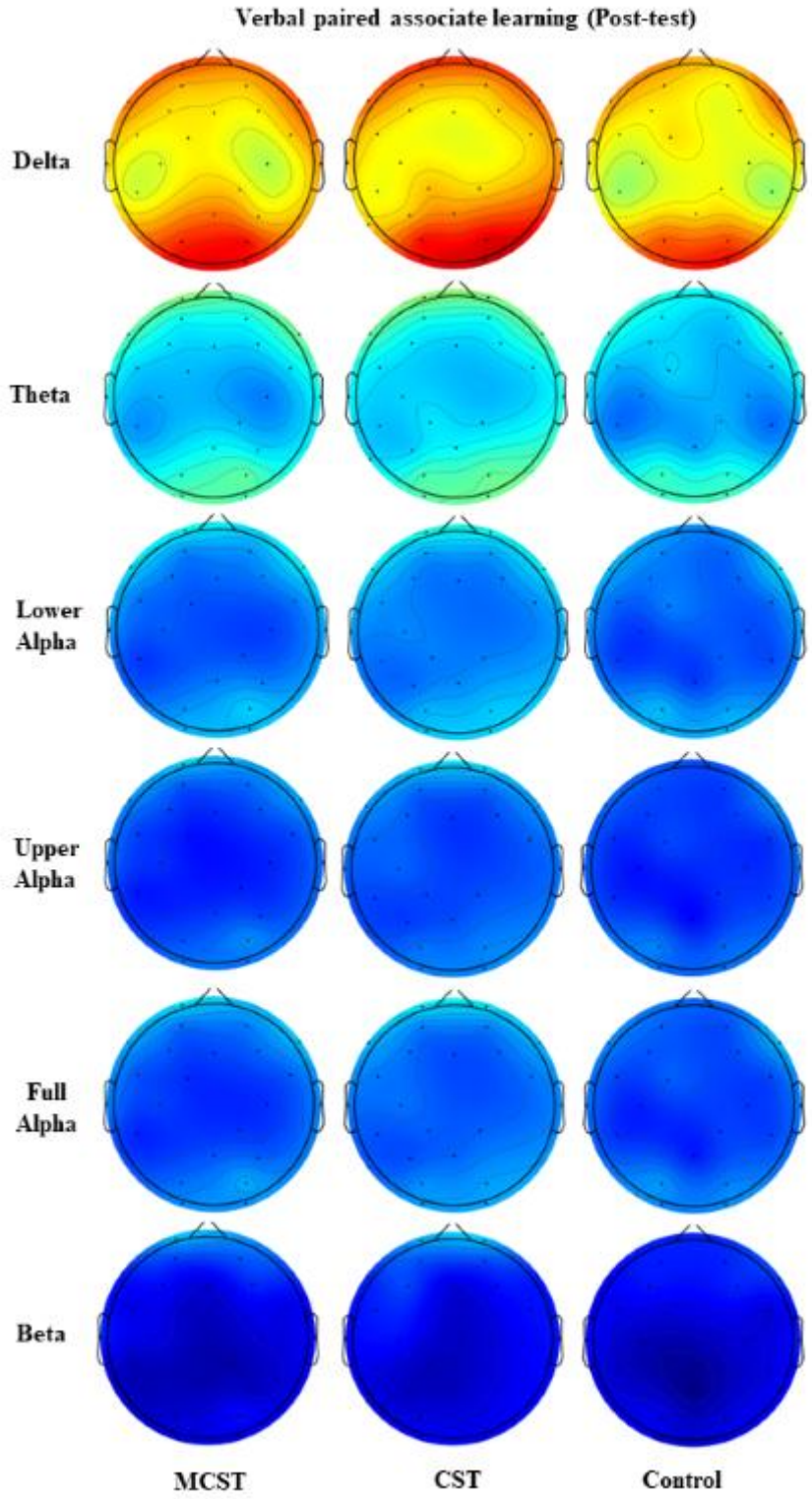

Figure 40 The topographic brain mapping of relative power during the Verbal paired associates learning task at post-test

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EEG - Non-verbal paired associates learning task

Analysis of the relative power characteristics

Across all brain regions, there was a consistent decrease in delta band power from pre to post-test assessments for all groups. Notably, the mean values (M) showed a significant decrease in delta band power post-test compared to pre-test across most brain regions, indicating a reduction in slow-wave activity during the non-paired associates learning task (see Table 36). For example, in the frontal lobe (FL), delta band power decreased from M = 80.93% pre-test to M = 74.94% post-test.

In the theta band, there were mixed findings observed across brain regions. While some regions showed increases in theta band power post-test compared to pre-test, others displayed decreases. However, the overall trend indicated slight changes in theta band power post-test, with mean values reflecting these alterations. For instance, in the frontal midline (FM), theta band power increased from M = 5.73% pre-test to M = 8.64% post-test.

For the lower alpha band, both increases and decreases in relative spectral power were observed across brain regions. The mean values indicated significant changes in lower alpha band power post-test compared to pre-test, with some regions showing increases and others showing decreases. For example, in central electrode locations (CL), lower alpha band power increased from M = 1.48% pre-test to M = 2.24% post-test.

Similar to the lower alpha band, the upper alpha band displayed mixed changes across brain regions. While some regions exhibited increases in upper alpha band power post-test compared to pre-test, others showed decreases. The mean values reflected these alterations in upper alpha band power. For example, in the frontal lobe (FL), upper alpha band power increased from M = 1.47% pre-test to M = 2.11% post-test.

In the full alpha band, there were significant increases in relative spectral power observed across most brain regions post-test compared to pre-test. The mean values indicated a substantial increase in full alpha band power post-test, suggesting widespread enhancement of alpha activity during the non-paired associates learning task. For instance, in the occipital lobe (OL), full alpha band power increased from M = 3.01% pre-test to M = 4.17% post-test.

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Across brain regions, the beta band showed mixed changes in relative spectral power from pre to post-test assessments. Some regions displayed increases in beta band power post-test, while others showed decreases. The mean values reflected these variable changes in beta band power. For example, in the frontal lobe (FL), beta band power increased from M = 6.77% pre-test to M = 10.95% post-test.

In summary, the analysis of relative spectral power across different brain regions and band frequencies during the non-paired associates learning task revealed diverse patterns of neural activity modulation. While there were consistent decreases in delta band power and increases in full alpha band power, other bands showed mixed changes across brain regions.

Table 36 Characteristic of relative spectral power (%) of band frequencies in the non-paired associates learning task

		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Delta										
FL	Pre	31	80.93	7.08	30	78.58	8.52	28	78.96	7.90
	Post	31	74.94	11.15	30	75.55	8.86	28	75.21	10.19
FM	Pre	31	87.87	8.13	30	80.59	13.61	28	80.86	11.24
	Post	31	78.33	12.14	30	74.61	14.94	28	78.41	11.15
CL	Pre	31	84.82	9.98	30	78.17	14.55	28	80.39	11.06
	Post	31	77.35	13.16	30	75.71	13.37	28	77.74	12.70
CM	Pre	31	87.70	11.28	30	82.56	15.98	28	83.82	12.55
	Post	31	81.86	14.31	30	79.15	14.69	28	81.54	12.95
PL	Pre	31	88.31	7.74	30	83.96	15.47	28	85.76	9.39
	Post	31	81.63	14.77	30	83.21	12.12	28	83.27	11.58
PM	Pre	31	90.16	7.72	30	85.63	16.30	28	88.16	8.54
	Post	31	84.41	15.32	30	85.10	13.46	28	85.44	13.39
OL	Pre	31	91.66	7.00	30	86.50	14.88	28	90.82	9.35
	Post	31	89.17	9.36	30	89.48	11.14	28	88.05	10.17

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
OM	Pre	31	92.59	7.56	30	87.34	14.39	28	89.31	11.85
	Post	31	89.25	8.87	30	89.59	11.85	28	88.14	10.70
LTL	Pre	31	82.74	8.13	30	77.39	11.64	28	78.63	10.41
	Post	31	75.08	12.98	30	76.61	11.76	28	77.54	10.60
RTL	Pre	31	84.00	7.92	30	78.09	13.34	28	81.56	9.42
	Post	31	77.84	13.54	30	79.75	10.57	28	78.31	11.51
LTPJ	Pre	31	86.10	10.37	30	80.07	16.05	28	80.48	14.54
	Post	31	78.06	16.69	30	80.05	12.60	28	79.87	12.78
RTPJ	Pre	31	87.82	9.84	30	81.22	17.16	28	88.21	9.80
	Post	31	81.24	16.88	30	84.08	13.57	28	82.92	13.68
Theta										
FL	Pre	31	9.28	2.87	30	8.73	2.58	28	9.12	2.01
	Post	31	9.93	2.28	30	9.79	2.47	28	9.21	2.30
FM	Pre	31	5.73	2.92	30	7.38	4.54	28	7.97	3.79
	Post	31	8.64	3.87	30	9.76	3.86	28	8.99	3.75
CL	Pre	31	5.86	2.88	30	6.85	3.00	28	7.04	2.90
	Post	31	7.66	2.51	30	8.24	2.85	28	7.42	2.71
CM	Pre	31	5.42	3.68	30	6.36	4.62	28	6.69	4.65
	Post	31	7.12	3.78	30	8.00	3.62	28	7.01	3.89
PL	Pre	31	5.36	2.44	30	5.53	3.04	28	6.39	3.51
	Post	31	6.67	3.39	30	6.55	3.03	28	6.61	3.15
PM	Pre	31	5.20	3.15	30	5.60	3.94	28	5.83	2.81
	Post	31	6.63	4.41	30	6.43	4.14	28	6.67	4.99
OL	Pre	31	4.52	2.88	30	5.38	3.95	28	4.89	4.78
	Post	31	5.15	2.98	30	5.00	3.76	28	5.28	2.98
OM	Pre	31	4.19	3.57	30	5.32	4.03	28	5.65	5.95
	Post	31	5.54	3.48	30	5.18	4.32	28	5.24	3.17
LTL	Pre	31	7.05	2.53	30	7.55	2.38	28	8.19	3.16
	Post	31	8.56	2.31	30	8.25	2.20	28	7.99	2.27

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
RTL	Pre	31	6.57	2.06	30	7.10	2.53	28	6.84	2.30
	Post	31	7.82	2.34	30	7.22	2.17	28	7.53	1.87
LTPJ	Pre	31	5.89	2.77	30	6.38	3.32	28	8.14	7.08
	Post	31	7.46	3.69	30	7.23	2.54	28	7.30	3.32
RTPJ	Pre	31	5.25	2.83	30	5.86	3.10	28	5.12	3.51
	Post	31	6.70	3.91	30	5.65	3.42	28	6.19	3.09
Lower Alpha										
FL	Pre	31	1.54	0.60	30	1.85	0.85	28	1.70	0.69
	Post	31	2.07	1.03	30	2.20	1.16	28	2.04	0.81
FM	Pre	31	1.18	0.72	30	2.30	2.08	28	1.96	1.35
	Post	31	2.19	1.42	30	3.16	2.82	28	2.40	1.45
CL	Pre	31	1.48	1.04	30	2.23	1.62	28	1.81	0.99
	Post	31	2.24	1.51	30	2.81	2.37	28	2.29	1.54
CM	Pre	31	1.29	1.31	30	1.98	2.07	28	1.63	1.27
	Post	31	2.04	1.96	30	2.64	2.56	28	2.10	1.71
PL	Pre	31	1.28	1.10	30	1.81	1.95	28	1.42	0.85
	Post	31	1.99	1.85	30	2.16	2.56	28	1.71	1.19
PM	Pre	31	1.13	1.38	30	1.66	2.22	28	1.23	0.87
	Post	31	1.67	1.78	30	2.04	2.71	28	1.50	1.38
OL	Pre	31	0.91	0.85	30	1.54	1.95	28	0.85	0.76
	Post	31	1.14	1.17	30	1.25	2.00	28	1.15	0.94
OM	Pre	31	0.76	0.86	30	1.39	1.82	28	0.98	0.99
	Post	31	1.13	1.09	30	1.22	2.02	28	1.10	1.02
LTL	Pre	31	1.73	0.96	30	2.32	1.38	28	1.94	1.06
	Post	31	2.50	1.68	30	2.44	1.60	28	2.33	1.36
RTL	Pre	31	1.61	0.83	30	2.19	1.38	28	1.56	0.85
	Post	31	2.29	1.70	30	2.10	1.68	28	2.06	1.04
LTPJ	Pre	31	1.37	1.04	30	2.16	1.94	28	1.81	1.25
	Post	31	2.33	2.34	30	2.21	2.15	28	2.13	1.55

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
RTPJ	Pre	31	1.33	1.29	30	2.02	2.09	28	1.08	0.84
	Post	31	2.20	2.59	30	1.92	2.70	28	1.73	1.37
Upper Alpha										
FL	Pre	31	1.47	0.88	30	1.81	0.93	28	1.73	0.92
	Post	31	2.11	1.38	30	2.18	1.23	28	2.21	1.24
FM	Pre	31	1.11	0.82	30	2.09	1.62	28	1.86	1.26
	Post	31	2.23	1.78	30	2.81	2.25	28	2.35	1.53
CL	Pre	31	1.61	1.23	30	2.65	2.38	28	2.09	1.39
	Post	31	2.51	2.20	30	2.94	2.23	28	2.63	1.95
CM	Pre	31	1.30	1.43	30	2.01	2.24	28	1.76	1.61
	Post	31	2.16	2.45	30	2.50	2.15	28	2.22	2.02
PL	Pre	31	1.27	1.16	30	2.08	2.73	28	1.56	1.17
	Post	31	2.24	2.47	30	2.16	2.33	28	2.01	1.74
PM	Pre	31	0.95	1.01	30	1.91	2.93	28	1.29	1.15
	Post	31	1.83	2.50	30	1.86	2.21	28	1.73	2.08
OL	Pre	31	0.84	0.85	30	1.66	2.29	28	0.92	1.03
	Post	31	1.16	1.38	30	1.23	1.91	28	1.27	1.29
OM	Pre	31	0.70	0.80	30	1.49	2.14	28	1.09	1.41
	Post	31	1.06	1.12	30	1.10	1.81	28	1.24	1.36
LTL	Pre	31	1.72	0.95	30	2.56	1.88	28	2.17	1.38
	Post	31	2.57	1.88	30	2.46	1.43	28	2.46	1.73
RTL	Pre	31	1.64	1.01	30	2.46	1.77	28	1.72	1.12
	Post	31	2.34	1.94	30	2.14	1.47	28	2.33	1.72
LTPJ	Pre	31	1.48	1.34	30	2.65	3.01	28	2.23	1.84
	Post	31	2.63	2.77	30	2.43	2.15	28	2.51	2.28
RTPJ	Pre	31	1.39	1.45	30	2.44	2.94	28	1.16	1.03
	Post	31	2.31	2.87	30	2.01	2.44	28	2.10	2.23
Full Alpha										
FL	Pre	31	3.01	1.44	30	3.66	1.74	28	3.42	1.59

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	31	4.17	2.38	30	4.38	2.30	28	4.25	1.99
FM	Pre	31	2.29	1.51	30	4.40	3.62	28	3.82	2.57
	Post	31	4.42	3.09	30	5.98	4.87	28	4.74	2.93
CL	Pre	31	3.09	2.25	30	4.88	3.91	28	3.90	2.36
	Post	31	4.75	3.65	30	5.75	4.48	28	4.91	3.28
CM	Pre	31	2.59	2.72	30	3.99	4.20	28	3.39	2.85
	Post	31	4.20	4.32	30	5.14	4.57	28	4.32	3.58
PL	Pre	31	2.55	2.24	30	3.89	4.59	28	2.99	2.01
	Post	31	4.23	4.28	30	4.33	4.83	28	3.72	2.89
PM	Pre	31	2.08	2.38	30	3.57	5.08	28	2.53	1.99
	Post	31	3.50	4.23	30	3.90	4.85	28	3.23	3.41
OL	Pre	31	1.75	1.69	30	3.20	4.20	28	1.77	1.79
	Post	31	2.30	2.54	30	2.48	3.90	28	2.42	2.20
OM	Pre	31	1.46	1.66	30	2.88	3.93	28	2.07	2.38
	Post	31	2.19	2.20	30	2.32	3.83	28	2.34	2.36
LTL	Pre	31	3.45	1.81	30	4.88	3.20	28	4.11	2.41
	Post	31	5.08	3.50	30	4.89	2.88	28	4.79	2.96
RTL	Pre	31	3.25	1.81	30	4.65	3.11	28	3.28	1.96
	Post	31	4.63	3.61	30	4.24	3.06	28	4.39	2.63
LTPJ	Pre	31	2.85	2.34	30	4.81	4.81	28	4.03	3.08
	Post	31	4.96	5.07	30	4.64	4.23	28	4.64	3.73
RTPJ	Pre	31	2.72	2.72	30	4.46	4.97	28	2.24	1.86
	Post	31	4.52	5.45	30	3.93	5.05	28	3.84	3.55
Beta										
FL	Pre	31	6.77	5.50	30	9.02	6.57	28	8.49	5.33
	Post	31	10.95	8.87	30	10.29	7.13	28	11.33	8.47
FM	Pre	31	4.11	4.53	30	7.63	6.36	28	7.36	5.60
	Post	31	8.61	6.98	30	9.65	7.95	28	7.85	5.40
CL	Pre	31	6.23	5.56	30	10.10	8.72	28	8.67	6.82

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		MCST			CST			Control	
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	31	10.24	8.20	30	10.30	7.22	28	9.93	7.84
CM	Pre	31	4.30	5.35	30	7.09	7.83	28	6.10	6.32
	Post	31	6.81	6.99	30	7.71	7.17	28	7.13	6.67
PL	Pre	31	3.77	3.74	30	6.62	8.44	28	4.87	4.86
	Post	31	7.46	7.95	30	5.92	5.12	28	6.40	6.68
PM	Pre	31	2.56	3.01	30	5.20	7.83	28	3.49	4.27
	Post	31	5.46	7.69	30	4.57	5.38	28	4.66	5.97
OL	Pre	31	2.07	2.64	30	4.91	6.97	28	2.52	3.52
	Post	31	3.38	4.27	30	3.03	3.84	28	4.25	5.95
OM	Pre	31	1.76	2.60	30	4.46	6.74	28	2.96	4.47
	Post	31	3.02	3.78	30	2.91	4.16	28	4.28	5.93
LTL	Pre	31	6.76	5.30	30	10.17	7.19	28	9.06	6.26
	Post	31	11.29	9.56	30	10.25	9.65	28	9.68	6.92
RTL	Pre	31	6.18	4.88	30	10.16	9.47	28	8.33	5.88
	Post	31	9.71	8.96	30	8.78	7.56	28	9.77	8.41
LTPJ	Pre	31	5.16	6.09	30	8.74	8.78	28	7.35	6.76
	Post	31	9.52	9.33	30	8.09	8.25	28	8.20	6.85
RTPJ	Pre	31	4.21	4.87	30	8.45	10.06	28	4.43	5.14
	Post	31	7.55	8.68	30	6.33	6.45	28	7.05	8.30

Analysis of assumptions

In the non-verbal paired associates learning task, within the delta band, normality assumptions were generally violated (W range = 0.74 - 0.94, all $p < .01$). Homoscedasticity was mostly observed (K-squared range = 0.07 - 2.60, all $p > .05$), except for PM. Parallelism was generally met (F range = 0.08 - 4.19, all $p > .05$), except for PM and RTPJ.

For the theta band, normality assumptions were frequently violated (W range = 0.83 - 0.97, all $p < .05$), except for OL. Homoscedasticity was generally observed (K-squared range = 0.03 - 6.92, all $p > .05$), except for OL and

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OM. Parallelism was generally upheld (F range = 0.03 - 9.34, all p > .05), except for RTL and RTPJ.

In the lower alpha band, , normality assumptions were frequently violated (W range = 0.60 - 0.90, all p < .01), except for OL. Homoscedasticity was generally observed (K-squared range = 0.11 - 34.78, all p > .05), except for RTL. Parallelism was generally met (F range = 0.11 - 4.74, all p > .05), except for RTL and RTPJ.

Within the upper alpha band, normality assumptions were commonly violated (W range = 0.63 - 0.89, all p < .01), except for OL. Homoscedasticity was mostly observed (K-squared range = 0.03 - 6.86, all p > .05), except for OL and OM. Parallelism was generally supported (F range = 0.01 - 5.05, all p > .05), except for OL, OM, RTL, and RTPJ.

For the full alpha band, normality assumptions were frequently violated (W range = 0.62 - 0.90, all p < .01), except for OL. Homoscedasticity was generally supported (K-squared range = 0.08 - 17.65, all p > .05), except for RTL. Parallelism was generally met (F range = 0.01 - 5.80, all p > .05), except for RTL and RTPJ.

Lastly, in the beta band, normality assumptions were frequently violated (W range = 0.68 - 0.90, all p < .01), except for OL. Homoscedasticity was mostly observed (K-squared range = 0.15 - 6.58, all p > .05), except for OL. Parallelism was generally supported (F range = 0.27 - 5.80, all p > .05), except for OL.

Analysis of group comparisons

This section presents the results of ANCOVA for various parameters during the non-verbal paired associates learning task. However, The results of the ANCOVA could not be interpreted due to violations of the regression slope homogeneity assumption. Therefore, separate regression analyses for each group are presented in the following section for the affected ROIs: Delta (LTPJ, PM), Theta (FL, LTL, LTPJ, OL, OM), Lower alpha (CM), Alpha Upper (CM, LTPJ, PM), Full alpha (CM, PM), and Beta (PM). The following are the ANCOVA results for ROIs that met the assumption.

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Overall, all of relative bands no significant group effects were observed across any brain regions in the non-verbal paired associates learning condition. Please see Table 37 and Figure 42, for more information. The analysis of the delta band across different regions showed no significant effects of the group condition. For instance, in the frontal lobe (FL), the group effect was not significant, with a small effect size *(F(*2, 85*)* = 0.55, *p* = .58, partial $\omega^2 < .01$). Similar non-significant effects with small effect sizes were observed in the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), and right temporal-parietal junction (RTPJ) (all $p > .05$). Consequently, no post-hoc analyses were necessary for the delta band.

In the theta band, no significant group effects were found in any regions. For example, the frontal midline (FM) showed a non-significant group effect with a small effect size *(F(*2, 85*)* = 0.51, *p* = .60, partial $\omega^2 < .01$). Similar non-significant effects with small effect sizes were observed in the central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), right temporal lobe (RTL), and right temporal-parietal junction (RTPJ) (all $p > .05$). Therefore, no post-hoc analyses were conducted.

In the lower alpha band, no significant group effects were observed. For instance, the frontal lobe (FL) exhibited a non-significant group effect with a small effect size *(F(*2, 85*)* = 0.17, *p* = .85, partial $\omega^2 < .01$). Similar results were seen in the frontal midline (FM), central lobe (CL), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all $p > .05$). No post-hoc analyses were needed due to the lack of significant main effects.

The upper alpha band analysis indicated no significant group effects across all regions. For example, the frontal lobe (FL) showed a non-significant group effect with a small effect size *(F(*2, 85*)* = 0.25, *p* = .78, partial $\omega^2 < .01$). Similar non-significant effects with small effect sizes in the full alpha band anlysis were found in the frontal midline (FM), central lobe (CL), parietal lobe (PL), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe

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(RTL), and right temporal-parietal junction (RTPJ) (all p > .05). No post-hoc analyses were required.

In the beta band, no significant group effects were observed across any regions. The frontal lobe (FL) showed a non-significant group effect with a small effect size *(F(*2, 85*)* = 0.82, *p* = .44, partial ω² < .01). Similar results were observed in the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all p > .05). Thus, no post-hoc analyses were performed for the beta band.

Overall, the ANCOVA results for the non-verbal paired associates learning task indicated no significant effects of group conditions across the delta, theta, lower alpha, upper alpha, and beta bands in various regions of interest. The effect sizes were generally small, indicating minimal influence of the group variable on EEG spectral power in these bands. Consequently, no post-hoc analyses were necessary due to the lack of significant group effects.

Table 37 ANCOVA of the non-verbal paired associates learning task

		df	*SS*	*MS*	*F*	*p*	ω_p^2
Delta							
FL	Pre-test	1	0.251	0.251	34.34	<.01	0.27
	Group	2	0.008	0.004	0.55	.58	<.01
	Residuals	85	0.622	0.007			
FM	Pre-test	1	0.082	0.082	5.19	.03	0.04
	Group	2	0.020	0.010	0.63	.53	<.01
	Residuals	85	1.351	0.016			
CL	Pre-test	1	0.240	0.240	16.57	<.01	0.15
	Group	2	0.008	0.004	0.27	.76	<.01
	Residuals	85	1.232	0.014			
CM	Pre-test	1	0.181	0.181	10.12	<.01	0.09
	Group	2	0.006	0.003	0.16	.85	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	85	1.520	0.018			
PL	Pre-test	1	0.179	0.179	12.13	<.01	0.11
	Group	2	0.019	0.010	0.65	.53	<.01
	Residuals	85	1.251	0.015			
PM*	Pre-test	1	0.204	0.204	11.59	<.01	0.11
	Group	2	0.011	0.006	0.32	.73	<.01
	Residuals	85	1.499	0.018			
OL	Pre-test	1	0.204	0.204	25.42	<.01	0.22
	Group	2	0.019	0.009	1.15	.32	<.01
	Residuals	85	0.683	0.008			
OM	Pre-test	1	0.228	0.228	27.12	<.01	0.23
	Group	2	0.013	0.006	0.76	.47	<.01
	Residuals	85	0.715	0.008			
LTL	Pre-test	1	0.311	0.311	30.75	<.01	0.25
	Group	2	0.048	0.024	2.35	.10	0.03
	Residuals	85	0.860	0.010			
RTL	Pre-test	1	0.360	0.360	36.93	<.01	0.29
	Group	2	0.049	0.025	2.53	.09	0.03
	Residuals	85	0.829	0.010			
LTPJ	Pre-test	1	0.138	0.138	7.42	<.01	0.07
*	Group	2	0.027	0.013	0.72	.49	<.01
	Residuals	85	1.580	0.019			
RTPJ	Pre-test	1	0.253	0.253	13.43	<.01	0.12
	Group	2	0.053	0.026	1.40	.25	0.01
	Residuals	85	1.601	0.019			
Theta							
FL*	Pre-test	1	0.002	0.002	3.39	.07	0.03
	Group	2	0.001	<.001	0.80	.45	<.01
	Residuals	85	0.046	0.001			
FM	Pre-test	1	0.004	0.004	2.65	.11	0.02

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	0.001	0.001	0.51	.60	<.01
	Residuals	85	0.123	0.001			
CL	Pre-test	1	0.003	0.003	4.18	.04	0.03
	Group	2	0.001	0.001	0.76	.47	<.01
	Residuals	85	0.059	0.001			
CM	Pre-test	1	0.004	0.004	3.03	.09	0.02
	Group	2	0.002	0.001	0.60	.55	<.01
	Residuals	85	0.118	0.001			
PL	Pre-test	1	0.006	0.006	5.99	.02	0.05
	Group	2	<.001	<.001	0.09	.92	<.01
	Residuals	85	0.082	0.001			
PM	Pre-test	1	0.026	0.026	15.04	<.01	0.14
	Group	2	<.001	<.001	0.07	.93	<.01
	Residuals	85	0.149	0.002			
OL*	Pre-test	1	0.010	0.010	10.75	<.01	0.10
	Group	2	<.001	<.001	0.17	.84	<.01
	Residuals	85	0.081	0.001			
OM*	Pre-test	1	0.011	0.011	8.68	<.01	0.08
	Group	2	0.001	<.001	0.35	.71	<.01
	Residuals	85	0.106	0.001			
LTL*	Pre-test	1	0.001	0.001	1.98	.16	0.01
	Group	2	0.001	<.001	0.77	.47	<.01
	Residuals	85	0.043	0.001			
RTL	Pre-test	1	0.005	0.005	12.56	<.01	0.11
	Group	2	0.001	<.001	1.15	.32	<.01
	Residuals	85	0.034	<.001			
LTPJ	Pre-test	1	<.001	<.001	0.19	.66	<.01
*	Group	2	<.001	<.001	0.06	.94	<.01
	Residuals	85	0.089	0.001			
RTPJ	Pre-test	1	0.008	0.008	6.78	.01	0.06

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	0.002	0.001	1.03	.36	<.01
	Residuals	85	0.097	0.001			
Lower Alpha							
FL	Pre-test	1	0.002	0.002	26.49	<.01	0.22
	Group	2	<.001	<.001	0.17	.85	<.01
	Residuals	85	0.007	<.001			
FM	Pre-test	1	0.004	0.004	10.35	<.01	0.10
	Group	2	0.001	<.001	0.87	.42	<.01
	Residuals	85	0.032	<.001			
CL	Pre-test	1	0.005	0.005	17.95	<.01	0.16
	Group	2	<.001	<.001	0.18	.83	<.01
	Residuals	85	0.025	<.001			
CM*	Pre-test	1	0.004	0.004	9.38	<.01	0.09
	Group	2	<.001	<.001	0.31	.73	<.01
	Residuals	85	0.035	<.001			
PL	Pre-test	1	0.004	0.004	13.17	<.01	0.12
	Group	2	<.001	<.001	0.28	.75	<.01
	Residuals	85	0.029	<.001			
PM	Pre-test	1	0.003	0.003	7.19	<.01	0.07
	Group	2	<.001	<.001	0.27	.76	<.01
	Residuals	85	0.033	<.001			
OL	Pre-test	1	0.005	0.005	34.71	<.01	0.27
	Group	2	<.001	<.001	0.53	.59	<.01
	Residuals	85	0.013	<.001			
OM	Pre-test	1	0.006	0.006	41.98	<.01	0.32
	Group	2	<.001	<.001	0.51	.60	<.01
	Residuals	85	0.012	<.001			
LTL	Pre-test	1	0.004	0.004	23.02	<.01	0.20
	Group	2	<.001	<.001	0.80	.45	<.01
	Residuals	85	0.016	<.001			

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
RTL	Pre-test	1	0.005	0.005	27.60	<.01	0.23
	Group	2	0.001	<.001	1.65	.20	0.01
	Residuals	85	0.015	<.001			
LTPJ	Pre-test	1	0.002	0.002	6.17	.01	0.05
	Group	2	<.001	<.001	0.39	.68	<.01
	Residuals	85	0.034	<.001			
RTPJ	Pre-test	1	0.007	0.007	16.17	<.01	0.15
	Group	2	0.001	<.001	0.84	.43	<.01
	Residuals	85	0.039	<.001			
Upper Alpha							
FL	Pre-test	1	0.004	0.004	38.64	<.01	0.30
	Group	2	<.001	<.001	0.25	.78	<.01
	Residuals	85	0.010	<.001			
FM	Pre-test	1	0.002	0.002	6.62	.01	0.06
	Group	2	<.001	<.001	0.32	.73	<.01
	Residuals	85	0.029	<.001			
CL	Pre-test	1	0.010	0.010	27.72	<.01	0.23
	Group	2	<.001	<.001	0.09	.91	<.01
	Residuals	85	0.030	<.001			
CM*	Pre-test	1	0.005	0.005	11.04	<.01	0.10
	Group	2	<.001	<.001	0.05	.95	<.01
	Residuals	85	0.038	<.001			
PL	Pre-test	1	0.005	0.005	11.23	<.01	0.10
	Group	2	<.001	<.001	0.34	.71	<.01
	Residuals	85	0.037	<.001			
PM*	Pre-test	1	0.005	0.005	11.21	<.01	0.10
	Group	2	<.001	<.001	0.22	.80	<.01
	Residuals	85	0.039	<.001			
OL	Pre-test	1	0.005	0.005	30.54	<.01	0.25
	Group	2	<.001	<.001	0.86	.43	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	85	0.015	<.001			
OM	Pre-test	1	0.005	0.005	35.71	<.01	0.28
	Group	2	<.001	<.001	0.85	.43	<.01
	Residuals	85	0.013	<.001			
LTL	Pre-test	1	0.008	0.008	42.47	<.01	0.32
	Group	2	0.001	<.001	1.90	.16	<.01
	Residuals	85	0.016	<.001			
RTL	Pre-test	1	0.008	0.008	40.93	<.01	0.31
	Group	2	0.001	0.001	3.01	.05	0.04
	Residuals	85	0.016	<.001			
LTPJ	Pre-test	1	0.005	0.005	9.17	<.01	0.08
*	Group	2	0.001	<.001	0.56	.57	<.01
	Residuals	85	0.045	0.001			
RTPJ	Pre-test	1	0.009	0.009	17.54	<.01	0.16
	Group	2	0.001	0.001	1.25	.29	0.01
	Residuals	85	0.045	0.001			
Full Alpha							
FL	Pre-test	1	0.012	0.012	32.92	<.01	0.26
	Group	2	<.001	<.001	0.18	.83	<.01
	Residuals	85	0.031	<.001			
FM	Pre-test	1	0.011	0.011	7.99	<.01	0.07
	Group	2	0.002	0.001	0.63	.54	<.01
	Residuals	85	0.112	0.001			
CL	Pre-test	1	0.027	0.027	22.92	<.01	0.20
	Group	2	<.001	<.001	0.07	.93	<.01
	Residuals	85	0.101	0.001			
CM*	Pre-test	1	0.016	0.016	10.31	<.01	0.09
	Group	2	<.001	<.001	0.16	.86	<.01
	Residuals	85	0.136	0.002			
PL	Pre-test	1	0.018	0.018	11.70	<.01	0.11

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	0.001	<.001	0.27	.77	<.01
	Residuals	85	0.127	0.001			
PM*	Pre-test	1	0.015	0.015	9.32	<.01	0.09
	Group	2	<.001	<.001	0.09	.91	<.01
	Residuals	85	0.138	0.002			
OL	Pre-test	1	0.021	0.021	32.21	<.01	0.26
	Group	2	0.001	<.001	0.70	.50	<.01
	Residuals	85	0.055	0.001			
OM	Pre-test	1	0.022	0.022	38.89	<.01	0.30
	Group	2	0.001	<.001	0.65	.53	<.01
	Residuals	85	0.049	0.001			
LTL	Pre-test	1	0.023	0.023	33.26	<.01	0.27
	Group	2	0.002	0.001	1.40	.25	0.01
	Residuals	85	0.059	0.001			
RTL	Pre-test	1	0.024	0.024	34.59	<.01	0.27
	Group	2	0.003	0.002	2.37	.10	0.03
	Residuals	85	0.058	0.001			
LTPJ	Pre-test	1	0.013	0.013	7.49	<.01	0.07
	Group	2	0.002	0.001	0.48	.62	<.01
	Residuals	85	0.152	0.002			
RTPJ	Pre-test	1	0.032	0.032	16.49	<.01	0.15
	Group	2	0.004	0.002	1.02	.36	<.01
	Residuals	85	0.162	0.002			
Beta							
FL	Pre-test	1	0.151	0.151	30.65	<.01	0.25
	Group	2	0.008	0.004	0.82	.44	<.01
	Residuals	85	0.419	0.005			
FM	Pre-test	1	0.032	0.032	7.19	<.01	0.06
	Group	2	0.006	0.003	0.70	.50	<.01
	Residuals	85	0.375	0.004			

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
CL	Pre-test	1	0.093	0.093	18.76	<.01	0.17
	Group	2	0.005	0.003	0.52	.60	<.01
	Residuals	85	0.421	0.005			
CM	Pre-test	1	0.060	0.060	14.31	<.01	0.13
	Group	2	<.001	<.001	0.03	.97	<.01
	Residuals	85	0.357	0.004			
PL	Pre-test	1	0.052	0.052	13.44	<.01	0.12
	Group	2	0.011	0.006	1.49	.23	0.01
	Residuals	85	0.327	0.004			
PM*	Pre-test	1	0.036	0.036	9.77	<.01	0.09
	Group	2	0.006	0.003	0.76	.47	<.01
	Residuals	85	0.317	0.004			
OL	Pre-test	1	0.040	0.040	23.40	<.01	0.20
	Group	2	0.008	0.004	2.44	.09	0.03
	Residuals	85	0.147	0.002			
OM	Pre-test	1	0.045	0.045	27.57	<.01	0.23
	Group	2	0.007	0.003	1.99	.14	0.02
	Residuals	85	0.140	0.002			
LTL	Pre-test	1	0.210	0.210	40.36	<.01	0.31
	Group	2	0.026	0.013	2.54	.08	0.03
	Residuals	85	0.441	0.005			
RTL	Pre-test	1	0.184	0.184	39.53	<.01	0.30
	Group	2	0.020	0.010	2.12	.13	0.02
	Residuals	85	0.396	0.005			
LTPJ	Pre-test	1	0.077	0.077	13.14	<.01	0.12
	Group	2	0.014	0.007	1.22	.30	<.01
	Residuals	85	0.498	0.006			
RTPJ	Pre-test	1	0.072	0.072	13.73	<.01	0.13
	Group	2	0.015	0.008	1.43	.25	0.01
	Residuals	85	0.448	0.005			

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*A significant interaction effect

Analysis of regression

The following analysis focuses on the relationships between pre-test and post-test relative powers for specific frequency bands (delta**,** theta**,** lower alpha**,** upper alpha**,** full alpha, and beta) in different brain regions for the three groups, including MCST, CST, and control (see Table 38).

For the relative delta, in the PM region, the MCST group demonstrates no significant predictive relationship between pre-test and post-test values ($\beta_1 = 0.18$, $p = .62$, adjusted $R^2 = -.03$), suggesting minimal explanatory power. The CST group, however, exhibits a moderate predictive relationship ($\beta_1 = 0.30$, $p = .05$, adjusted $R^2 = .10$), with pre-test scores accounting for 10% of the variance in post-test values. The control group shows a much stronger relationship ($\beta_1 = 1.17$, $p < .001$, adjusted $R^2 = .54$), indicating a substantial natural association between pre-test and post-test values in this region. In the LTPJ region, the MCST group exhibits a significant predictive relationship ($\beta_1 = 0.77$, $p = .01$, adjusted $R^2 = .20$), suggesting moderate explanatory power. Similarly, the CST group demonstrates a strong predictive relationship ($\beta_1 = 0.38$, $p = .01$, adjusted $R^2 = .21$), with pre-test scores explaining 21% of the post-test variance. However, the control group shows no significant relationship ($\beta_1 = -0.05$, $p = .78$, adjusted $R^2 = -.04$), indicating no predictive power.

For the relative theta, in the OL region, the MCST group demonstrates a moderate and significant relationship ($\beta_1 = 0.46$, $p = .01$, adjusted $R^2 = .17$), while the CST group exhibits a stronger relationship ($\beta_1 = 0.61$, $p < .001$, adjusted $R^2 = .39$). The control group shows no significant predictive power ($\beta_1 = -0.03$, $p = .81$, adjusted $R^2 = -.04$) (see Figure 41). In the OM region, the MCST group shows no significant relationship ($\beta_1 = 0.22$, $p = .23$, adjusted $R^2 = .02$), while the CST group exhibits a strong predictive relationship ($\beta_1 = 0.67$, $p < .001$, adjusted $R^2 = .37$), with pre-test values explaining 37% of the post-test variance. The control group demonstrates no significant relationship ($\beta_1 = 0.06$, $p = .58$, adjusted $R^2 = -.03$). In the LTPJ region, the MCST group shows a weak and non-significant relationship ($\beta_1 = 0.45$, $p = .07$, adjusted $R^2 = .08$), while the CST group

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demonstrates a strong and significant predictive relationship (β_1 = 0.53, p < .001, adjusted R^2 = .46), indicating pre-test values strongly predict post-test outcomes. The control group exhibits no significant relationship (β_1 = −0.15, p = .09, adjusted R^2 = .07).

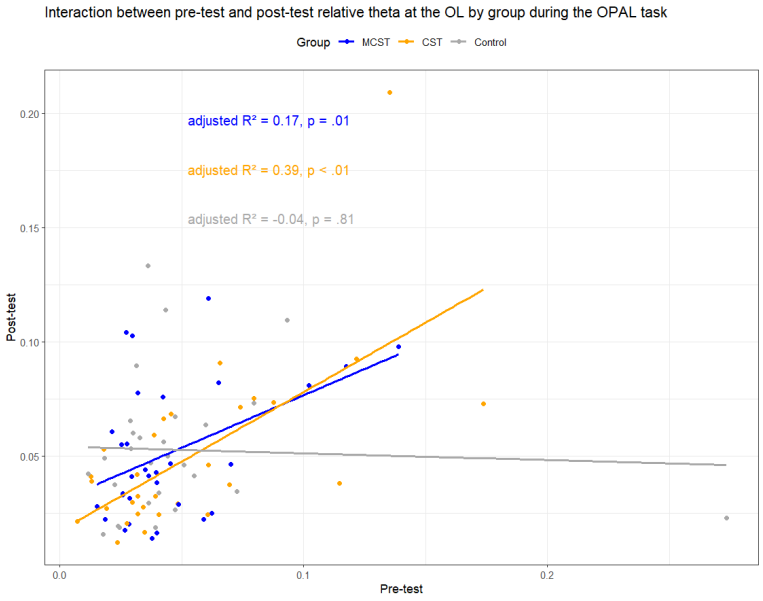

Figure 41 A scatter plot and the regression lines are shows interaction between pre-test and post-test relative theta at the occipital lobe (OL) by group during the OPAL task.

For the lower alpha, in the CM region, the MCST group fails to show any significant relationship (β_1 = 0.04, p = .90, adjusted R^2 = −.03), while the CST group demonstrates a strong and significant relationship (β_1 = 0.69, p < .001, adjusted R^2 = .29), with pre-test values explaining 29% of the variance in post-test scores. The control group similarly fails to show a significant relationship (β_1 = −0.02, p = .95, adjusted R^2 = −.04).

For the relative upper alpha, In the PM region, the MCST group demonstrates no significant relationship (β_1 = 0.29, p = .52, adjusted R^2 = −.02), while the CST group exhibits a marginally significant relationship (β_1 = 0.28, p = .04, adjusted R^2 = .11). The control group demonstrates the strongest predictive relationship (β_1 = 1.44, p < .001, adjusted R^2 = .62), highlighting a substantial natural association between pre-test and post-test values. In the LTPJ region, the MCST

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group shows a strong and significant relationship (β_1 = 1.07, p < .001, adjusted R^2 = .24), indicating moderate predictive power. The CST group also exhibits a significant relationship (β_1 = 0.31, p = .02, adjusted R^2 = .16), while the control group shows no significant relationship (β_1 = 0.10, p = .69, adjusted R^2 = −.03).

For the relative full alpha, in the CM region, the MCST group fails to show significance (β_1 = 0.06, p = .84, adjusted R^2 = −.03), while the CST group demonstrates a strong and significant relationship (β_1 = 0.72, p < .001, adjusted R^2 = .42). The control group again fails to show a significant relationship (β_1 = 0.01, p = .97, adjusted R^2 = −.04). In the PM region, the MCST group fails to show a significant relationship (β_1 = 0.23, p = .49, adjusted R^2 = −.02), while the CST group exhibits a marginal relationship (β_1 = 0.28, p = .11, adjusted R^2 = .06). The control group demonstrates the strongest relationship (β_1 = 1.29, p < .001, adjusted R^2 = .55), indicating substantial predictive power.

For the relative beta, in the PM region, the MCST group shows no significant relationship (β_1 = −0.01, p = .99, adjusted R^2 = −.03), while the CST group exhibits a marginal relationship (β_1 = 0.24, p = .05, adjusted R^2 = .10). The control group demonstrates a strong and significant relationship (β_1 = 1.18, p < .001, adjusted R^2 = .70), indicating robust natural predictive power.

In summary, the CST group consistently demonstrates moderate to strong predictive relationships across most and regions, with notable effectiveness in regions such as LTPJ in the Theta and Upper alpha bands. The MCST group shows limited predictive power, with significant relationships only in a few regions, such as the LTPJ region in the Delta and Upper alpha bands. The control group often demonstrates the strongest predictive relationships, particularly in the PM region across the Upper alpha, Full Alpha, and Beta bands, suggesting natural associations rather than intervention effects. These findings indicate that CST is moderately effective in enhancing predictive relationships, while MCST shows limited efficacy in this context.

Table 38 Regression analysis of the non-verbal paired associates learning task

ROI	Model	Variable	β	*SE*	*t*	*p*

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ROI	Model	Variable	*β*	*SE*	*t*	*p*
Delta						
PM	MCST	Constant	0.68	0.33	2.05	.05
		Pre-test	0.18	0.37	0.50	.62
	CST	Constant	0.59	0.13	4.68	<.01
		Pre-test	0.30	0.15	2.08	.05
	Control	Constant	-0.17	0.18	-0.95	.35
		Pre-test	1.17	0.21	5.68	<.01
LTPJ	MCST	Constant	0.12	0.23	0.52	.60
		Pre-test	0.77	0.26	2.92	.01
	CST	Constant	0.49	0.11	4.67	<.01
		Pre-test	0.38	0.13	2.98	.01
	Control	Constant	0.84	0.14	5.95	<.01
		Pre-test	-0.05	0.17	-0.28	.78
Theta						
FL	MCST	Constant	0.09	0.01	6.26	<.01
		Pre-test	0.11	0.15	0.78	.44
	CST	Constant	0.05	0.01	3.85	<.01
		Pre-test	0.50	0.15	3.25	<.01
	Control	Constant	0.11	0.02	5.49	<.01
		Pre-test	-0.22	0.22	-1.02	.32
OL	MCST	Constant	0.03	0.01	3.35	<.01
		Pre-test	0.46	0.17	2.67	.01
	CST	Constant	0.02	0.01	1.89	.07
		Pre-test	0.61	0.14	4.40	<.01
	Control	Constant	0.05	0.01	6.55	<.01
		Pre-test	-0.03	0.12	-0.24	.81
OM	MCST	Constant	0.05	0.01	4.80	<.01
		Pre-test	0.22	0.18	1.23	.23
	CST	Constant	0.02	0.01	1.54	.14
		Pre-test	0.67	0.16	4.27	<.01
	Control	Constant	0.05	0.01	5.82	<.01
		Pre-test	0.06	0.10	0.56	.58
LTL	MCST	Constant	0.07	0.01	5.92	<.01
		Pre-test	0.17	0.17	1.01	.32
	CST	Constant	0.04	0.01	3.70	<.01
		Pre-test	0.55	0.14	3.88	<.01
	Control	Constant	0.09	0.01	7.39	<.01
		Pre-test	-0.12	0.14	-0.87	.39
LTPJ	MCST	Constant	0.05	0.02	3.19	<.01
		Pre-test	0.45	0.23	1.91	.07
	CST	Constant	0.04	0.01	5.15	<.01
		Pre-test	0.53	0.10	5.07	<.01

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ROI	Model	Variable	β	*SE*	*t*	*p*
	Control	Constant	0.09	0.01	9.16	<.01
		Pre-test	-0.15	0.09	-1.74	.09
Lower Alpha						
FL	MCST	Constant	0.02	0.01	3.95	<.01
		Pre-test	0.04	0.28	0.13	.90
	CST	Constant	0.01	0.01	2.32	.03
		Pre-test	0.69	0.19	3.57	<.01
	Control	Constant	0.02	0.01	3.91	<.01
		Pre-test	-0.02	0.27	-0.06	.95
Upper Alpha						
CM	MCST	Constant	0.02	0.01	3.34	<.01
		Pre-test	0.09	0.32	0.28	.78
	CST	Constant	0.01	0.00	2.94	.01
		Pre-test	0.72	0.12	6.07	<.01
	Control	Constant	0.02	0.01	3.65	<.01
		Pre-test	0.05	0.25	0.21	.83
PM	MCST	Constant	0.02	0.01	2.48	.02
		Pre-test	0.29	0.45	0.64	.52
	CST	Constant	0.01	0.00	2.91	.01
		Pre-test	0.28	0.13	2.11	.04
	Control	Constant	0.00	0.00	-0.37	.71
		Pre-test	1.44	0.22	6.65	<.01
LTPJ	MCST	Constant	0.01	0.01	1.62	.12
		Pre-test	1.07	0.33	3.25	<.01
	CST	Constant	0.02	0.00	3.31	<.01
		Pre-test	0.31	0.12	2.56	.02
	Control	Constant	0.02	0.01	3.31	<.01
		Pre-test	0.10	0.24	0.41	.69
Full Alpha						
CM	MCST	Constant	0.04	0.01	3.69	<.01
		Pre-test	0.06	0.30	0.20	.84
	CST	Constant	0.02	0.01	2.57	.02
		Pre-test	0.72	0.15	4.66	<.01
	Control	Constant	0.04	0.01	3.96	<.01
		Pre-test	0.01	0.25	0.04	.97
PM	MCST	Constant	0.03	0.01	2.95	.01
		Pre-test	0.23	0.33	0.71	.49
	CST	Constant	0.03	0.01	2.73	.01
		Pre-test	0.28	0.17	1.65	.11
	Control	Constant	0.00	0.01	-0.04	.97
		Pre-test	1.29	0.22	5.80	<.01
Beta						

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ROI	Model	Variable	β	*SE*	*t*	*p*
PM	MCST	Constant	0.05	0.02	2.95	.01
		Pre-test	-0.01	0.47	-0.01	.99
	CST	Constant	0.03	0.01	2.92	.01
		Pre-test	0.24	0.12	2.02	.05
	Control	Constant	0.01	0.01	0.68	.51
		Pre-test	1.18	0.15	8.07	<.01

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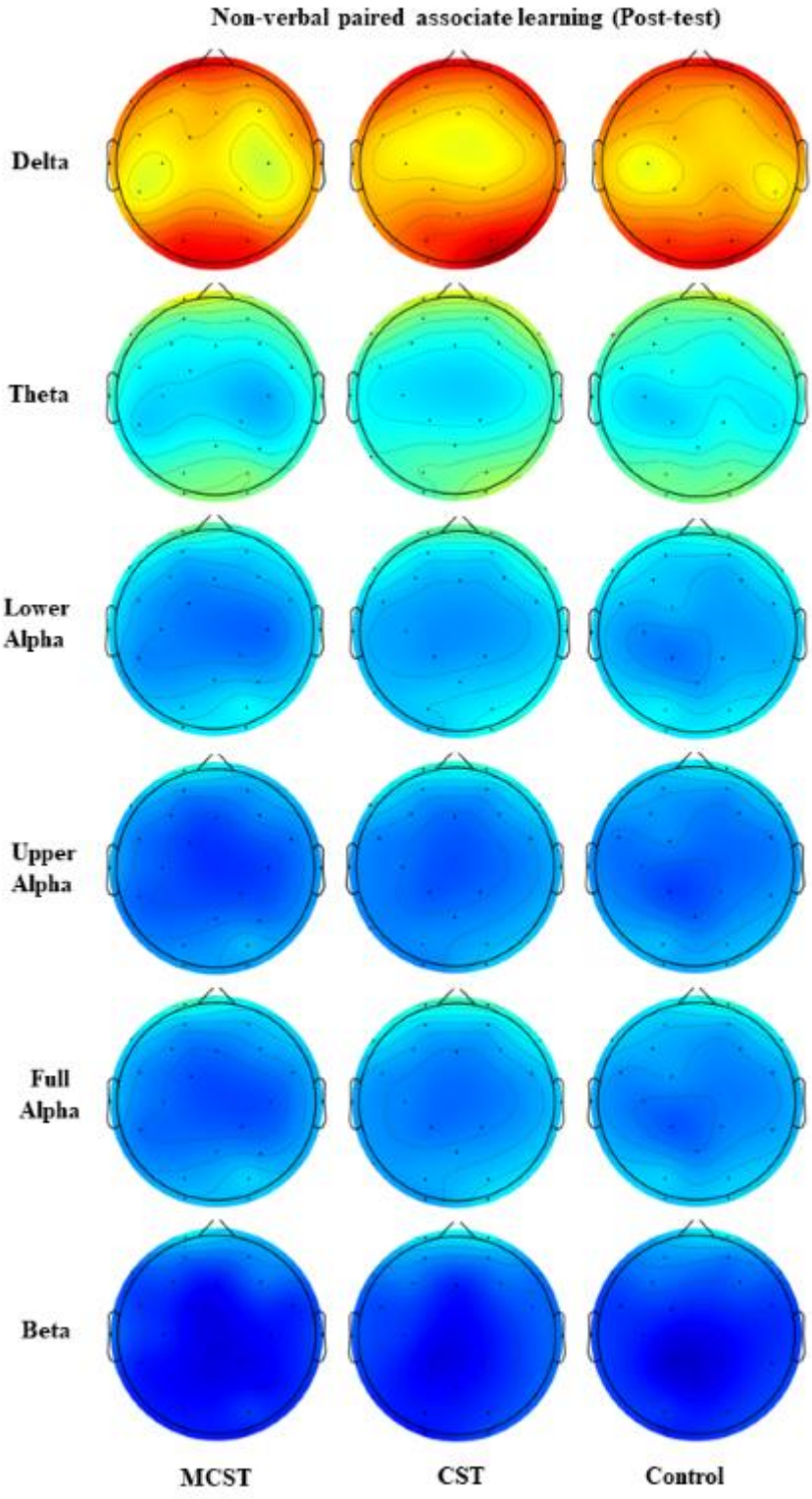

Figure 42 The topographic brain mapping of relative power during the non-verbal paired associates learning task at post-test

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EEG - Verbal fluency task

Analysis of the relative power characteristics

In the delta band frequency, there were notable changes observed across various brain regions. Pre-test values for all regions ranged from approximately 77% to 92%. Post-test values generally showed a decrease in spectral power, ranging from approximately 71% to 88%. Specifically, the central midline (CM) and occipital midline (OM) regions showed the least change, with decreases of approximately 1-3%, while the frontal lobe (FL) and frontal midline (FM) regions exhibited decreases of around 4-10%.

Theta band frequency also displayed changes across brain regions. Pre-test values ranged from about 4% to 9%, with post-test values showing slight fluctuations. Overall, there were minor increases or decreases in spectral power, typically within a range of 1-2%.

Lower alpha band frequency exhibited variability across regions. Pre-test values ranged from approximately 1% to 3%, with post-test values generally showing increases of around 1-2% in most regions. Notably, the occipital midline (OL) region displayed a decrease of approximately 1% in spectral power.

Similar to lower alpha, upper alpha band frequency showed increases in spectral power across most regions, ranging from approximately 1-3%. However, the occipital midline (OL) region displayed a slight decrease of around 0.5% in spectral power.

Full alpha band frequency demonstrated consistent increases in spectral power across most regions, ranging from approximately 1-3%. The occipital midline (OL) region again exhibited a slight decrease of around 0.5% in spectral power.

In the beta band frequency, there were noticeable changes observed across various brain regions. Pre-test values ranged from approximately 4% to 14%, with post-test values generally showing increases in spectral power, ranging from approximately 6% to 15%. The largest increases were observed in the frontal lobe (FL) and central lobe (CL) regions, with changes of approximately 2-6%.

Overall, the analysis reveals dynamic changes in spectral power across different frequency bands and brain regions during the verbal fluency learning

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task. These changes suggest varying levels of neural activity and engagement across different cognitive processes associated with verbal fluency learning.

Table 39 Characteristic of relative spectral power (%) of band frequencies in the verbal fluency learning task

		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Delta										
FL	Pre	31	81.66	8.13	31	79.36	10.00	21	83.64	5.09
	Post	31	77.33	11.93	31	73.51	12.48	21	81.88	7.19
FM	Pre	31	87.69	8.13	31	80.60	13.42	21	84.51	7.95
	Post	31	77.59	14.85	31	70.42	16.13	21	83.05	8.21
CL	Pre	31	85.34	9.80	31	77.95	15.34	21	84.59	5.73
	Post	31	76.97	13.04	31	70.11	18.23	21	83.28	7.22
CM	Pre	31	87.37	10.63	31	83.56	14.08	21	87.33	5.78
	Post	31	81.86	14.43	31	72.62	19.52	21	86.83	7.16
PL	Pre	31	86.98	10.47	31	83.60	14.34	21	88.10	4.97
	Post	31	82.61	13.80	31	75.92	17.69	21	87.44	6.29
PM	Pre	31	89.44	8.93	31	85.84	15.42	21	90.46	6.13
	Post	31	86.34	13.28	31	79.62	18.46	21	88.83	8.76
OL	Pre	31	90.19	8.48	31	86.35	13.72	21	92.50	4.08
	Post	31	87.87	13.57	31	86.24	13.16	21	91.50	5.24
OM	Pre	31	91.80	6.66	31	87.29	12.19	21	91.81	5.20
	Post	31	88.47	12.01	31	86.05	14.38	21	92.16	4.44
LTL	Pre	31	81.68	9.41	31	77.25	14.94	21	82.63	6.98
	Post	31	75.44	11.32	31	71.26	16.51	21	80.55	8.97
RTL	Pre	31	82.00	10.66	31	79.10	13.03	21	83.68	6.30
	Post	31	77.77	12.40	31	75.65	14.83	21	82.71	7.60
LTPJ	Pre	31	83.35	12.49	31	79.08	19.79	21	84.44	9.57
	Post	31	78.98	14.53	31	71.00	19.98	21	82.92	9.59
RTPJ	Pre	31	85.51	12.77	31	79.32	17.68	21	88.83	6.02

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	31	82.49	17.28	31	76.79	20.77	21	87.50	8.58
Theta										
FL	Pre	31	9.01	2.36	31	8.15	2.89	21	8.37	2.87
	Post	31	8.48	2.37	31	9.28	2.22	21	8.01	3.72
FM	Pre	31	5.75	2.75	31	7.33	4.17	21	6.95	2.96
	Post	31	8.31	4.86	31	10.30	3.86	21	7.78	3.91
CL	Pre	31	5.76	2.52	31	6.80	2.79	21	5.95	1.64
	Post	31	7.06	2.73	31	8.45	3.31	21	6.34	2.57
CM	Pre	31	5.72	3.32	31	5.93	3.69	21	5.69	2.12
	Post	31	6.32	3.62	31	8.65	3.69	21	5.79	3.34
PL	Pre	31	5.41	2.35	31	5.52	2.72	21	5.28	1.75
	Post	31	5.75	2.68	31	7.13	2.70	21	5.75	2.93
PM	Pre	31	5.19	2.74	31	5.39	3.58	21	4.68	2.55
	Post	31	5.41	3.38	31	6.71	3.79	21	5.68	4.63
OL	Pre	31	4.62	2.46	31	5.02	2.84	21	3.91	1.69
	Post	31	4.70	2.86	31	4.93	2.38	21	4.33	2.05
OM	Pre	31	4.27	2.57	31	4.98	2.85	21	4.25	2.03
	Post	31	4.89	2.88	31	5.00	2.61	21	3.88	1.50
LTL	Pre	31	6.98	2.41	31	6.62	2.03	21	6.61	2.00
	Post	31	7.43	1.82	31	8.10	1.91	21	7.13	2.90
RTL	Pre	31	6.49	2.14	31	6.56	1.73	21	6.13	1.42
	Post	31	6.92	2.01	31	7.22	2.11	21	6.29	2.21
LTPJ	Pre	31	6.26	2.96	31	5.66	2.96	21	6.15	2.79
	Post	31	6.61	2.90	31	7.58	2.14	21	6.69	3.28
RTPJ	Pre	31	5.62	2.55	31	6.12	2.91	21	4.71	1.81
	Post	31	5.71	3.10	31	6.11	2.80	21	4.95	2.72
Lower Alpha										
FL	Pre	31	1.53	1.02	31	1.89	1.04	21	1.47	0.63
	Post	31	2.06	1.34	31	2.58	1.52	21	1.77	1.07

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
FM	Pre	31	1.39	1.34	31	2.28	1.94	21	1.82	1.31
	Post	31	2.76	2.53	31	3.77	2.70	21	2.16	1.62
CL	Pre	31	1.56	1.43	31	2.40	1.85	21	1.54	0.60
	Post	31	2.63	2.16	31	3.57	3.00	21	2.06	1.60
CM	Pre	31	1.45	1.66	31	2.02	2.19	21	1.36	0.73
	Post	31	2.23	2.14	31	3.62	3.32	21	1.83	1.52
PL	Pre	31	1.49	1.84	31	2.02	2.27	21	1.35	0.77
	Post	31	2.07	1.88	31	3.15	2.77	21	1.52	1.09
PM	Pre	31	1.13	1.60	31	2.01	3.44	21	1.15	0.82
	Post	31	1.56	1.60	31	2.95	3.11	21	1.45	1.50
OL	Pre	31	1.09	1.05	31	1.64	2.18	21	0.74	0.36
	Post	31	1.43	2.05	31	1.59	1.74	21	0.95	0.66
OM	Pre	31	0.83	0.76	31	1.41	1.77	21	0.80	0.46
	Post	31	1.31	1.89	31	1.45	1.51	21	0.87	0.63
LTL	Pre	31	1.79	1.09	31	2.17	1.48	21	1.70	0.84
	Post	31	2.48	1.56	31	2.93	1.68	21	2.29	2.51
RTL	Pre	31	1.77	1.18	31	2.16	1.37	21	1.44	0.55
	Post	31	2.33	1.83	31	2.56	1.73	21	1.71	1.06
LTPJ	Pre	31	1.79	1.52	31	2.15	2.47	21	1.70	1.26
	Post	31	2.35	2.15	31	3.11	2.19	21	2.14	2.33
RTPJ	Pre	31	1.68	2.06	31	2.39	2.44	21	1.04	0.54
	Post	31	2.32	3.33	31	2.75	2.84	21	1.29	0.99
Upper Alpha										
FL	Pre	31	1.33	1.03	31	1.91	1.20	21	1.34	0.58
	Post	31	2.14	1.69	31	2.72	1.82	21	1.74	1.22
FM	Pre	31	1.10	0.84	31	2.16	1.69	21	1.68	1.02
	Post	31	2.48	2.33	31	3.51	2.59	21	1.98	1.73
CL	Pre	31	1.60	1.49	31	2.68	2.22	21	1.72	0.89
	Post	31	2.81	2.48	31	3.72	2.78	21	2.02	1.23

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
CM	Pre	31	1.43	1.68	31	1.94	1.80	21	1.49	0.94
	Post	31	2.30	2.70	31	3.50	3.20	21	1.71	1.51
PL	Pre	31	1.55	2.09	31	2.19	2.47	21	1.41	0.77
	Post	31	2.51	3.07	31	3.43	2.98	21	1.60	1.48
PM	Pre	31	1.07	1.53	31	1.92	2.92	21	1.20	0.94
	Post	31	1.93	2.67	31	2.90	3.09	21	1.36	1.51
OL	Pre	31	1.08	1.33	31	1.78	2.31	21	0.82	0.70
	Post	31	1.66	3.16	31	1.66	1.85	21	1.05	1.16
OM	Pre	31	0.81	1.09	31	1.51	1.90	21	0.91	0.80
	Post	31	1.44	2.72	31	1.54	1.79	21	0.91	0.88
LTL	Pre	31	1.78	1.11	31	2.48	1.97	21	1.85	1.11
	Post	31	2.67	1.79	31	3.25	2.21	21	2.06	1.34
RTL	Pre	31	1.81	1.36	31	2.32	1.57	21	1.59	0.83
	Post	31	2.49	2.05	31	2.75	1.95	21	1.81	1.33
LTPJ	Pre	31	1.90	2.05	31	2.71	3.30	21	1.92	1.55
	Post	31	2.72	2.84	31	3.92	3.18	21	2.11	1.77
RTPJ	Pre	31	1.75	2.27	31	2.69	2.90	21	1.12	0.81
	Post	31	2.44	3.51	31	3.14	3.27	21	1.50	1.70
Full Alpha										
FL	Pre	31	2.86	1.93	31	3.80	2.19	21	2.82	1.13
	Post	31	4.20	2.98	31	5.30	3.23	21	3.51	2.18
FM	Pre	31	2.49	1.92	31	4.44	3.50	21	3.49	2.23
	Post	31	5.24	4.69	31	7.28	4.96	21	4.14	3.21
CL	Pre	31	3.17	2.88	31	5.08	3.96	21	3.26	1.40
	Post	31	5.44	4.49	31	7.29	5.42	21	4.08	2.60
CM	Pre	31	2.88	3.27	31	3.97	3.83	21	2.85	1.61
	Post	31	4.53	4.70	31	7.13	6.01	21	3.55	2.81
PL	Pre	31	3.04	3.90	31	4.21	4.70	21	2.76	1.40
	Post	31	4.58	4.91	31	6.58	5.58	21	3.12	2.42

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
PM	Pre	31	2.20	3.12	31	3.93	6.33	21	2.35	1.68
	Post	31	3.49	4.19	31	5.85	6.11	21	2.81	2.80
OL	Pre	31	2.17	2.30	31	3.42	4.46	21	1.55	1.05
	Post	31	3.10	5.16	31	3.26	3.54	21	2.00	1.76
OM	Pre	31	1.64	1.81	31	2.92	3.64	21	1.71	1.24
	Post	31	2.75	4.56	31	3.00	3.28	21	1.78	1.44
LTL	Pre	31	3.57	2.11	31	4.65	3.41	21	3.55	1.90
	Post	31	5.15	3.28	31	6.18	3.74	21	4.35	3.58
RTL	Pre	31	3.58	2.46	31	4.48	2.89	21	3.04	1.34
	Post	31	4.82	3.80	31	5.31	3.51	21	3.52	2.21
LTPJ	Pre	31	3.69	3.47	31	4.86	5.71	21	3.61	2.69
	Post	31	5.07	4.92	31	7.03	5.25	21	4.25	3.81
RTPJ	Pre	31	3.42	4.24	31	5.08	5.20	21	2.16	1.31
	Post	31	4.76	6.77	31	5.90	5.89	21	2.79	2.57
Beta										
FL	Pre	31	6.47	6.48	31	8.69	7.21	21	5.17	3.09
	Post	31	10.00	9.41	31	11.92	9.61	21	6.60	4.69
FM	Pre	31	4.07	4.51	31	7.63	6.87	21	5.05	3.63
	Post	31	8.86	8.15	31	12.01	9.14	21	5.03	2.95
CL	Pre	31	5.73	5.53	31	10.17	9.70	21	6.20	3.67
	Post	31	10.53	7.37	31	14.15	11.21	21	6.30	3.10
CM	Pre	31	4.03	4.95	31	6.55	7.14	21	4.13	3.08
	Post	31	7.29	7.30	31	11.60	11.18	21	3.83	2.19
PL	Pre	31	4.57	5.50	31	6.67	7.71	21	3.86	2.98
	Post	31	7.06	7.44	31	10.37	10.63	21	3.68	2.50
PM	Pre	31	3.17	4.62	31	4.84	6.41	21	2.51	2.67
	Post	31	4.75	6.73	31	7.82	10.07	21	2.68	2.29
OL	Pre	31	3.02	4.56	31	5.21	6.82	21	2.04	2.38
	Post	31	4.33	6.52	31	5.57	8.45	21	2.18	2.06

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		MCST			CST			Control	
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
OM	Pre	31	2.30	3.27	31	4.82	6.31	21	2.24	2.84
	Post	31	3.89	5.85	31	5.96	10.20	21	2.18	1.99
LTL	Pre	31	7.77	6.44	31	11.48	11.11	21	7.21	4.01
	Post	31	11.98	7.68	31	14.45	12.93	21	7.97	4.86
RTL	Pre	31	7.93	7.37	31	9.86	9.58	21	7.15	4.20
	Post	31	10.49	7.91	31	11.82	11.33	21	7.49	5.05
LTPJ	Pre	31	6.71	7.46	31	10.41	12.47	21	5.79	5.21
	Post	31	9.34	8.00	31	14.39	14.33	21	6.15	4.62
RTPJ	Pre	31	5.45	7.27	31	9.47	10.75	21	4.30	3.93
	Post	31	7.05	9.02	31	11.21	13.99	21	4.76	5.23

Analysis of assumptions

In the delta band, normality assumptions were often violated (W range = 0.73 - 0.95, all p < .01), except for OL and OM. Homoscedasticity was generally observed (K-squared range = 6.86 - 24.25, all p < .05). Parallelism was generally met (F range = 0.09 - 2.41, all p > .05), except for PM, OL, and OM.

For the theta band, normality assumptions were frequently violated (W range = 0.84 - 0.98, all p < .05), except for PM and OL. Homoscedasticity was mostly observed (K-squared range = 0.08 - 25.53, all p > .05), except for RTL. Parallelism was generally upheld (F range = 0.08 - 3.18, all p > .05), except for RTL and RTPJ.

Within the lower alpha band, , normality assumptions were commonly violated (W range = 0.66 - 0.91, all *p* < .01), except for OL. Homoscedasticity was generally observed (K-squared range = 0.04 - 22.64, all p > .05), except for RTL and OM. Parallelism was generally met (F range = 0.04 - 4.26, all p > .05), except for RTL and RTPJ.

In the upper alpha band, normality assumptions were frequently violated (W range = 0.55 - 0.90, all p < .01), except for OL. Homoscedasticity was generally observed (K-squared range = 0.15 - 24.01, all p > .05), except for OL and

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OM. Parallelism was generally supported (F range = 0.15 - 3.43, all p > .05), except for OL.

For the full alpha band, normality assumptions were commonly violated (W range = 0.61 - 0.91, all p < .01), except for OL. Homoscedasticity was mostly observed (K-squared range = 0.09 - 23.84, all p > .05), except for OL and OM. Parallelism was generally met (F range = 0.09 - 4.26, all p > .05), except for OL.

Lastly, in the beta band, normality assumptions were frequently violated (W range = 0.61 - 0.91, all p < .01), except for OL. Homoscedasticity was mostly observed (K-squared range = 0.14 - 43.84, all p > .05), except for OL and OM. Parallelism was generally supported (F range = 0.11 - 2.29, all p > .05), except for OL and OM.

Analysis of group comparisons

This section presents the results of ANCOVA for various parameters during the verbal fluency task to measure language skills in older adults with MCI. The results of the ANCOVA could not be interpreted due to violations of the regression slope homogeneity assumption. Therefore, separate regression analyses for each group are presented in the following section for the affected ROIs: Theta (LTL), Lower alpha (PM), Upper alpha (PM), and Full alpha (PM). The following are the ANCOVA results for ROIs that met the assumption.

ANCOVA revealed significant effects of group condition on various frequency bands during verbal fluency measurements. Main regions shown in frontal midline, central midline, and central lobe (see Table 40 and Figure 44 for more details and illustrations). The delta band analysis indicated significant group effects in the frontal midline (FM), central lobe (CL), and central midline (CM). The frontal midline showed a significant effect of the group condition with a moderate effect size *(F(*2, 79*)* = 4.32, *p* = .02, partial $\omega^2 = 0.07$). Post hoc comparisons revealed that the CST group significantly differed from the control group with a large effect size *(t(*79*)* = -2.94, *p* = .01, Cohen's *d* = -0.84). Similarly, central electrode locations (CL) exhibited a significant group effect with a moderate effect size *(F(*2, 79*)* = 3.82, *p* = .03, partial $\omega^2 = 0.06$), and post hoc analysis indicated significant differences between the CST and control groups *(t(*79*)* = -2.76, *p* = .02, Cohen's *d* = -0.80). The central midline (CM) also showed a significant group effect with a moderate effect size *(F(*2,

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79) = 4.92, $p < .01$, partial $\omega^2 = 0.09$), with post hoc comparisons revealing significant differences between the CST and control groups ($t(79) = -3.04$, $p < .01$, Cohen's $d = -0.87$).

In the theta band, the central midline (CM) showed a significant group effect with a moderate effect size ($F(2, 79) = 4.98$, $p < .01$, partial $\omega^2 = 0.09$). Post hoc analysis revealed significant differences between the CST and control groups with a large effect size ($t(79) = 2.81$, $p = .02$, Cohen's $d = 0.80$), as well as between the MCST and CST groups with a medium effect size ($t(79) = -2.54$, $p = .04$, Cohen's $d = -0.65$). However, a non-significant difference showed between the MCST and control groups with a small effect size ($t(79) = 0.53$, $p = .04$, Cohen's $d = 0.15$).

The lower alpha band did not show any significant group effects. For example, the frontal lobe (FL) showed a non-significant group effect with a small effect size ($F(2, 79) = 1.46$, $p = .24$, partial $\omega^2 = 0.01$). Similarly, the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) all showed non-significant group effects (all $p > .05$).

For the upper alpha band, no significant group effects were observed. For instance, the frontal lobe (FL) exhibited a non-significant group effect with a small effect size ($F(2, 79) = 1.07$, $p = .35$, partial $\omega^2 < .01$). This pattern was consistent across other regions including the frontal midline (FM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all $p > .05$).

In the full alpha band, no significant group effects were detected across any regions. The frontal lobe (FL) showed a non-significant group effect with a small effect size ($F(2, 79) = 1.28$, $p = .28$, partial $\omega^2 = 0.01$). Similarly, the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right

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temporal-parietal junction (RTPJ) all showed non-significant group effects (all p > .05).

The beta band analysis showed significant group effects in the frontal midline (FM), central lobe (CL), and central midline (CM). The frontal midline exhibited a significant effect of the group condition with a moderate effect size *(F(*2, 79*)* = 4.06, *p* = .02, partial ω² = 0.07). Post hoc comparisons revealed that the CST group significantly differed from the control group with a large effect size *(t(*79*)* = 2.81, *p* = .02, Cohen's *d* = 0.81). Similarly, central electrode locations (CL) showed a significant group effect with a moderate effect size *(F(*2, 79*)* = 3.90, *p* = .02, partial ω² = 0.07), with post hoc analysis indicating significant differences between the CST and control groups *(t(*79*)* = 2.76, *p* = .02, Cohen's *d* = 0.80). The central midline (CM) also demonstrated a significant group effect with a moderate effect size *(F(*2, 79*)* = 4.33, *p* = .02, partial ω² = 0.07), and post hoc comparisons revealed significant differences between the CST and control groups *(t(*79*)* = 2.94, *p* = .01, Cohen's *d* = 0.84).

Overall, the ANCOVA results for the verbal fluency learning task indicated significant group effects in specific regions and frequency bands. Significant effects were observed in the delta and beta bands in the frontal midline, central lobe, and central midline, as well as in the theta band in the central midline. Post hoc analyses highlighted significant differences primarily between the CST and control groups, with large effect sizes. Other frequency bands such as lower alpha, upper alpha, and full alpha did not show significant group effects, indicating minimal influence of the group variable on EEG spectral power in these bands.

Table 40 ANCOVA of the verbal fluency learning task

		df	*SS*	*MS*	*F*	*p*	ω_p^2
Delta							
FL	Pre-test	1	0.148	0.148	13.17	<.01	0.13
	Group	2	0.050	0.025	2.23	.11	0.03
	Residuals	79	0.888	0.011			
FM	Pre-test	1	0.099	0.099	5.12	.03	0.05

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	0.166	0.083	4.32	.02	0.07
	Residuals	79	1.521	0.019			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	79	0.054	0.037	1.46	.45	0.39
	MCST-Control	79	-0.063	0.039	-1.59	.35	-0.45
	CST-Control	79	-0.116	0.040	-2.94	.01	-0.84
CL	Pre-test	1	0.188	0.188	9.87	<.01	0.10
	Group	2	0.145	0.073	3.82	.03	0.06
	Residuals	79	1.501	0.019			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	79	0.045	0.036	1.23	.67	0.33
	MCST-Control	79	-0.066	0.039	-1.68	.29	-0.48
	CST-Control	79	-0.110	0.040	-2.76	.02	-0.80
CM	Pre-test	1	0.173	0.173	7.80	<.01	0.08
	Group	2	0.219	0.109	4.92	<.01	0.09
	Residuals	79	1.755	0.022			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	79	0.079	0.038	2.08	.12	0.53
	MCST-Control	79	-0.050	0.042	-1.18	.72	-0.33
	CST-Control	79	-0.129	0.042	-3.04	<.01	-0.87
PL	Pre-test	1	0.482	0.482	32.05	<.01	0.27
	Group	2	0.093	0.047	3.11	.05	0.05
	Residuals	79	1.188	0.015			
PM*	Pre-test	1	0.501	0.501	31.10	<.01	0.27
	Group	2	0.054	0.027	1.66	.20	0.02
	Residuals	79	1.273	0.016			
OL	Pre-test	1	0.238	0.238	20.57	<.01	0.19
	Group	2	0.008	0.004	0.35	.70	<.01
	Residuals	79	0.915	0.012			
OM	Pre-test	1	0.109	0.109	8.55	<.01	0.08

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	0.026	0.013	1.03	.36	<.01
	Residuals	79	1.005	0.013			
LTL	Pre-test	1	0.384	0.384	29.22	<.01	0.25
	Group	2	0.049	0.025	1.87	.16	0.02
	Residuals	79	1.038	0.013			
RTL	Pre-test	1	0.377	0.377	33.23	<.01	0.28
	Group	2	0.026	0.013	1.15	.32	<.01
	Residuals	79	0.896	0.011			
LTPJ	Pre-test	1	0.691	0.691	38.47	<.01	0.31
	Group	2	0.103	0.052	2.87	.06	0.04
	Residuals	79	1.419	0.018			
RTPJ	Pre-test	1	1.041	1.041	57.49	<.01	0.40
	Group	2	0.013	0.007	0.37	.69	<.01
	Residuals	79	1.430	0.018			
Theta							
FL	Pre-test	1	0.001	0.001	1.60	.21	0.01
	Group	2	0.002	0.001	1.66	.20	0.02
	Residuals	79	0.058	0.001			
FM*	Pre-test	1	0.003	0.003	1.45	.23	0.01
	Group	2	0.009	0.004	2.37	.10	0.03
	Residuals	79	0.145	0.002			
CL*	Pre-test	1	0.001	0.001	1.58	.21	0.01
	Group	2	0.005	0.003	3.11	.05	0.05
	Residuals	79	0.068	0.001			
CM	Pre-test	1	0.003	0.003	2.48	.12	0.02
	Group	2	0.013	0.006	4.98	<.01	0.09
	Residuals	79	0.100	0.001			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	79	-0.023	0.009	-2.54	.04	-0.65
	MCST-Control	79	0.005	0.010	0.53	1	0.15

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	CST-Control	79	0.028	0.010	2.81	.02	0.80
PL	Pre-test	1	0.005	0.005	7.09	<.01	0.07
	Group	2	0.003	0.002	2.42	.10	0.03
	Residuals	79	0.056	0.001			
PM	Pre-test	1	0.013	0.013	9.16	<.01	0.09
	Group	2	0.002	0.001	0.85	.43	<.01
	Residuals	79	0.108	0.001			
OL*	Pre-test	1	0.008	0.008	14.67	<.01	0.14
	Group	2	<.001	<.001	0.03	.97	<.01
	Residuals	79	0.043	0.001			
OM	Pre-test	1	0.003	0.003	4.96	.03	0.05
	Group	2	0.001	0.001	1.25	.29	0.01
	Residuals	79	0.047	0.001			
LTL	Pre-test	1	<.001	<.001	0.38	.54	<.01
	Group	2	0.001	0.001	1.44	.24	0.01
	Residuals	79	0.038	<.001			
RTL	Pre-test	1	0.002	0.002	4.42	.04	0.04
	Group	2	0.001	<.001	1.01	.37	<.01
	Residuals	79	0.034	<.001			
LTPJ	Pre-test	1	0.003	0.003	4.33	.04	0.04
*	Group	2	0.002	0.001	1.52	.23	0.01
	Residuals	79	0.057	0.001			
RTPJ	Pre-test	1	0.009	0.009	11.75	<.01	0.11
	Group	2	<.001	<.001	0.30	.74	<.01
	Residuals	79	0.059	0.001			
Lower Alpha							
FL	Pre-test	1	0.002	0.002	11.75	<.01	0.11
	Group	2	<.001	<.001	1.46	.24	0.01
	Residuals	79	0.013	<.001			
FM	Pre-test	1	0.003	0.003	5.55	.02	0.05

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	0.003	0.001	2.38	.10	0.03
	Residuals	79	0.044	0.001			
CL	Pre-test	1	0.007	0.007	14.55	<.01	0.14
	Group	2	0.001	0.001	1.21	.30	<.01
	Residuals	79	0.040	0.001			
CM	Pre-test	1	0.003	0.003	5.07	.03	0.05
	Group	2	0.004	0.002	3.00	.06	0.05
	Residuals	79	0.049	0.001			
PL	Pre-test	1	0.011	0.011	34.57	<.01	0.29
	Group	2	0.002	0.001	2.94	.06	0.04
	Residuals	79	0.026	<.001			
PM	Pre-test	1	0.014	0.014	37.52	<.01	0.31
	Group	2	0.002	0.001	2.46	.09	0.03
	Residuals	79	0.029	<.001			
OL	Pre-test	1	0.005	0.005	21.39	<.01	0.20
	Group	2	<.001	<.001	0.26	.77	<.01
	Residuals	79	0.018	<.001			
OM	Pre-test	1	0.002	0.002	7.43	<.01	0.07
	Group	2	<.001	<.001	0.61	.54	<.01
	Residuals	79	0.017	<.001			
LTL	Pre-test	1	0.005	0.005	15.13	<.01	0.15
	Group	2	<.001	<.001	0.28	.76	<.01
	Residuals	79	0.024	<.001			
RTL	Pre-test	1	0.003	0.003	14.94	<.01	0.14
	Group	2	<.001	<.001	0.72	.49	<.01
	Residuals	79	0.018	<.001			
LTPJ	Pre-test	1	0.009	0.009	23.86	<.01	0.22
	Group	2	0.001	<.001	1.03	.36	<.01
	Residuals	79	0.031	<.001			
RTPJ	Pre-test	1	0.013	0.013	21.65	<.01	0.20

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	0.001	<.001	0.52	.60	<.01
	Residuals	79	0.048	0.001			
Upper Alpha							
FL	Pre-test	1	0.003	0.003	14.74	<.01	0.14
	Group	2	0.001	<.001	1.07	.35	<.01
	Residuals	79	0.019	<.001			
FM	Pre-test	1	0.005	0.005	10.52	<.01	0.10
	Group	2	0.002	0.001	2.02	.14	0.02
	Residuals	79	0.039	<.001			
CL*	Pre-test	1	0.009	0.009	19.55	<.01	0.18
	Group	2	0.002	0.001	1.79	.17	0.02
	Residuals	79	0.037	<.001			
CM*	Pre-test	1	0.006	0.006	9.14	<.01	0.09
	Group	2	0.003	0.002	2.42	.10	0.03
	Residuals	79	0.052	0.001			
PL	Pre-test	1	0.017	0.017	31.17	<.01	0.27
	Group	2	0.002	0.001	1.85	.16	0.02
	Residuals	79	0.044	0.001			
PM	Pre-test	1	0.017	0.017	32.96	<.01	0.28
	Group	2	0.001	0.001	1.39	.26	0.01
	Residuals	79	0.040	0.001			
OL	Pre-test	1	0.006	0.006	12.66	<.01	0.12
	Group	2	<.001	<.001	0.36	.70	<.01
	Residuals	79	0.037	<.001			
OM	Pre-test	1	0.002	0.002	4.83	.03	0.04
	Group	2	<.001	<.001	0.51	.60	<.01
	Residuals	79	0.031	<.001			
LTL	Pre-test	1	0.009	0.009	35.94	<.01	0.30
	Group	2	0.001	<.001	1.59	.21	0.01
	Residuals	79	0.020	<.001			

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
RTL	Pre-test	1	0.008	0.008	30.76	<.01	0.26
	Group	2	<.001	<.001	0.70	.50	<.01
	Residuals	79	0.020	<.001			
LTPJ	Pre-test	1	0.022	0.022	43.23	<.01	0.34
	Group	2	0.002	0.001	2.06	.13	0.02
	Residuals	79	0.041	0.001			
RTPJ	Pre-test	1	0.028	0.028	45.29	<.01	0.35
	Group	2	<.001	<.001	0.23	.79	<.01
	Residuals	79	0.049	0.001			
Full Alpha							
FL	Pre-test	1	0.010	0.010	13.59	<.01	0.13
	Group	2	0.002	0.001	1.28	.28	0.01
	Residuals	79	0.060	0.001			
FM	Pre-test	1	0.013	0.013	6.69	.01	0.06
	Group	2	0.009	0.005	2.47	.09	0.03
	Residuals	79	0.151	0.002			
CL	Pre-test	1	0.029	0.029	16.02	<.01	0.15
	Group	2	0.006	0.003	1.70	.19	0.02
	Residuals	79	0.141	0.002			
CM	Pre-test	1	0.014	0.014	6.34	.01	0.06
	Group	2	0.014	0.007	3.07	.05	0.05
	Residuals	79	0.180	0.002			
PL	Pre-test	1	0.055	0.055	33.49	<.01	0.28
	Group	2	0.008	0.004	2.40	.10	0.03
	Residuals	79	0.130	0.002			
PM	Pre-test	1	0.061	0.061	37.66	<.01	0.31
	Group	2	0.006	0.003	1.83	.17	0.02
	Residuals	79	0.128	0.002			
OL	Pre-test	1	0.021	0.021	15.68	<.01	0.15
	Group	2	0.001	<.001	0.31	.74	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	79	0.104	0.001			
OM	Pre-test	1	0.007	0.007	5.69	.02	0.05
	Group	2	0.001	0.001	0.56	.57	<.01
	Residuals	79	0.093	0.001			
LTL	Pre-test	1	0.025	0.025	25.00	<.01	0.22
	Group	2	0.002	0.001	0.82	.44	<.01
	Residuals	79	0.078	0.001			
RTL	Pre-test	1	0.020	0.020	22.12	<.01	0.20
	Group	2	0.001	0.001	0.74	.48	<.01
	Residuals	79	0.073	0.001			
LTPJ	Pre-test	1	0.058	0.058	34.48	<.01	0.29
	Group	2	0.005	0.003	1.64	.20	0.02
	Residuals	79	0.132	0.002			
RTPJ	Pre-test	1	0.078	0.078	33.14	<.01	0.28
	Group	2	0.002	0.001	0.36	.70	<.01
	Residuals	79	0.187	0.002			
Beta							
FL	Pre-test	1	0.098	0.098	15.14	<.01	0.15
	Group	2	0.016	0.008	1.22	.30	0.01
	Residuals	79	0.509	0.006			
FM	Pre-test	1	0.051	0.051	9.26	<.01	0.09
	Group	2	0.045	0.022	4.06	.02	0.07
	Residuals	79	0.433	0.005			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	79	-0.018	0.020	-0.91	1	-0.24
	MCST-Control	79	0.042	0.021	2.00	.15	0.57
	CST-Control	79	0.060	0.021	2.81	.02	0.81
CL	Pre-test	1	0.083	0.083	13.04	<.01	0.13
	Group	2	0.050	0.025	3.90	.02	0.07
	Residuals	79	0.504	0.006			

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	79	-0.020	0.021	-0.94	1	-0.25
	MCST-Control	79	0.044	0.023	1.95	.16	0.55
	CST-Control	79	0.064	0.023	2.76	.02	0.80
CM	Pre-test	1	0.078	0.078	12.62	<.01	0.12
	Group	2	0.054	0.027	4.33	.02	0.07
	Residuals	79	0.490	0.006			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	79	-0.031	0.020	-1.54	.39	-0.40
	MCST-Control	79	0.035	0.022	1.57	.36	0.44
	CST-Control	79	0.066	0.023	2.94	.01	0.84
PL	Pre-test	1	0.155	0.155	31.17	<.01	0.27
	Group	2	0.028	0.014	2.84	.06	0.04
	Residuals	79	0.392	0.005			
PM*	Pre-test	1	0.122	0.122	27.70	<.01	0.24
	Group	2	0.015	0.008	1.72	.19	0.02
	Residuals	79	0.348	0.004			
OL*	Pre-test	1	0.060	0.060	15.80	<.01	0.15
	Group	2	0.005	0.002	0.63	.54	<.01
	Residuals	79	0.300	0.004			
OM	Pre-test	1	0.035	0.035	7.00	<.01	0.07
	Group	2	0.009	0.005	0.91	.41	<.01
	Residuals	79	0.397	0.005			
LTL	Pre-test	1	0.252	0.252	39.36	<.01	0.32
	Group	2	0.021	0.010	1.63	.20	0.02
	Residuals	79	0.505	0.006			
RTL	Pre-test	1	0.247	0.247	49.82	<.01	0.37
	Group	2	0.009	0.005	0.94	.40	<.01
	Residuals	79	0.392	0.005			
LTPJ	Pre-test	1	0.316	0.316	42.38	<.01	0.33

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	0.036	0.018	2.39	.10	0.03
	Residuals	79	0.590	0.007			
RTPJ	Pre-test	1	0.457	0.457	75.13	<.01	0.47
	Group	2	0.005	0.002	0.37	.69	<.01
	Residuals	79	0.481	0.006			

*A significant interaction effect

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Analysis of regression

The following analysis explores the predictive relationships between pre-test and post-test relative powers for specific frequency bands (lower alpha, upper alpha, full alpha, and theta) for the PM and LTL regions in the three groups, including MCST, CST, and control (see Table 41).

For the relative theta, in the LTL region, the MCST group shows marginal significance ($\beta_1 = 0.23$, $p = .09$, adjusted $R^2 = .06$), suggesting a small predictive relationship. The CST group fails to demonstrate a significant relationship ($\beta_1 = 0.19$, $p = .27$, adjusted $R^2 = .01$), while the control group also shows no significant predictive power ($\beta_1 = -0.46$, $p = .16$, adjusted $R^2 = .05$).

For the relative lower alpha, in the PM region, the MCST group shows no significant relationship between pre-test and post-test values ($\beta_1 = -0.03$, $p = .89$, adjusted $R^2 = -.03$), indicating no predictive power. In contrast, the CST group demonstrates strong predictive power ($\beta_1 = 0.61$, $p < .001$, adjusted $R^2 = .44$), with pre-test values explaining 44% of the variance in post-test outcomes. The control group also shows a significant relationship ($\beta_1 = 1.01$, $p = .01$, adjusted $R^2 = .27$), though with lower predictive strength compared to CST.

For the relative upper alpha, in the PM region, the MCST group again fails to demonstrate significant predictive power ($\beta_1 = 0.05$, $p = .88$, adjusted $R^2 = -.03$). The CST group exhibits strong predictive power ($\beta_1 = 0.81$, $p < .001$, adjusted $R^2 = .57$), indicating that pre-test scores account for 57% of the variance in post-test values. The control group also shows a significant relationship ($\beta_1 = 0.89$, $p = .01$, adjusted $R^2 = .27$), though its predictive power remains weaker than CST.

For the relative full alpha, in the PM region, the MCST group shows no significant relationship (β_1 = 0.00, p = .99, adjusted R^2 = −.03), indicating no predictive capacity. The CST group exhibits strong predictive power (β_1 = 0.71, p < .001, adjusted R^2 = .52), with pre-test values explaining 52% of the variance in post-test scores. The control group demonstrates a significant predictive relationship (β_1 = 0.91, p = .01, adjusted R^2 = .26), though with weaker explanatory power compared to CST (see Figure 43).

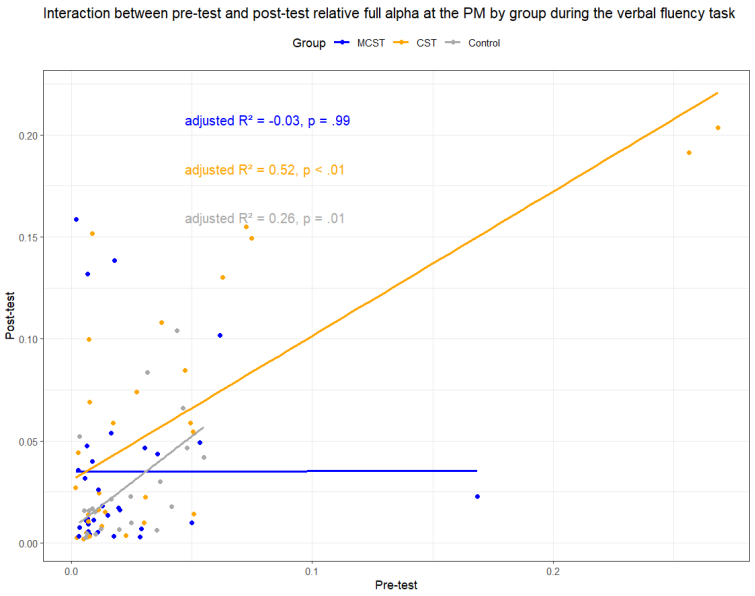

Figure 43 A scatter plot and the regression lines are shows interaction between pre-test and post-test relative full alpha at the parietal midline (PM) by group during the verbal fluency task.

Table 41 Regression analysis of the verbal fluency task

ROI	Model	Variable	β	*SE*	*t*	*p*
Theta						
LTL	MCST	Constant	0.06	0.01	5.91	<.01
		Pre-test	0.23	0.13	1.74	.09
	CST	Constant	0.07	0.01	5.76	<.01
		Pre-test	0.19	0.17	1.13	.27
	Control	Constant	0.10	0.02	4.65	<.01
		Pre-test	-0.46	0.32	-1.44	.16
Lower Alpha						

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ROI	Model	Variable	*β*	*SE*	*t*	*p*
PM	MCST	Constant	0.02	0.00	4.43	<.01
		Pre-test	-0.03	0.19	-0.14	.89
	CST	Constant	0.02	0.00	3.53	<.01
		Pre-test	0.61	0.12	4.97	<.01
	Control	Constant	0.00	0.00	0.59	.56
		Pre-test	1.01	0.35	2.89	.01
Upper Alpha						
PM	MCST	Constant	0.02	0.01	3.14	<.01
		Pre-test	0.05	0.32	0.15	.88
	CST	Constant	0.01	0.00	3.08	<.01
		Pre-test	0.81	0.13	6.33	<.01
	Control	Constant	0.00	0.00	0.64	.53
		Pre-test	0.89	0.31	2.90	.01
Full Alpha						
PM	MCST	Constant	0.03	0.01	3.70	<.01
		Pre-test	0.00	0.25	0.01	.99
	CST	Constant	0.03	0.01	3.42	<.01
		Pre-test	0.71	0.12	5.83	<.01
	Control	Constant	0.01	0.01	0.73	.47
		Pre-test	0.91	0.32	2.84	.01

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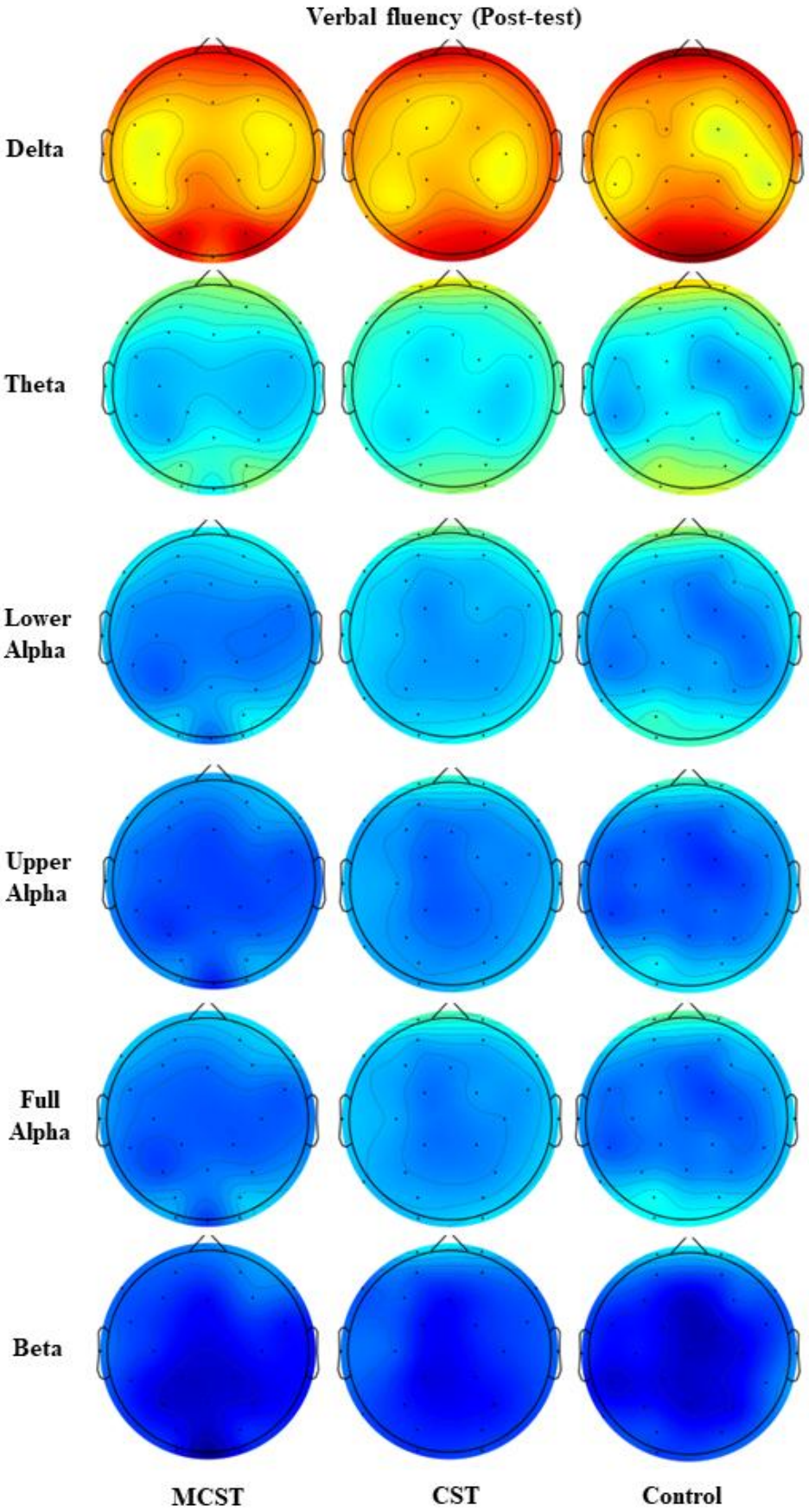

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Figure 44 The topographic brain mapping of relative power during the Verbal fluency task at post-test

EEG - Corsi block-tapping task

Analysis of the relative power characteristics

Overall, the analysis highlights dynamic changes in spectral power across different frequency bands and brain regions during the Corsi Block-Tapping Task (see Table 42). These findings contribute to our understanding of the neural mechanisms underlying task performance and cognitive control.

Across brain regions, there was a general decrease in delta band spectral power from pre to post-test. Notable decreases were observed in the frontal lobe (FL), frontal midline (FM), central lobe (CL), and central midline (CM). For example, in the FL, spectral power decreased from M = 79.98% to M = 72.30%. Similar trends were observed in other regions, suggesting a reduction in slow-wave activity following task engagement.

Theta band spectral power showed mixed changes across brain regions. While some regions exhibited increases in post-test, such as the frontal lobe (FL), others demonstrated decreases or minimal change. For instance, in the FL, theta power increased from M = 8.99% to M = 10.43%. In contrast, the occipital lobe (OL) showed relatively stable spectral power pre and post-test, with minor fluctuations observed.

Lower alpha band spectral power generally increased across brain regions from pre to post-test. This increase was particularly prominent in regions such as the frontal lobe (FL) and frontal midline (FM). For example, in the FL, spectral power increased from M = 1.51% to M = 2.77%, indicating heightened relaxation or passive neural states during task performance.

Similar to lower alpha, upper alpha band spectral power increased across brain regions post-test. Significant increases were observed in regions such as the frontal lobe (FL) and frontal midline (FM), reflecting heightened cognitive processing and attentional engagement. For instance, in the FL, spectral power increased from M = 1.55% to M = 2.44%.

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Full alpha band spectral power showed consistent increases across brain regions from pre to post-test. This suggests a global shift towards alpha-dominant states during post-test sessions, with spectral power increasing notably in regions such as the frontal lobe (FL) and frontal midline (FM). For example, in the FL, spectral power increased from M = 3.06% to M = 5.22%, indicating increased cognitive load and attentional focus.

Beta band spectral power demonstrated varied changes across brain regions post-test. Some regions showed increased spectral power, such as the frontal lobe (FL), while others exhibited minimal changes. For instance, in the FL, spectral power increased from M = 7.98% to M = 12.05%, suggesting differential engagement of neural networks involved in motor planning and execution during the Corsi Block-Tapping Task.

Table 42 Characteristic of relative spectral power (%) of band frequencies in the Corsi block-tapping task

		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Delta										
FL	Pre	30	80.71	9.77	31	76.33	9.70	27	76.55	7.80
	Post	30	72.30	12.60	31	71.99	10.62	27	75.29	7.84
FM	Pre	30	86.37	12.18	31	79.19	13.79	27	79.60	12.23
	Post	30	74.99	17.29	31	71.23	15.80	27	78.66	11.37
CL	Pre	30	84.81	10.61	31	75.71	14.78	27	79.71	10.22
	Post	30	74.09	16.47	31	70.00	16.83	27	77.62	12.61
CM	Pre	30	88.06	9.54	31	81.75	15.43	27	84.29	8.82
	Post	30	79.46	18.47	31	75.09	18.13	27	83.18	14.54
PL	Pre	30	87.99	9.24	31	82.80	14.55	27	87.92	5.62
	Post	30	81.54	15.71	31	79.32	15.53	27	85.99	9.22
PM	Pre	30	88.91	9.15	31	83.69	15.86	27	91.70	6.86
	Post	30	83.52	15.98	31	80.83	16.91	27	87.19	11.45
OL	Pre	30	90.43	11.07	31	86.29	13.97	27	92.33	5.44

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	30	87.16	14.64	31	87.02	13.02	27	90.43	9.36
OM	Pre	30	91.97	9.52	31	85.63	15.31	27	89.92	8.05
	Post	30	85.67	16.48	31	88.03	11.11	27	91.02	9.34
LTL	Pre	30	80.24	12.80	31	73.73	14.20	27	76.73	10.27
	Post	30	70.93	14.38	31	69.79	15.41	27	72.55	13.73
RTL	Pre	30	82.23	12.46	31	77.02	13.19	27	79.90	9.25
	Post	30	73.94	16.13	31	74.71	14.33	27	75.56	14.98
LTPJ	Pre	30	83.73	13.59	31	76.63	18.25	27	81.71	11.49
	Post	30	76.54	17.62	31	73.84	19.78	27	80.67	14.09
RTPJ	Pre	30	86.57	13.70	31	80.04	16.07	27	89.15	7.27
	Post	30	80.06	21.11	31	79.73	18.46	27	84.35	13.81
Theta										
FL	Pre	30	9.12	3.09	31	9.47	2.49	27	10.09	2.93
	Post	30	10.43	4.46	31	10.66	2.96	27	9.56	2.48
FM	Pre	30	5.93	3.11	31	8.00	4.92	27	7.34	3.45
	Post	30	9.22	6.82	31	9.97	4.21	27	8.10	3.43
CL	Pre	30	5.79	2.50	31	7.16	2.86	27	6.64	2.31
	Post	30	7.58	5.19	31	8.10	3.24	27	6.94	3.28
CM	Pre	30	5.39	3.27	31	6.74	4.44	27	6.21	3.20
	Post	30	7.00	6.37	31	7.85	4.08	27	6.34	4.25
PL	Pre	30	5.29	2.57	31	6.02	2.77	27	5.30	2.03
	Post	30	6.25	4.10	31	6.94	3.50	27	5.47	2.48
PM	Pre	30	5.34	2.89	31	6.36	3.99	27	4.14	2.79
	Post	30	6.32	4.64	31	7.06	4.75	27	5.56	4.41
OL	Pre	30	4.64	3.07	31	5.56	3.53	27	3.86	1.76
	Post	30	5.01	3.97	31	5.27	3.65	27	4.32	2.81
OM	Pre	30	4.08	2.92	31	5.75	4.01	27	4.86	2.69
	Post	30	5.75	4.98	31	5.22	4.03	27	3.99	2.87
LTL	Pre	30	6.80	2.97	31	7.59	2.56	27	7.75	1.99

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	30	8.50	3.77	31	8.14	2.49	27	7.84	2.75
RTL	Pre	30	6.26	2.34	31	6.99	1.98	27	6.45	1.94
	Post	30	7.91	4.12	31	7.10	2.39	27	6.95	2.11
LTPJ	Pre	30	6.04	2.98	31	6.75	3.34	27	6.78	2.54
	Post	30	7.31	3.99	31	7.32	3.22	27	6.42	3.24
RTPJ	Pre	30	5.24	2.87	31	5.95	2.73	27	4.61	2.22
	Post	30	5.78	4.12	31	5.69	3.43	27	5.03	2.63
Lower Alpha										
FL	Pre	30	1.50	0.67	31	2.11	1.15	27	2.04	0.84
	Post	30	2.77	3.14	31	2.41	1.06	27	2.31	1.23
FM	Pre	30	1.30	1.02	31	2.35	2.14	27	2.20	1.83
	Post	30	3.25	4.80	31	3.40	2.55	27	2.63	2.23
CL	Pre	30	1.42	0.91	31	2.30	1.39	27	1.95	1.03
	Post	30	2.91	3.53	31	2.95	2.01	27	2.50	2.43
CM	Pre	30	1.19	0.94	31	1.96	1.85	27	1.67	1.06
	Post	30	2.56	3.65	31	2.73	2.08	27	2.12	2.57
PL	Pre	30	1.23	0.98	31	1.75	1.46	27	1.28	0.69
	Post	30	2.05	1.89	31	2.31	2.00	27	1.57	1.23
PM	Pre	30	1.19	1.05	31	1.78	1.86	27	1.04	1.23
	Post	30	1.96	2.04	31	2.37	2.27	27	1.46	1.53
OL	Pre	30	0.95	1.10	31	1.48	1.68	27	0.80	0.52
	Post	30	1.45	1.81	31	1.44	1.84	27	1.02	1.05
OM	Pre	30	0.75	0.91	31	1.53	1.80	27	1.06	0.82
	Post	30	1.72	2.41	31	1.31	1.52	27	0.94	1.04
LTL	Pre	30	1.72	1.11	31	2.35	1.17	27	2.15	1.16
	Post	30	3.04	2.57	31	2.76	1.47	27	2.82	2.92
RTL	Pre	30	1.59	1.10	31	2.09	1.02	27	1.70	0.78
	Post	30	2.84	2.72	31	2.20	1.24	27	2.21	1.50
LTPJ	Pre	30	1.51	1.38	31	2.14	1.78	27	1.77	1.27

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	30	2.51	2.23	31	2.65	2.35	27	2.20	2.46
RTPJ	Pre	30	1.33	1.43	31	1.92	1.44	27	1.04	0.75
	Post	30	2.23	2.65	31	1.83	1.83	27	1.54	1.44
Upper Alpha										
FL	Pre	30	1.50	1.04	31	2.16	1.26	27	1.99	0.87
	Post	30	2.44	1.53	31	2.48	1.29	27	2.40	1.29
FM	Pre	30	1.29	1.25	31	2.18	1.56	27	2.16	1.56
	Post	30	2.66	2.03	31	3.18	2.11	27	2.48	1.53
CL	Pre	30	1.58	1.17	31	2.79	2.00	27	2.28	1.39
	Post	30	3.00	2.20	31	3.62	2.56	27	2.58	1.55
CM	Pre	30	1.22	1.09	31	2.13	2.10	27	1.81	1.22
	Post	30	2.37	2.28	31	3.08	2.67	27	1.97	1.94
PL	Pre	30	1.36	1.26	31	2.10	2.21	27	1.41	0.91
	Post	30	2.30	2.49	31	2.67	2.50	27	1.72	1.46
PM	Pre	30	1.22	1.24	31	2.05	2.51	27	1.00	1.18
	Post	30	2.05	2.49	31	2.48	2.51	27	1.54	1.60
OL	Pre	30	0.95	1.23	31	1.63	2.03	27	0.78	0.70
	Post	30	1.45	1.96	31	1.52	1.94	27	1.10	1.30
OM	Pre	30	0.74	0.97	31	1.71	2.26	27	1.05	1.05
	Post	30	1.55	2.07	31	1.27	1.40	27	1.00	1.28
LTL	Pre	30	2.02	1.48	31	2.85	1.85	27	2.50	1.64
	Post	30	3.13	1.98	31	3.24	1.76	27	2.99	1.86
RTL	Pre	30	1.88	1.50	31	2.47	1.50	27	1.99	1.17
	Post	30	2.82	2.00	31	2.73	1.75	27	2.66	2.02
LTPJ	Pre	30	1.82	1.81	31	2.85	2.80	27	2.20	1.95
	Post	30	2.84	2.91	31	3.30	2.90	27	2.36	2.02
RTPJ	Pre	30	1.64	2.10	31	2.40	2.34	27	1.13	0.96
	Post	30	2.47	3.13	31	2.48	2.96	27	1.93	2.16
Full Alpha										

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
FL	Pre	30	3.01	1.65	31	4.27	2.33	27	4.03	1.66
	Post	30	5.22	4.13	31	4.89	2.21	27	4.71	2.37
FM	Pre	30	2.59	2.21	31	4.53	3.60	27	4.36	3.35
	Post	30	5.91	6.20	31	6.58	4.36	27	5.11	3.47
CL	Pre	30	3.00	2.05	31	5.08	3.28	27	4.23	2.41
	Post	30	5.91	5.16	31	6.57	4.43	27	5.08	3.66
CM	Pre	30	2.41	2.01	31	4.09	3.83	27	3.47	2.25
	Post	30	4.93	5.49	31	5.81	4.57	27	4.09	4.22
PL	Pre	30	2.59	2.23	31	3.85	3.61	27	2.69	1.57
	Post	30	4.35	4.21	31	4.98	4.42	27	3.29	2.57
PM	Pre	30	2.40	2.25	31	3.83	4.34	27	2.04	2.39
	Post	30	4.01	4.32	31	4.85	4.72	27	3.00	2.99
OL	Pre	30	1.90	2.32	31	3.12	3.67	27	1.59	1.21
	Post	30	2.90	3.65	31	2.97	3.74	27	2.11	2.32
OM	Pre	30	1.49	1.87	31	3.24	3.99	27	2.11	1.84
	Post	30	3.27	4.20	31	2.59	2.89	27	1.94	2.27
LTL	Pre	30	3.74	2.55	31	5.21	2.97	27	4.65	2.76
	Post	30	6.17	4.19	31	6.00	3.10	27	5.81	4.32
RTL	Pre	30	3.47	2.57	31	4.56	2.49	27	3.69	1.94
	Post	30	5.66	4.30	31	4.93	2.94	27	4.87	3.22
LTPJ	Pre	30	3.33	3.16	31	4.99	4.45	27	3.97	3.20
	Post	30	5.35	5.00	31	5.95	5.11	27	4.56	4.17
RTPJ	Pre	30	2.98	3.49	31	4.32	3.72	27	2.18	1.70
	Post	30	4.70	5.70	31	4.31	4.74	27	3.47	3.42
Beta										
FL	Pre	30	7.17	7.79	31	9.92	7.54	27	9.33	6.19
	Post	30	12.05	8.22	31	12.46	9.06	27	10.44	5.82
FM	Pre	30	5.10	7.96	31	8.27	7.20	27	8.70	7.53
	Post	30	9.87	7.45	31	12.22	9.24	27	8.13	5.84

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
CL	Pre	30	6.40	6.83	31	12.04	9.69	27	9.42	6.90
	Post	30	12.42	8.93	31	15.33	11.29	27	10.36	7.40
CM	Pre	30	4.14	4.81	31	7.42	7.99	27	6.03	4.87
	Post	30	8.60	8.77	31	11.25	10.88	27	6.40	7.04
PL	Pre	30	4.14	4.95	31	7.32	8.97	27	4.08	2.99
	Post	30	7.87	8.38	31	8.75	8.76	27	5.26	4.98
PM	Pre	30	3.34	4.56	31	6.12	8.35	27	2.13	2.25
	Post	30	6.15	7.93	31	7.26	8.59	27	4.25	4.86
OL	Pre	30	3.02	6.11	31	5.04	7.18	27	2.22	3.10
	Post	30	4.93	7.67	31	4.74	6.37	27	3.14	4.73
OM	Pre	30	2.45	5.16	31	5.37	8.00	27	3.11	4.47
	Post	30	5.31	8.69	31	4.16	5.25	27	3.04	4.73
LTL	Pre	30	9.22	8.99	31	13.47	9.93	27	10.87	6.95
	Post	30	14.39	9.72	31	16.07	12.60	27	13.81	9.44
RTL	Pre	30	8.04	8.81	31	11.43	10.00	27	9.95	6.53
	Post	30	12.48	10.22	31	13.27	10.75	27	12.62	11.14
LTPJ	Pre	30	6.91	8.29	31	11.62	11.95	27	7.54	6.74
	Post	30	10.80	10.27	31	12.90	13.54	27	8.35	7.86
RTPJ	Pre	30	5.21	8.23	31	9.69	10.77	27	4.06	4.01
	Post	30	9.46	12.32	31	10.27	12.07	27	7.15	8.66

Analysis of assumptions

In the assumption testing for the Corsi Block-Tapping Task across various frequency bands, several patterns emerge similar to those observed in the Choice Reaction Time Task.

In the delta band, normality assumptions were frequently violated (W = 0.77 - 0.94, $p < 0.01$), while homoscedasticity was mostly observed (*K-squared* = 0.01 - 9.59, $p < 0.05$). Parallelism generally held (F = 0.08 - 6.92, $p <$

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0.05), with few exceptions such as FM and RTL, indicating potential issues with variance across groups.

Moving to the theta band, normality assumptions continued to be challenged (W = 0.84 - 0.97, $p < 0.01$), particularly for variables like RTL and LTPJ. Homoscedasticity was mostly observed (*K-squared* = 0.16 - 14.88, $p < 0.05$), except for outliers like OM. Parallelism generally held (F = 0.02 - 3.61, $p < 0.05$), although deviations were seen in cases like RTL, PM, and LTPJ, suggesting unequal variances across conditions.

In the lower alpha band, , violations of normality were common across variables (W = 0.55 - 0.86, $p < 0.01$), but homoscedasticity was mostly observed (*K-squared* = 0.05 - 41.06, $p < 0.05$). Parallelism was generally supported (F = 0.02 - 3.01, $p < 0.05$), although deviations were observed in cases like RTL and LTPJ, indicating potential issues with variance across groups.

Similarly, in the upper alpha band, normality assumptions were frequently challenged (W = 0.67 - 0.91, $p < 0.01$), but homoscedasticity was mostly observed (*K-squared* = 0.02 - 11.54, $p < 0.05$). Parallelism was generally supported (F = 0.02 - 3.61, $p < 0.05$), although deviations were observed in cases like RTL, LTPJ, and RTPJ, suggesting unequal variances across groups.

In the full alpha and beta bands, patterns of normality violations, homoscedasticity, and parallelism were consistent with those seen in previous bands (W = 0.66 - 0.91, $p < 0.01$; *K-squared* = 0.01 - 12.82, $p < 0.05$; F = 0.01 - 3.77, $p < 0.05$).

Analysis of group comparisons

This section presents the results of ANCOVA for various EEG frequency bands during the Corsi block-tapping task to measure visuospatial skills in older adults with MCI. Overall, all of relative spectral power bands showed no significant group effects and these results were observed across any brain regions in the Corsi block-tapping task. However, the results of the ANCOVA could not be interpreted due to violations of the regression slope homogeneity assumption. Therefore, separate regression analyses for each group are presented in the following section for the affected ROIs: Delta (OM), Upper alpha (OL, OM), Full alpha (LTPJ,

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OM), and Beta (OL, OM). The following are the ANCOVA results for ROIs that met the assumption.

To summarize, these results suggest that both interventions of MCST and CST do not have main effect on visuospatial skills in term of EEG frequency brain waves during performing the Corsi block-tapping task. See Table 43 and Figure 46 for more information and illustrations.

In the delta band, no significant group effects were observed across most regions. For instance, the frontal lobe (FL) showed a non-significant group effect with a small effect size *(F(*2, 84*)* = 1.49, *p* = .23, partial $\omega^2 = 0.01$). Similarly, the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) all exhibited non-significant group effects (all $p > .05$).

For the theta band, no significant group effects were found in any region. For example, the frontal lobe (FL) exhibited a non-significant group effect with a small effect size *(F(*2, 84*)* = 0.98, *p* = .38, partial $\omega^2 < .01$). This pattern was consistent across other regions including the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all $p > .05$).

In the lower alpha band, no significant group effects were observed. For instance, the frontal lobe (FL) showed a non-significant group effect with a small effect size *(F(*2, 84*)* = 1.07, *p* = .35, partial $\omega^2 < .01$). Other regions, including the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ), also showed non-significant group effects (all $p > .05$).

The upper alpha band analysis showed no significant group effects across any regions. For example, the frontal lobe (FL) exhibited a non-significant group effect with a small effect size *(F(*2, 84*)* = 0.43, *p* = .65, partial $\omega^2 <$

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.01). Similarly, no significant effects were found in the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all p > .05).

In the full alpha band, no significant group effects were observed. The frontal lobe (FL) showed a non-significant group effect with a small effect size *(F(*2, 84*)* = 0.96, *p* = .39, partial ω² < .01). This pattern was consistent across other regions including the frontal midline (FM), central lobe (CL), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), and right temporal-parietal junction (RTPJ) (all p > .05).

In the beta band, no significant group effects were detected in any regions. For instance, the frontal lobe (FL) exhibited a non-significant group effect with a small effect size *(F(*2, 84*)* = 0.86, *p* = .43, partial ω² < .01). Other regions, including the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ), also showed non-significant group effects (all *p* > .05).

Table 43 ANCOVA of the Corsi block-tapping task

		df	*SS*	*MS*	*F*	*p*	ω_p^2
Delta							
FL	Pre-test	1	0.092	0.092	9.07	<.01	0.08
	Group	2	0.030	0.015	1.49	.23	0.01
	Residuals	84	0.855	0.010			
FM	Pre-test	1	0.131	0.131	6.06	.02	0.05
	Group	2	0.084	0.042	1.93	.15	0.02
	Residuals	84	1.817	0.022			
CL	Pre-test	1	0.235	0.235	10.77	<.01	0.10
	Group	2	0.063	0.032	1.45	.24	0.01
	Residuals	84	1.835	0.022			

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
CM	Pre-test	1	0.216	0.216	7.80	<.01	0.07
	Group	2	0.076	0.038	1.37	.26	0.01
	Residuals	84	2.328	0.028			
PL	Pre-test	1	0.509	0.509	35.95	<.01	0.28
	Group	2	0.030	0.015	1.05	.36	<.01
	Residuals	84	1.188	0.014			
PM	Pre-test	1	0.532	0.532	30.59	<.01	0.25
	Group	2	0.005	0.002	0.14	.87	<.01
	Residuals	84	1.461	0.017			
OL	Pre-test	1	0.359	0.359	29.86	<.01	0.25
	Group	2	0.010	0.005	0.41	.67	<.01
	Residuals	84	1.010	0.012			
OM*	Pre-test	1	0.254	0.254	19.30	<.01	0.17
	Group	2	0.068	0.034	2.60	.08	0.04
	Residuals	84	1.104	0.013			
LTL	Pre-test	1	0.503	0.503	32.83	<.01	0.27
	Group	2	0.022	0.011	0.72	.49	<.01
	Residuals	84	1.288	0.015			
RTL	Pre-test	1	0.621	0.621	40.05	<.01	0.31
	Group	2	0.033	0.017	1.07	.35	<.01
	Residuals	84	1.303	0.016			
LTPJ	Pre-test	1	0.724	0.724	32.16	<.01	0.26
	Group	2	0.043	0.021	0.94	.39	<.01
	Residuals	84	1.892	0.023			
RTPJ	Pre-test	1	0.736	0.736	29.67	<.01	0.25
	Group	2	0.027	0.014	0.55	.58	<.01
	Residuals	84	2.084	0.025			
Theta							
FL	Pre-test	1	0.001	0.001	0.88	.35	<.01
	Group	2	0.002	0.001	0.98	.38	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	84	0.099	0.001			
FM	Pre-test	1	0.011	0.011	4.33	.04	0.04
	Group	2	0.005	0.002	0.98	.38	<.01
	Residuals	84	0.208	0.002			
CL	Pre-test	1	0.008	0.008	5.18	.03	0.05
	Group	2	0.002	0.001	0.57	.57	<.01
	Residuals	84	0.130	0.002			
CM	Pre-test	1	0.014	0.014	6.00	.02	0.05
	Group	2	0.003	0.001	0.56	.57	<.01
	Residuals	84	0.201	0.002			
PL	Pre-test	1	0.019	0.019	19.11	<.01	0.17
	Group	2	0.002	0.001	0.85	.43	<.01
	Residuals	84	0.084	0.001			
PM	Pre-test	1	0.027	0.027	14.61	<.01	0.13
	Group	2	<.001	<.001	0.05	.95	<.01
	Residuals	84	0.156	0.002			
OL	Pre-test	1	0.026	0.026	27.48	<.01	0.23
	Group	2	<.001	<.001	0.07	.93	<.01
	Residuals	84	0.081	0.001			
OM	Pre-test	1	0.017	0.017	11.81	<.01	0.11
	Group	2	0.006	0.003	2.19	.12	0.03
	Residuals	84	0.123	0.001			
LTL	Pre-test	1	0.002	0.002	1.99	.16	0.01
	Group	2	0.001	0.001	0.57	.57	<.01
	Residuals	84	0.077	0.001			
RTL	Pre-test	1	0.006	0.006	7.37	<.01	0.07
	Group	2	0.002	0.001	1.38	.26	0.01
	Residuals	84	0.071	0.001			
LTPJ	Pre-test	1	0.011	0.011	10.08	<.01	0.09
	Group	2	0.002	0.001	0.96	.39	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	84	0.093	0.001			
RTPJ	Pre-test	1	0.013	0.013	12.29	<.01	0.11
	Group	2	<.001	<.001	0.18	.84	<.01
	Residuals	84	0.090	0.001			
Lower Alpha							
FL	Pre-test	1	0.001	0.001	2.82	.10	0.02
	Group	2	0.001	<.001	1.07	.35	<.01
	Residuals	84	0.034	<.001			
FM	Pre-test	1	0.009	0.009	8.40	<.01	0.08
	Group	2	0.002	0.001	0.90	.41	<.01
	Residuals	84	0.089	0.001			
CL	Pre-test	1	0.003	0.003	3.64	.06	0.03
	Group	2	0.001	<.001	0.45	.64	<.01
	Residuals	84	0.061	0.001			
CM	Pre-test	1	0.003	0.003	3.31	.07	0.03
	Group	2	0.001	<.001	0.39	.68	<.01
	Residuals	84	0.066	0.001			
PL	Pre-test	1	0.008	0.008	34.96	<.01	0.28
	Group	2	<.001	<.001	0.88	.42	<.01
	Residuals	84	0.019	<.001			
PM	Pre-test	1	0.009	0.009	29.23	<.01	0.24
	Group	2	<.001	<.001	0.48	.62	<.01
	Residuals	84	0.026	<.001			
OL	Pre-test	1	0.005	0.005	23.03	<.01	0.20
	Group	2	<.001	<.001	0.53	.59	<.01
	Residuals	84	0.018	<.001			
OM	Pre-test	1	0.003	0.003	10.78	<.01	0.10
	Group	2	0.001	0.001	2.61	.08	0.04
	Residuals	84	0.023	<.001			
LTL	Pre-test	1	0.003	0.003	4.87	.03	0.04

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	0.001	<.001	0.54	.59	<.01
	Residuals	84	0.045	0.001			
RTL	Pre-test	1	0.003	0.003	9.73	<.01	0.09
	Group	2	0.002	0.001	2.28	.11	0.03
	Residuals	84	0.028	<.001			
LTPJ	Pre-test	1	0.008	0.008	17.24	<.01	0.16
	Group	2	<.001	<.001	0.35	.70	<.01
	Residuals	84	0.039	<.001			
RTPJ	Pre-test	1	0.008	0.008	25.05	<.01	0.21
	Group	2	0.001	0.001	1.70	.19	0.02
	Residuals	84	0.027	<.001			
Upper Alpha							
FL	Pre-test	1	0.002	0.002	13.03	<.01	0.12
	Group	2	<.001	<.001	0.43	.65	<.01
	Residuals	84	0.014	<.001			
FM	Pre-test	1	0.004	0.004	11.84	<.01	0.11
	Group	2	0.001	<.001	1.16	.32	<.01
	Residuals	84	0.028	<.001			
CL	Pre-test	1	0.009	0.009	24.27	<.01	0.21
	Group	2	0.001	0.001	1.58	.21	0.01
	Residuals	84	0.031	<.001			
CM	Pre-test	1	0.006	0.006	11.28	<.01	0.10
	Group	2	0.001	0.001	1.42	.25	0.01
	Residuals	84	0.041	<.001			
PL	Pre-test	1	0.013	0.013	37.44	<.01	0.29
	Group	2	0.001	<.001	0.81	.45	<.01
	Residuals	84	0.030	<.001			
PM	Pre-test	1	0.014	0.014	38.81	<.01	0.30
	Group	2	<.001	<.001	0.25	.78	<.01
	Residuals	84	0.030	<.001			

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
OL*	Pre-test	1	0.007	0.007	27.65	<.01	0.23
	Group	2	<.001	<.001	0.39	.68	<.01
	Residuals	84	0.020	<.001			
OM*	Pre-test	1	0.004	0.004	17.64	<.01	0.16
	Group	2	0.001	<.001	2.22	.12	0.03
	Residuals	84	0.018	<.001			
LTL	Pre-test	1	0.010	0.010	46.23	<.01	0.34
	Group	2	<.001	<.001	0.91	.41	<.01
	Residuals	84	0.019	<.001			
RTL	Pre-test	1	0.011	0.011	49.26	<.01	0.35
	Group	2	0.001	<.001	1.10	.34	<.01
	Residuals	84	0.019	<.001			
LTPJ	Pre-test	1	0.017	0.017	33.13	<.01	0.27
	Group	2	0.001	<.001	0.75	.48	<.01
	Residuals	84	0.044	0.001			
RTPJ	Pre-test	1	0.022	0.022	41.55	<.01	0.32
	Group	2	0.001	<.001	0.58	.56	<.01
	Residuals	84	0.045	0.001			
Full Alpha							
FL	Pre-test	1	0.006	0.006	6.47	.01	0.06
	Group	2	0.002	0.001	0.96	.39	<.01
	Residuals	84	0.072	0.001			
FM	Pre-test	1	0.021	0.021	10.12	<.01	0.09
	Group	2	0.005	0.002	1.08	.34	<.01
	Residuals	84	0.177	0.002			
CL	Pre-test	1	0.019	0.019	10.50	<.01	0.10
	Group	2	0.003	0.002	0.92	.40	<.01
	Residuals	84	0.152	0.002			
CM	Pre-test	1	0.014	0.014	6.53	.01	0.06
	Group	2	0.004	0.002	0.83	.44	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	84	0.183	0.002			
PL	Pre-test	1	0.039	0.039	36.57	<.01	0.29
	Group	2	0.002	0.001	0.89	.41	<.01
	Residuals	84	0.090	0.001			
PM	Pre-test	1	0.045	0.045	36.06	<.01	0.28
	Group	2	0.001	<.001	0.36	.70	<.01
	Residuals	84	0.104	0.001			
OL	Pre-test	1	0.022	0.022	25.96	<.01	0.22
	Group	2	0.001	<.001	0.47	.63	<.01
	Residuals	84	0.073	0.001			
OM*	Pre-test	1	0.013	0.013	14.99	<.01	0.14
	Group	2	0.005	0.002	2.67	.08	0.04
	Residuals	84	0.074	0.001			
LTL	Pre-test	1	0.021	0.021	17.16	<.01	0.16
	Group	2	0.002	0.001	0.74	.48	<.01
	Residuals	84	0.105	0.001			
RTL	Pre-test	1	0.025	0.025	26.54	<.01	0.22
	Group	2	0.004	0.002	1.94	.15	0.02
	Residuals	84	0.079	0.001			
LTPJ	Pre-test	1	0.044	0.044	24.45	<.01	0.21
*	Group	2	0.002	0.001	0.56	.57	<.01
	Residuals	84	0.152	0.002			
RTPJ	Pre-test	1	0.055	0.055	34.04	<.01	0.27
	Group	2	0.003	0.002	1.01	.37	<.01
	Residuals	84	0.136	0.002			
Beta							
FL	Pre-test	1	0.075	0.075	13.88	<.01	0.13
	Group	2	0.009	0.005	0.86	.43	<.01
	Residuals	84	0.452	0.005			
FM	Pre-test	1	0.028	0.028	5.01	.03	0.04

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	0.026	0.013	2.26	.11	0.03
	Residuals	84	0.476	0.006			
CL	Pre-test	1	0.110	0.110	13.98	<.01	0.13
	Group	2	0.025	0.012	1.57	.21	0.01
	Residuals	84	0.658	0.008			
CM	Pre-test	1	0.073	0.073	9.57	<.01	0.09
	Group	2	0.027	0.013	1.76	.18	0.02
	Residuals	84	0.642	0.008			
PL	Pre-test	1	0.143	0.143	32.85	<.01	0.27
	Group	2	0.009	0.005	1.08	.34	<.01
	Residuals	84	0.365	0.004			
PM	Pre-test	1	0.125	0.125	29.81	<.01	0.25
	Group	2	0.002	0.001	0.22	.80	<.01
	Residuals	84	0.352	0.004			
OL*	Pre-test	1	0.087	0.087	27.63	<.01	0.23
	Group	2	0.003	0.002	0.54	.59	<.01
	Residuals	84	0.265	0.003			
OM*	Pre-test	1	0.073	0.073	21.69	<.01	0.19
	Group	2	0.013	0.006	1.94	.15	0.02
	Residuals	84	0.281	0.003			
LTL	Pre-test	1	0.375	0.375	51.72	<.01	0.37
	Group	2	0.005	0.003	0.38	.69	<.01
	Residuals	84	0.609	0.007			
RTL	Pre-test	1	0.360	0.360	49.65	<.01	0.36
	Group	2	0.005	0.003	0.35	.71	<.01
	Residuals	84	0.608	0.007			
LTPJ	Pre-test	1	0.326	0.326	38.59	<.01	0.30
	Group	2	0.012	0.006	0.71	.49	<.01
	Residuals	84	0.709	0.008			
RTPJ	Pre-test	1	0.252	0.252	25.56	<.01	0.22

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	df	*SS*	*MS*	*F*	*p*	ω_p^2
Group	2	0.007	0.003	0.35	.71	<.01
Residuals	84	0.828	0.010			

*A significant interaction effect

Analysis of regression

The following analysis explores the predictive relationships between pre-test and post-test relative powers for specific frequency bands (delta, upper alpha, full alpha, and beta) for the OM, OL, and LTPJ regions in the three groups, including MCST, CST, and control (see Table 44).

For the relative delta, in the OM region, the MCST group demonstrates strong predictive power with significant relationships (β_1 = 1.17, p < .001, adjusted R^2 = .44), indicating that pre-test values account for 44% of the variance in post-test values. The CST group exhibits moderate predictive power (β_1 = 0.26, p = .04, adjusted R^2 = .10). The control group shows marginal significance (β_1 = 0.42, p = .07, adjusted R^2 = .09), suggesting a weaker relationship compared to the intervention groups.

For the relative upper alpha, in the OL region, the MCST group demonstrates strong predictive power (β_1 = 1.09, p < .001, adjusted R^2 = .45). The CST group shows moderate predictive power (β_1 = 0.40, p = .02, adjusted R^2 = .15), while the control group also demonstrates significance (β_1 = 0.90, p = .01, adjusted R^2 = .20) but with less explanatory power compared to MCST. In the OM region, the MCST group again demonstrates strong predictive power (β_1 = 1.54, p < .001, adjusted R^2 = .50), while the CST group exhibits moderate predictive power (β_1 = 0.23, p = .04, adjusted R^2 = .11). The control group also shows a significant relationship (β_1 = 0.61, p = .01, adjusted R^2 = .22), though less than MCST.

For the relative full alpha, in the OM region, the MCST group again demonstrates strong predictive power (β_1 = 1.32, p < .001, adjusted R^2 = .32). The CST group exhibits moderate predictive power (β_1 = 0.27, p = .04, adjusted R^2 = .11), while the control group shows a significant relationship (β_1 = 0.66, p < .001, adjusted R^2 = .26), though less than MCST. In the LTPJ region, the MCST group shows strong predictive power (β_1 = 0.98, p < .001, adjusted R^2 = .37), while the

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CST group also demonstrates significant predictive power (β_1 = 0.66, p < .001, adjusted R^2 = .31). The control group, however, shows no significant predictive relationship (β_1 = 0.11, p = .66, adjusted R^2 = −.03).

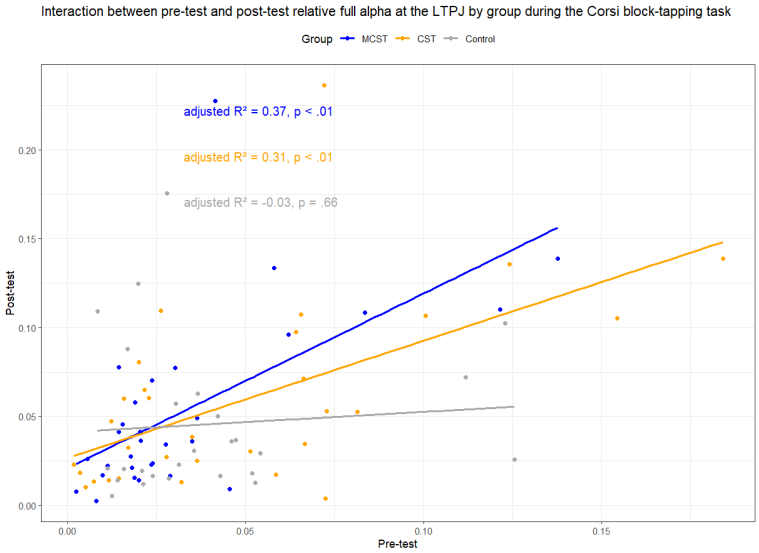

Figure 45 A scatter plot and the regression lines are shows interaction between pre-test and post-test relative full alpha at the left TPJ (LTPJ) by group during the verbal fluency task.

For the relative beta, in the OL region, the MCST group demonstrates strong predictive power (β_1 = 0.86, p < .001, adjusted R^2 = .45). The CST group shows marginal significance (β_1 = 0.31, p = .05, adjusted R^2 = .09), and the control group shows a weaker relationship (β_1 = 0.61, p = .04, adjusted R^2 = .13). In the OM region, the MCST group demonstrates strong predictive power (β_1 = 1.30, p < .001, adjusted R^2 = .58), while the CST group shows marginal significance (β_1 = 0.21, p = .08, adjusted R^2 = .07). The control group fails to demonstrate significance (β_1 = 0.34, p = .10, adjusted R^2 = .07).

Across the Corsi Block-Tapping Task, the MCST group consistently demonstrates strong predictive relationships, particularly in the Delta and Upper alpha in the OM and OL regions (adjusted R^2 ≈ .44−0.58). The CST group generally exhibits moderate predictive power, especially in the Upper alpha and Full Alpha bands (adjusted R^2 ≈ .10−0.31). The control group shows significant but

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weaker relationships in some regions (adjusted $R^2 \approx .07-0.22$), indicating that the interventions (particularly MCST) enhance predictive power compared to natural associations in this task.

Table 44 Regression analysis of the Corsi block-tapping task

ROI	Model	Variable	*β*	*SE*	*t*	*p*
Delta						
OM	MCST	Constant	-0.22	0.22	-1.00	.32
		Pre-test	1.17	0.24	4.88	<.01
	CST	Constant	0.65	0.11	5.99	<.01
		Pre-test	0.26	0.13	2.11	.04
	Control	Constant	0.54	0.20	2.74	.01
		Pre-test	0.42	0.22	1.93	.07
Upper Alpha						
OL	MCST	Constant	0.00	0.00	1.24	.23
		Pre-test	1.09	0.22	4.93	<.01
	CST	Constant	0.01	0.00	2.08	.05
		Pre-test	0.40	0.16	2.49	.02
	Control	Constant	0.00	0.00	1.16	.26
		Pre-test	0.90	0.32	2.78	.01
OM	MCST	Constant	0.00	0.00	1.22	.23
		Pre-test	1.54	0.28	5.48	<.01
	CST	Constant	0.01	0.00	2.93	.01
		Pre-test	0.23	0.11	2.20	.04
	Control	Constant	0.00	0.00	1.15	.26
		Pre-test	0.61	0.21	2.91	.01
Full Alpha						
OM	MCST	Constant	0.01	0.01	1.59	.12
		Pre-test	1.32	0.34	3.86	<.01
	CST	Constant	0.02	0.01	2.69	.01
		Pre-test	0.27	0.12	2.16	.04
	Control	Constant	0.01	0.01	0.94	.36
		Pre-test	0.66	0.21	3.17	<.01
LTPJ	MCST	Constant	0.02	0.01	1.95	.06
		Pre-test	0.98	0.23	4.20	<.01
	CST	Constant	0.03	0.01	2.29	.03
		Pre-test	0.66	0.17	3.79	<.01
	Control	Constant	0.04	0.01	3.13	<.01
		Pre-test	0.11	0.26	0.44	.66
Beta						
OL	MCST	Constant	0.02	0.01	2.00	.05

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ROI	Model	Variable	*β*	*SE*	*t*	*p*
		Pre-test	0.86	0.17	4.95	<.01
	CST	Constant	0.03	0.01	2.37	.02
		Pre-test	0.31	0.15	2.03	.05
	Control	Constant	0.02	0.01	1.69	.10
		Pre-test	0.61	0.28	2.20	.04
OM	MCST	Constant	0.02	0.01	1.86	.07
		Pre-test	1.30	0.20	6.45	<.01
	CST	Constant	0.03	0.01	2.76	.01
		Pre-test	0.21	0.12	1.83	.08
	Control	Constant	0.02	0.01	1.84	.08
		Pre-test	0.34	0.20	1.69	.10

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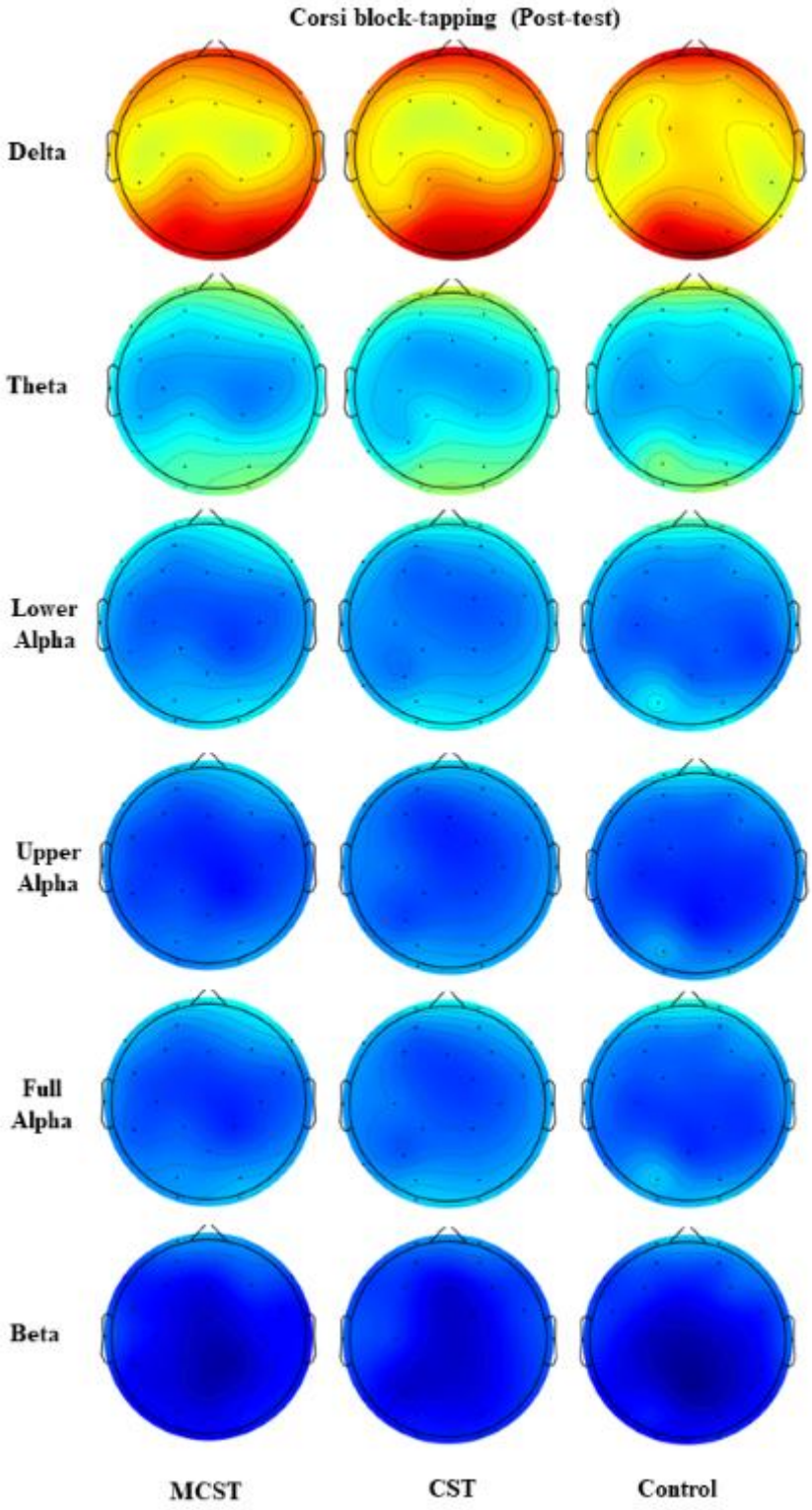

Figure 46 The topographic brain mapping of relative power during the Corsi block-tapping task at post-test

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EEG - Mental rotation task

Analysis of the relative power characteristics

The analysis focused on the relative spectral power of band frequencies across different brain regions during a mental rotation task. The parameters considered include delta, theta, lower alpha, upper alpha, full alpha, and beta band frequencies (see Table 45).

In the delta band frequency, there was a notable decrease in frontal lobe (FL) activity from pre-test (M = 80.76%) to post-test (M = 70.51%). A similar trend was observed in central electrode locations (CL) and occipital lobe (OL). However, the parietal lobe (PL) showed a slight increase from pre-test (M = 88.48%) to post-test (M = 77.24%).

Theta band activity showed varied patterns across different brain regions. Notably, there was an increase in theta band activity in the frontal lobe (FL) from pre-test (M = 8.33%) to post-test (M = 10.14%). Similar trends were observed in other lobes and midline regions.

Lower alpha band activity demonstrated diverse changes across brain regions. For instance, in the frontal lobe (FL), there was a slight increase from pre-test (M = 1.62%) to post-test (M = 2.62%). Conversely, central electrode locations (CL) exhibited a more substantial increase from pre-test (M = 1.45%) to post-test (M = 3.51%).

Upper alpha band activity also displayed variations across different regions. In the frontal lobe (FL), there was a notable increase from pre-test (M = 1.58%) to post-test (M = 2.79%). Similarly, central electrode locations (CL) and parietal lobe (PL) showed increases in upper alpha band activity from pre- to post-test.

Full alpha band activity reflected changes similar to those observed in lower and upper alpha bands. Noteworthy increases were seen in the frontal lobe (FL) and central lobe (CL) from pre-test to post-test.

Beta band activity demonstrated changes across brain regions, with fluctuations observed in both pre- and post-test conditions. Notable changes were seen in the frontal lobe (FL), where beta band activity increased from pre-test (M = 7.71%) to post-test (M = 13.94%).

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Across all band frequencies, there were notable changes in brain activity during the mental rotation task. Increases or decreases in spectral power varied across brain regions, indicating differential engagement depending on the cognitive demands of the task. Notably, frontal and central regions showed consistent patterns of increased activity across multiple band frequencies.

Table 45 Characteristic of relative spectral power (%) of band frequencies in the mental rotation task

		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Delta										
FL	Pre	30	80.84	9.81	31	74.19	10.51	27	75.58	8.65
	Post	30	70.51	13.53	31	70.61	11.77	27	74.39	10.59
FM	Pre	30	87.26	9.43	31	78.09	15.07	27	79.38	9.32
	Post	30	70.75	19.49	31	70.31	16.96	27	75.23	14.88
CL	Pre	30	86.26	9.79	31	76.53	17.21	27	79.00	11.96
	Post	30	69.83	15.16	31	69.50	16.41	27	75.73	16.36
CM	Pre	30	89.47	9.74	31	81.13	18.18	27	83.88	11.75
	Post	30	72.98	16.52	31	75.31	16.53	27	80.32	17.13
PL	Pre	30	88.22	9.95	31	83.79	15.17	27	85.49	11.04
	Post	30	77.24	16.26	31	78.12	15.73	27	81.65	13.57
PM	Pre	30	90.12	9.05	31	84.54	16.85	27	87.76	11.22
	Post	30	81.77	17.35	31	81.32	13.87	27	82.97	13.93
OL	Pre	30	90.94	8.29	31	86.42	14.04	27	91.91	8.66
	Post	30	84.02	15.67	31	87.29	12.25	27	89.14	8.26
OM	Pre	30	91.65	8.22	31	85.90	15.62	27	90.71	8.91
	Post	30	82.79	16.09	31	87.04	13.89	27	89.09	9.82
LTL	Pre	30	82.13	10.78	31	73.69	14.46	27	74.21	12.42
	Post	30	69.00	14.05	31	68.87	13.80	27	74.30	12.31
RTL	Pre	30	82.96	10.86	31	76.09	13.99	27	78.83	8.49
	Post	30	73.37	15.57	31	75.47	13.59	27	76.61	13.04

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
LTPJ	Pre	30	84.15	13.34	31	78.36	18.46	27	77.46	15.18
	Post	30	71.87	17.58	31	72.39	16.71	27	77.48	14.74
RTPJ	Pre	30	87.18	12.49	31	80.16	18.06	27	87.61	9.65
	Post	30	75.98	21.28	31	81.44	17.20	27	82.46	17.45
Theta										
FL	Pre	30	8.14	3.18	31	8.75	2.51	27	9.06	2.89
	Post	30	10.14	2.69	31	10.10	3.75	27	9.79	3.24
FM	Pre	30	5.89	3.53	31	7.87	4.93	27	8.47	3.50
	Post	30	10.04	5.06	31	10.60	4.50	27	10.08	5.36
CL	Pre	30	5.28	2.73	31	6.55	3.13	27	6.37	2.54
	Post	30	8.98	2.93	31	8.79	3.40	27	7.83	4.32
CM	Pre	30	4.68	3.30	31	6.79	5.56	27	5.40	3.01
	Post	30	8.99	4.23	31	8.11	4.24	27	7.65	5.59
PL	Pre	30	5.01	2.86	31	5.64	3.46	27	5.39	2.57
	Post	30	7.36	3.34	31	7.44	4.25	27	7.02	4.00
PM	Pre	30	4.87	3.45	31	5.78	4.38	27	5.33	3.55
	Post	30	6.98	4.72	31	7.65	4.90	27	7.30	5.34
OL	Pre	30	4.66	3.08	31	5.49	4.09	27	4.02	3.05
	Post	30	6.53	4.29	31	5.87	4.65	27	5.38	3.41
OM	Pre	30	4.45	3.20	31	5.87	4.91	27	4.60	3.15
	Post	30	7.23	4.87	31	6.15	5.40	27	5.32	4.35
LTL	Pre	30	6.84	3.49	31	7.68	2.88	27	8.24	2.34
	Post	30	10.02	2.34	31	9.31	2.55	27	8.89	3.30
RTL	Pre	30	6.42	2.57	31	7.34	2.79	27	6.93	1.81
	Post	30	8.74	2.81	31	7.94	2.91	27	7.85	2.90
LTPJ	Pre	30	6.01	3.70	31	6.14	3.73	27	7.03	2.62
	Post	30	8.74	3.72	31	8.21	3.34	27	7.82	3.70
RTPJ	Pre	30	5.04	3.13	31	5.82	3.58	27	4.58	2.30
	Post	30	7.18	4.07	31	6.13	4.26	27	6.32	4.36

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Lower Alpha										
FL	Pre	30	1.61	0.89	31	2.25	1.01	27	2.11	1.03
	Post	30	2.62	1.27	31	2.77	1.58	27	2.55	1.84
FM	Pre	30	1.25	0.93	31	2.53	2.07	27	2.40	1.90
	Post	30	3.19	2.44	31	4.12	3.84	27	3.29	3.60
CL	Pre	30	1.46	1.26	31	2.51	1.92	27	2.16	1.60
	Post	30	3.51	2.21	31	3.80	3.22	27	3.54	4.97
CM	Pre	30	1.26	1.53	31	2.30	2.40	27	1.84	1.61
	Post	30	3.68	3.26	31	3.57	3.45	27	3.31	6.18
PL	Pre	30	1.47	1.56	31	1.83	1.92	27	1.55	1.27
	Post	30	2.72	2.17	31	2.96	2.87	27	2.69	4.24
PM	Pre	30	1.30	1.70	31	1.82	2.25	27	1.35	1.32
	Post	30	2.10	2.04	31	2.61	2.63	27	2.49	3.54
OL	Pre	30	1.08	1.21	31	1.55	1.95	27	0.80	0.82
	Post	30	1.76	1.89	31	1.53	1.84	27	1.33	1.47
OM	Pre	30	0.93	1.02	31	1.58	2.17	27	0.92	0.77
	Post	30	1.92	2.05	31	1.57	2.18	27	1.40	1.96
LTL	Pre	30	2.18	1.72	31	3.11	2.06	27	2.97	2.06
	Post	30	4.16	2.53	31	3.94	2.63	27	3.83	4.36
RTL	Pre	30	2.02	1.54	31	2.80	1.92	27	2.18	1.40
	Post	30	3.53	2.55	31	3.17	2.62	27	3.28	4.37
LTPJ	Pre	30	1.93	2.01	31	2.50	2.28	27	2.57	2.34
	Post	30	3.64	3.32	31	3.54	2.88	27	3.27	4.58
RTPJ	Pre	30	1.64	2.02	31	2.32	2.59	27	1.26	0.93
	Post	30	3.03	3.21	31	2.69	3.20	27	2.78	5.65
Upper Alpha										
FL	Pre	30	1.59	1.20	31	2.47	1.31	27	2.11	1.13
	Post	30	2.79	1.79	31	2.62	1.45	27	2.36	1.39
FM	Pre	30	1.13	0.90	31	2.56	2.10	27	2.06	1.19

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	30	3.22	2.92	31	3.35	2.53	27	2.61	1.65
CL	Pre	30	1.54	1.40	31	3.03	2.74	27	2.46	1.91
	Post	30	3.68	2.50	31	3.83	2.78	27	2.87	2.19
CM	Pre	30	1.12	1.36	31	2.20	2.36	27	1.94	1.80
	Post	30	3.34	2.63	31	3.18	2.39	27	2.38	2.28
PL	Pre	30	1.41	1.62	31	2.23	2.68	27	1.81	1.84
	Post	30	3.09	2.98	31	3.01	2.83	27	2.27	1.86
PM	Pre	30	1.10	1.34	31	2.18	3.13	27	1.50	1.83
	Post	30	2.42	3.28	31	2.39	2.23	27	2.05	1.92
OL	Pre	30	0.91	1.03	31	1.68	2.14	27	0.83	1.01
	Post	30	1.87	2.23	31	1.39	1.70	27	1.20	1.17
OM	Pre	30	0.78	0.94	31	1.67	2.37	27	0.93	0.99
	Post	30	1.92	2.15	31	1.33	1.80	27	1.16	1.29
LTL	Pre	30	2.05	1.48	31	3.36	2.47	27	3.04	1.96
	Post	30	3.81	2.31	31	3.81	2.21	27	3.06	2.03
RTL	Pre	30	1.96	1.55	31	2.91	2.10	27	2.25	1.35
	Post	30	3.28	2.43	31	2.90	2.15	27	2.60	1.79
LTPJ	Pre	30	2.05	2.17	31	3.27	3.57	27	3.07	2.78
	Post	30	3.79	2.97	31	3.88	3.17	27	3.00	2.50
RTPJ	Pre	30	1.65	2.04	31	2.77	3.34	27	1.36	1.25
	Post	30	3.42	3.85	31	2.54	3.03	27	2.09	2.45
Full Alpha										
FL	Pre	30	3.19	2.05	31	4.73	2.21	27	4.22	2.09
	Post	30	5.42	2.87	31	5.39	2.95	27	4.92	3.01
FM	Pre	30	2.39	1.80	31	5.09	3.89	27	4.46	2.97
	Post	30	6.41	4.97	31	7.47	6.16	27	5.89	4.85
CL	Pre	30	3.00	2.64	31	5.54	4.53	27	4.62	3.46
	Post	30	7.18	4.39	31	7.64	5.91	27	6.41	6.43
CM	Pre	30	2.38	2.87	31	4.50	4.65	27	3.78	3.37

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		MCST			CST			Control	
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	30	7.03	5.42	31	6.75	5.66	27	5.69	7.64
PL	Pre	30	2.88	3.13	31	4.06	4.51	27	3.36	3.09
	Post	30	5.82	4.94	31	5.98	5.65	27	4.96	5.47
PM	Pre	30	2.40	2.98	31	4.00	5.25	27	2.85	3.13
	Post	30	4.52	5.11	31	5.00	4.78	27	4.53	4.83
OL	Pre	30	1.99	2.20	31	3.23	4.05	27	1.64	1.82
	Post	30	3.63	3.93	31	2.92	3.53	27	2.53	2.50
OM	Pre	30	1.72	1.94	31	3.25	4.51	27	1.86	1.73
	Post	30	3.84	4.02	31	2.90	3.96	27	2.55	3.04
LTL	Pre	30	4.23	3.10	31	6.47	4.40	27	6.01	3.86
	Post	30	7.97	4.54	31	7.74	4.68	27	6.89	5.61
RTL	Pre	30	3.99	3.01	31	5.71	3.94	27	4.43	2.68
	Post	30	6.81	4.70	31	6.06	4.70	27	5.88	5.32
LTPJ	Pre	30	3.98	4.08	31	5.77	5.72	27	5.64	4.97
	Post	30	7.43	5.93	31	7.42	5.92	27	6.26	6.15
RTPJ	Pre	30	3.29	3.98	31	5.09	5.88	27	2.62	2.15
	Post	30	6.45	6.85	31	5.23	6.17	27	4.86	7.17
Beta										
FL	Pre	30	7.83	7.36	31	12.33	7.66	27	11.14	6.47
	Post	30	13.94	10.96	31	13.91	9.86	27	10.90	6.88
FM	Pre	30	4.47	5.52	31	8.95	7.77	27	7.69	4.08
	Post	30	12.79	12.70	31	11.61	8.41	27	8.79	6.75
CL	Pre	30	5.46	4.88	31	11.38	10.46	27	10.00	7.31
	Post	30	14.01	9.19	31	14.07	8.97	27	10.02	8.10
CM	Pre	30	3.47	3.95	31	7.58	9.22	27	6.94	6.23
	Post	30	11.00	8.54	31	9.83	7.50	27	6.35	5.91
PL	Pre	30	3.88	4.42	31	6.50	8.20	27	5.75	6.13
	Post	30	9.59	9.35	31	8.46	6.92	27	6.36	6.15
PM	Pre	30	2.62	3.08	31	5.68	8.24	27	4.06	5.16

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		MCST			CST			Control	
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	30	6.73	9.43	31	6.03	5.15	27	5.19	5.20
OL	Pre	30	2.41	3.40	31	4.86	6.29	27	2.43	3.91
	Post	30	5.83	8.67	31	3.93	4.89	27	2.95	2.77
OM	Pre	30	2.19	3.52	31	4.97	6.79	27	2.84	4.36
	Post	30	6.13	8.57	31	3.91	5.43	27	3.03	2.94
LTL	Pre	30	6.81	5.42	31	12.16	8.85	27	11.54	8.91
	Post	30	13.01	9.60	31	14.08	9.36	27	9.92	6.21
RTL	Pre	30	6.63	6.01	31	10.85	8.37	27	9.81	5.53
	Post	30	11.07	9.54	31	10.53	7.90	27	9.65	7.41
LTPJ	Pre	30	5.86	6.40	31	9.73	9.82	27	9.88	9.15
	Post	30	11.96	10.44	31	11.98	9.44	27	8.44	7.23
RTPJ	Pre	30	4.49	6.00	31	8.93	9.40	27	5.19	5.93
	Post	30	10.39	12.48	31	7.20	7.77	27	6.36	7.91

Analysis of assumptions

In the assumption testing for the Mental Rotation Task across various frequency bands, similar patterns to those observed in the previous tasks can be noted.

In the delta band, normality assumptions were frequently violated (W = 0.77 - 0.95, $p < 0.01$), while homoscedasticity was mostly observed (*K-squared* = 0.05 - 10.22, $p < 0.05$). Parallelism generally held (F = 0.05 - 3.58, $p < 0.05$), with few exceptions like FM, OL, and OM, indicating potential issues with variance across groups (see Table …. In appendix).

Moving to the theta band, normality assumptions continued to be challenged (W = 0.84 - 0.98, $p < 0.01$), particularly for variables like FM and LTPJ. Homoscedasticity was mostly observed (*K-squared* = 0.05 - 4.16, $p < 0.05$), except for outliers like RTL and LTPJ. Parallelism generally held (F = 0.02 - 1.75, $p < 0.05$), although deviations were seen in cases like RTL and RTPJ, suggesting unequal variances across conditions.

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In the lower alpha band, , violations of normality were common across variables (W = 0.60 - 0.85, p < 0.01), but homoscedasticity was mostly observed (*K-squared* = 0.06 - 17.41, p < 0.05). Parallelism was generally supported (F = 0.04 - 2.06, p < 0.05), although deviations were observed in cases like RTL, LTL, and LTPJ, indicating potential issues with variance across groups.

Similarly, in the upper alpha band, normality assumptions were frequently challenged (W = 0.70 - 0.91, p < 0.01), but homoscedasticity was mostly observed (*K-squared* = 0.02 - 10.39, p < 0.05). Parallelism was generally supported (F = 0.02 - 3.29, p < 0.05), although deviations were observed in cases like RTL and LTPJ.

In the full alpha and beta bands, patterns of normality violations, homoscedasticity, and parallelism were consistent with those seen in previous bands (W = 0.65 - 0.90, p < 0.01; *K-squared* = 0.05 - 31.61, p < 0.05; F = 0.03 - 7.56, p < 0.05).

Analysis of group comparisons

This section presents the results of ANCOVA for various parameters during the mental rotation task to visuospatial ability in older adults with MCI. ANCOVA revealed significant effects of group condition on many relative power spectrum bands in the main region of left temporal lobe and central midline. However, The results of the ANCOVA could not be interpreted due to violations of the regression slope homogeneity assumption. Therefore, separate regression analyses for each group are presented in the following section for the affected ROIs: Delta (FM), Upper alpha (LTL), and Beta (FM). The following are the ANCOVA results for ROIs that met the assumption.

In the delta band, no significant group effects were observed across most regions. For example, the frontal lobe (FL) showed a non-significant group effect with a small effect size *(F(*2, 84*)* = 1.62, p = .20, partial ω^2 = 0.01). Similarly, central electrode locations (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) exhibited non-significant group effects (all p > .05). However, significant group effects were observed in the occipital midline (OM) *(F(*2, 84*)* = 3.06, p = .05, partial ω^2 = 0.04)

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and left temporal lobe (LTL) *(F(*2, 84*)* = 3.55, *p* = .03, partial ω² = 0.05) with small effect sizes. Post-hoc comparisons revealed that for the LTL, the MCST group differed significantly from the control group *(t(84)* = -2.65, *p* = .03, Cohen's *d* = -0.72), indicating a moderate effect size.

For the theta band, no significant group effects were found in any region. For instance, the frontal lobe (FL) exhibited a non-significant group effect with a small effect size *(F(*2, 84*)* = 0.13, *p* = .88, partial ω² < .01). This pattern was consistent across the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all *p* > .05).

In the lower alpha band, , no significant group effects were observed. For instance, the frontal lobe (FL) showed a non-significant group effect with a small effect size *(F(*2, 84*)* = 0.29, *p* = .75, partial ω² < .01). Other regions including the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) also showed non-significant group effects (all p > .05).

The upper alpha band analysis showed some significant group effects. Specifically, the occipital midline (OM) exhibited a significant group effect with a small effect size *(F(*2, 84*)* = 3.89, *p* = .02, partial ω² = 0.06). Post-hoc comparisons indicated that for the OM, the MCST group was significantly different from the CST group *(t(84)* = 2.65, *p* = .03, Cohen's *d* = 0.70), indicating a moderate effect size. In the full alpha band, no significant group effects were observed. For instance, the frontal lobe (FL) exhibited a non-significant group effect with a small effect size *(F(*2, 84*)* = 0.75, *p* = .48, partial ω² < .01). This non-significant pattern was consistent across the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all p > .05).

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In the beta band, some significant group effects were observed. The central midline (CM) exhibited a significant group effect with a moderate effect size *(F(*2, 84*)* = 4.16, p = .02, partial $\omega^2 = 0.07$). Post-hoc comparisons indicated that the MCST group was significantly different from the control group *(t(84)* = 2.87, p = .02, Cohen's d = 0.78), showing a moderate effect size.

The ANCOVA results for the mental rotation task indicated some significant group effects in the delta, upper alpha, and beta bands. Notably, the occipital midline (OM) showed significant group effects in both the delta and upper alpha bands. The central midline (CM) exhibited significant group effects in the beta band, suggesting differences in spectral power between groups. Post-hoc comparisons revealed significant differences between specific groups, indicating moderate effect sizes in some cases. These findings suggest that certain brain regions and frequency bands are sensitive to group differences in the mental rotation task. See Table 46, for more information.

Table 46 ANCOVA of the mental rotation task

		df	*SS*	*MS*	*F*	*p*	ω_p^2
Delta							
FL	Pre-test	1	0.077	0.077	5.62	.02	0.05
	Group	2	0.044	0.022	1.62	.20	0.01
	Residuals	84	1.145	0.014			
FM*	Pre-test	1	0.050	0.050	1.71	.19	0.01
	Group	2	0.058	0.029	0.99	.38	0.00
	Residuals	84	2.473	0.029			
CL	Pre-test	1	0.141	0.141	5.91	.02	0.05
	Group	2	0.097	0.049	2.04	.14	0.02
	Residuals	84	2.001	0.024			
CM	Pre-test	1	0.080	0.080	2.96	.09	0.02
	Group	2	0.107	0.053	1.97	.15	0.02
	Residuals	84	2.266	0.027			
PL	Pre-test	1	0.162	0.162	7.52	<.01	0.07

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	0.041	0.021	0.96	.39	0.00
	Residuals	84	1.815	0.022			
PM	Pre-test	1	0.218	0.218	10.56	<.01	0.10
	Group	2	0.007	0.004	0.18	.84	0.00
	Residuals	84	1.733	0.021			
OL	Pre-test	1	0.111	0.111	7.62	<.01	0.07
	Group	2	0.045	0.023	1.56	.22	0.01
	Residuals	84	1.223	0.015			
OM	Pre-test	1	0.253	0.253	16.45	<.01	0.15
	Group	2	0.094	0.047	3.06	.05	0.04
	Residuals	84	1.292	0.015			
LTL	Pre-test	1	0.226	0.226	15.03	<.01	0.14
	Group	2	0.106	0.053	3.55	.03	0.05
	Residuals	84	1.260	0.015			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	84	-0.037	0.033	-1.13	.79	-0.30
	MCST-Control	84	-0.089	0.034	-2.65	.03	-0.72
	CST-Control	84	-0.052	0.032	-1.61	.33	-0.42
RTL	Pre-test	1	0.161	0.161	8.97	<.01	0.08
	Group	2	0.046	0.023	1.28	.28	0.01
	Residuals	84	1.508	0.018			
LTPJ	Pre-test	1	0.292	0.292	12.48	<.01	0.12
	Group	2	0.097	0.048	2.07	.13	0.02
	Residuals	84	1.964	0.023			
RTPJ	Pre-test	1	0.070	0.070	2.02	.16	0.01
	Group	2	0.089	0.044	1.29	.28	0.01
	Residuals	84	2.905	0.035			
Theta							
FL	Pre-test	1	<.001	<.001	0.36	.55	0.00
	Group	2	<.001	<.001	0.13	.88	0.00

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	84	0.090	0.001			
FM	Pre-test	1	0.001	0.001	0.54	.46	0.00
	Group	2	0.001	<.001	0.10	.90	0.00
	Residuals	84	0.208	0.002			
CL	Pre-test	1	0.003	0.003	2.20	.14	0.01
	Group	2	0.003	0.001	1.11	.33	0.00
	Residuals	84	0.105	0.001			
CM	Pre-test	1	0.004	0.004	1.99	.16	0.01
	Group	2	0.004	0.002	0.86	.43	0.00
	Residuals	84	0.182	0.002			
PL	Pre-test	1	0.010	0.010	6.80	.01	0.06
	Group	2	<.001	<.001	0.11	.89	0.00
	Residuals	84	0.118	0.001			
PM	Pre-test	1	0.020	0.020	8.77	<.01	0.08
	Group	2	<.001	<.001	0.03	.97	0.00
	Residuals	84	0.191	0.002			
OL	Pre-test	1	0.014	0.014	9.01	<.01	0.08
	Group	2	0.002	0.001	0.55	.58	0.00
	Residuals	84	0.134	0.002			
OM	Pre-test	1	0.028	0.028	13.15	<.01	0.12
	Group	2	0.007	0.003	1.64	.20	0.01
	Residuals	84	0.176	0.002			
LTL	Pre-test	1	0.005	0.005	6.84	.01	0.06
	Group	2	0.003	0.002	2.42	.10	0.03
	Residuals	84	0.057	0.001			
RTL	Pre-test	1	0.005	0.005	6.43	.01	0.06
	Group	2	0.002	0.001	1.50	.23	0.01
	Residuals	84	0.064	0.001			
LTPJ	Pre-test	1	0.007	0.007	6.06	.02	0.05
	Group	2	0.002	0.001	0.86	.43	0.00

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	84	0.101	0.001			
RTPJ	Pre-test	1	0.003	0.003	1.88	.17	0.01
	Group	2	0.002	0.001	0.65	.53	0.00
	Residuals	84	0.148	0.002			
Lower Alpha							
FL	Pre-test	1	0.002	0.002	8.12	<.01	0.07
	Group	2	<.001	<.001	0.29	.75	0.00
	Residuals	84	0.019	<.001			
FM	Pre-test	1	0.003	0.003	2.39	.13	0.02
	Group	2	0.001	<.001	0.44	.65	0.00
	Residuals	84	0.093	0.001			
CL	Pre-test	1	0.008	0.008	6.64	.01	0.06
	Group	2	<.001	<.001	0.10	.90	0.00
	Residuals	84	0.101	0.001			
CM	Pre-test	1	0.003	0.003	1.81	.18	0.01
	Group	2	0.001	<.001	0.14	.87	0.00
	Residuals	84	0.162	0.002			
PL	Pre-test	1	0.005	0.005	5.42	.02	0.05
	Group	2	<.001	<.001	0.01	.99	0.00
	Residuals	84	0.080	0.001			
PM	Pre-test	1	0.003	0.003	3.60	.06	0.03
	Group	2	<.001	<.001	0.17	.84	0.00
	Residuals	84	0.063	0.001			
OL	Pre-test	1	0.003	0.003	10.93	<.01	0.10
	Group	2	<.001	<.001	0.53	.59	0.00
	Residuals	84	0.023	<.001			
OM	Pre-test	1	0.009	0.009	27.37	<.01	0.23
	Group	2	0.001	<.001	1.54	.22	0.01
	Residuals	84	0.027	<.001			
LTL	Pre-test	1	0.014	0.014	15.73	<.01	0.14

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	0.001	0.001	0.80	.45	0.00
	Residuals	84	0.074	0.001			
RTL	Pre-test	1	0.009	0.009	9.51	<.01	0.09
	Group	2	0.001	0.001	0.60	.55	0.00
	Residuals	84	0.079	0.001			
LTPJ	Pre-test	1	0.007	0.007	5.79	.02	0.05
	Group	2	0.001	<.001	0.23	.79	0.00
	Residuals	84	0.104	0.001			
RTPJ	Pre-test	1	0.005	0.005	3.31	.07	0.03
	Group	2	0.001	<.001	0.20	.82	0.00
	Residuals	84	0.138	0.002			
Upper Alpha							
FL	Pre-test	1	0.001	0.001	5.44	.02	0.05
	Group	2	0.001	<.001	1.27	.29	0.01
	Residuals	84	0.019	<.001			
FM	Pre-test	1	<.001	<.001	0.63	.43	0.00
	Group	2	0.001	<.001	0.79	.46	0.00
	Residuals	84	0.051	0.001			
CL	Pre-test	1	0.008	0.008	14.32	<.01	0.13
	Group	2	0.002	0.001	1.95	.15	0.02
	Residuals	84	0.045	0.001			
CM	Pre-test	1	0.001	0.001	2.55	.11	0.02
	Group	2	0.002	0.001	1.66	.20	0.01
	Residuals	84	0.049	0.001			
PL	Pre-test	1	0.006	0.006	9.51	<.01	0.09
	Group	2	0.001	0.001	1.11	.33	0.00
	Residuals	84	0.052	0.001			
PM	Pre-test	1	0.005	0.005	7.93	<.01	0.07
	Group	2	<.001	<.001	0.34	.71	0.00
	Residuals	84	0.051	0.001			

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
OL	Pre-test	1	0.002	0.002	8.46	<.01	0.08
	Group	2	0.001	<.001	1.75	.18	0.02
	Residuals	84	0.024	<.001			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	84	0.011	0.004	2.65	.03	0.70
	MCST-Control	84	0.008	0.004	2.05	.13	0.54
	CST-Control	84	-0.002	0.004	-0.57	1	-0.15
OM	Pre-test	1	0.006	0.006	24.39	<.01	0.21
	Group	2	0.002	0.001	3.89	.02	0.06
	Residuals	84	0.020	<.001			
LTL*	Pre-test	1	0.010	0.010	26.97	<.01	0.23
	Group	2	0.002	0.001	3.25	.04	0.05
	Residuals	84	0.030	<.001			
RTL	Pre-test	1	0.006	0.006	15.11	<.01	0.14
	Group	2	0.001	0.001	1.78	.17	0.02
	Residuals	84	0.033	<.001			
LTPJ	Pre-test	1	0.012	0.012	16.43	<.01	0.15
	Group	2	0.002	0.001	1.50	.23	0.01
	Residuals	84	0.060	0.001			
RTPJ	Pre-test	1	0.005	0.005	5.24	.02	0.05
	Group	2	0.003	0.002	1.57	.21	0.01
	Residuals	84	0.081	0.001			
Full Alpha							
FL	Pre-test	1	0.005	0.005	6.70	.01	0.06
	Group	2	0.001	0.001	0.75	.48	0.00
	Residuals	84	0.067	0.001			
FM	Pre-test	1	0.004	0.004	1.28	.26	0.00
	Group	2	0.003	0.002	0.53	.59	0.00
	Residuals	84	0.243	0.003			
CL	Pre-test	1	0.029	0.029	10.35	<.01	0.10

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	0.004	0.002	0.64	.53	0.00
	Residuals	84	0.237	0.003			
CM	Pre-test	1	0.008	0.008	1.96	.17	0.01
	Group	2	0.004	0.002	0.53	.59	0.00
	Residuals	84	0.324	0.004			
PL	Pre-test	1	0.021	0.021	8.07	<.01	0.07
	Group	2	0.002	0.001	0.31	.73	0.00
	Residuals	84	0.223	0.003			
PM	Pre-test	1	0.015	0.015	6.52	.01	0.06
	Group	2	<.001	<.001	0.01	.99	0.00
	Residuals	84	0.191	0.002			
OL	Pre-test	1	0.011	0.011	10.50	<.01	0.10
	Group	2	0.002	0.001	1.16	.32	0.00
	Residuals	84	0.087	0.001			
OM	Pre-test	1	0.029	0.029	28.75	<.01	0.24
	Group	2	0.006	0.003	2.81	.07	0.04
	Residuals	84	0.086	0.001			
LTL	Pre-test	1	0.042	0.042	22.25	<.01	0.19
	Group	2	0.007	0.004	1.84	.16	0.02
	Residuals	84	0.160	0.002			
RTL	Pre-test	1	0.027	0.027	13.02	<.01	0.12
	Group	2	0.005	0.002	1.10	.34	0.00
	Residuals	84	0.174	0.002			
LTPJ	Pre-test	1	0.035	0.035	10.88	<.01	0.10
	Group	2	0.005	0.002	0.76	.47	0.00
	Residuals	84	0.268	0.003			
RTPJ	Pre-test	1	0.021	0.021	4.79	.03	0.04
	Group	2	0.006	0.003	0.65	.52	0.00
	Residuals	84	0.362	0.004			

Beta

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
FL	Pre-test	1	0.056	0.056	6.67	.01	0.06
	Group	2	0.026	0.013	1.54	.22	0.01
	Residuals	84	0.699	0.008			
FM*	Pre-test	1	0.040	0.040	4.52	.04	0.04
	Group	2	0.039	0.020	2.21	.12	0.03
	Residuals	84	0.743	0.009			
CL	Pre-test	1	0.048	0.048	6.76	.01	0.06
	Group	2	0.043	0.021	2.99	.06	0.04
	Residuals	84	0.597	0.007			
CM	Pre-test	1	0.020	0.020	3.88	.05	0.03
	Group	2	0.044	0.022	4.16	.02	0.07
	Residuals	84	0.440	0.005			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	84	0.023	0.019	1.21	.69	0.32
	MCST-Control	84	0.056	0.020	2.87	.02	0.78
	CST-Control	84	0.033	0.019	1.73	.26	0.46
PL	Pre-test	1	0.034	0.034	6.34	.01	0.06
	Group	2	0.021	0.010	1.93	.15	0.02
	Residuals	84	0.456	0.005			
PM	Pre-test	1	0.037	0.037	8.42	<.01	0.08
	Group	2	0.007	0.004	0.84	.44	0.00
	Residuals	84	0.367	0.004			
OL	Pre-test	1	0.011	0.011	3.10	.08	0.02
	Group	2	0.014	0.007	2.04	.14	0.02
	Residuals	84	0.297	0.004			
OM	Pre-test	1	0.025	0.025	7.33	<.01	0.07
	Group	2	0.021	0.011	3.04	.05	0.04
	Residuals	84	0.292	0.003			
LTL	Pre-test	1	0.076	0.076	11.67	<.01	0.11
	Group	2	0.038	0.019	2.92	.06	0.04

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	84	0.544	0.006			
RTL	Pre-test	1	0.052	0.052	8.19	<.01	0.08
	Group	2	0.011	0.006	0.88	.42	0.00
	Residuals	84	0.534	0.006			
LTPJ	Pre-test	1	0.081	0.081	10.83	<.01	0.10
	Group	2	0.038	0.019	2.52	.09	0.03
	Residuals	84	0.625	0.007			
RTPJ	Pre-test	1	0.007	0.007	0.77	.38	0.00
	Group	2	0.031	0.016	1.67	.19	0.01
	Residuals	84	0.783	0.009			

*A significant interaction effect

Analysis of regression

This analysis evaluates the predictive relationships of the relative powers (i.e., pre-test and post-test) for specific frequency bands (delta, upper alpha, and beta) across the LTL and FM regions for the three groups, including MCST, CST, and control.

For the relative delta, in the FM region, the MCST group shows significant predictive power ($\beta_1 = 0.95$, $p = .01$, adjusted $R^2 = .18$), suggesting a moderate intervention effect. The CST group fails to show significance ($\beta_1 = 0.15$, $p = .49$, adjusted $R^2 = -.02$), indicating a lack of predictive capacity. The control group also fails to demonstrate a significant relationship ($\beta_1 = -0.28$, $p = .37$, adjusted $R^2 = -.01$) (see Figure 47).

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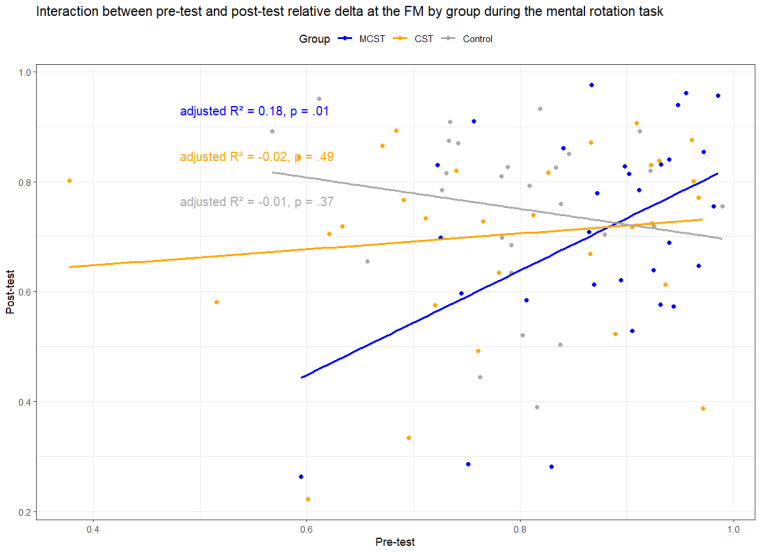

Figure 47 A scatter plot and the regression lines are shows interaction between pre-test and post-test relative delta at the frontal midline (FM) by group during the mental rotation task

For the relative upper alpha, the LTL region, ihe MCST group demonstrates strong predictive power ($\beta_1 = 1.08$, $p < .001$, adjusted $R^2 = .46$), indicating a significant intervention effect. The CST group shows a moderate relationship ($\beta_1 = 0.39$, $p = .01$, adjusted $R^2 = .16$), but the effect is weaker compared to MCST. The control group exhibits a moderate relationship ($\beta_1 = 0.55$, $p < .001$, adjusted $R^2 = .25$), suggesting natural predictive capacity.

For the relative beta, in the FM region, the MCST group demonstrates significant predictive power ($\beta_1 = 1.38$, $p < .001$, adjusted $R^2 = .34$), highlighting the impact of the intervention on this frequency band. The CST group fails to demonstrate significance ($\beta_1 = 0.09$, $p = .65$, adjusted $R^2 = -.03$), indicating minimal intervention effects. The control group also fails to demonstrate a significant relationship ($\beta_1 = -0.16$, $p = .63$, adjusted $R^2 = -.03$), suggesting no natural predictive capacity in this band for the FM region.

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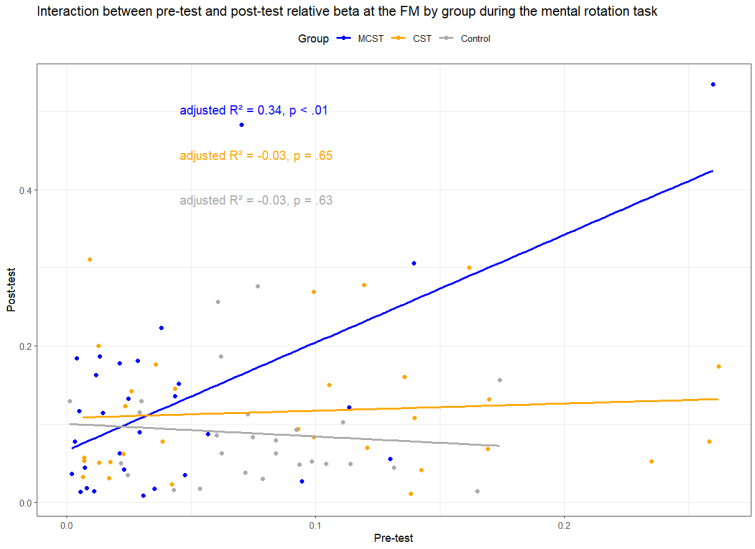

Figure 48 A scatter plot and the regression lines are shows interaction between pre-test and post-test relative beta at the frontal midline (FM) by group during the mental rotation task

In summary, in the mental rotation task, the MCST group consistently demonstrates significant predictive relationships, particularly in the upper alpha and beta, indicating strong intervention effects (adjusted $R^2 \approx .34–0.46$). The CST group shows moderate significance only in the upper alpha band (adjusted $R^2 \approx .16$) but fails to reach significance in the beta and delta bands. The control group demonstrates moderate predictive capacity in the upper alpha band (adjusted $R^2 \approx .25$R) but fails to show significance in other bands, highlighting the importance of targeted interventions in improving mental rotation task performance.

Table 47 Regression analysis of the mental rotation task

ROI	Model	Variable	*β*	*SE*	*t*	*p*
Delta						
FM	MCST	Constant	-0.12	0.30	-0.40	.69
		Pre-test	0.95	0.35	2.74	.01
	CST	Constant	0.59	0.16	3.58	<.01
		Pre-test	0.15	0.21	0.70	.49
	Control	Constant	0.98	0.25	3.90	<.01
		Pre-test	-0.28	0.31	-0.91	.37
Upper Alpha						

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ROI	Model	Variable	*β*	*SE*	*t*	*p*
LTL	MCST	Constant	0.02	0.01	2.99	.01
		Pre-test	1.08	0.21	5.05	<.01
	CST	Constant	0.02	0.01	4.02	<.01
		Pre-test	0.39	0.15	2.60	.01
	Control	Constant	0.01	0.01	2.21	.04
		Pre-test	0.55	0.18	3.11	<.01
Beta						
FM	MCST	Constant	0.07	0.02	2.71	.01
		Pre-test	1.38	0.35	3.97	<.01
	CST	Constant	0.11	0.02	4.58	<.01
		Pre-test	0.09	0.20	0.46	.65
	Control	Constant	0.10	0.03	3.51	<.01
		Pre-test	-0.16	0.33	-0.49	.63

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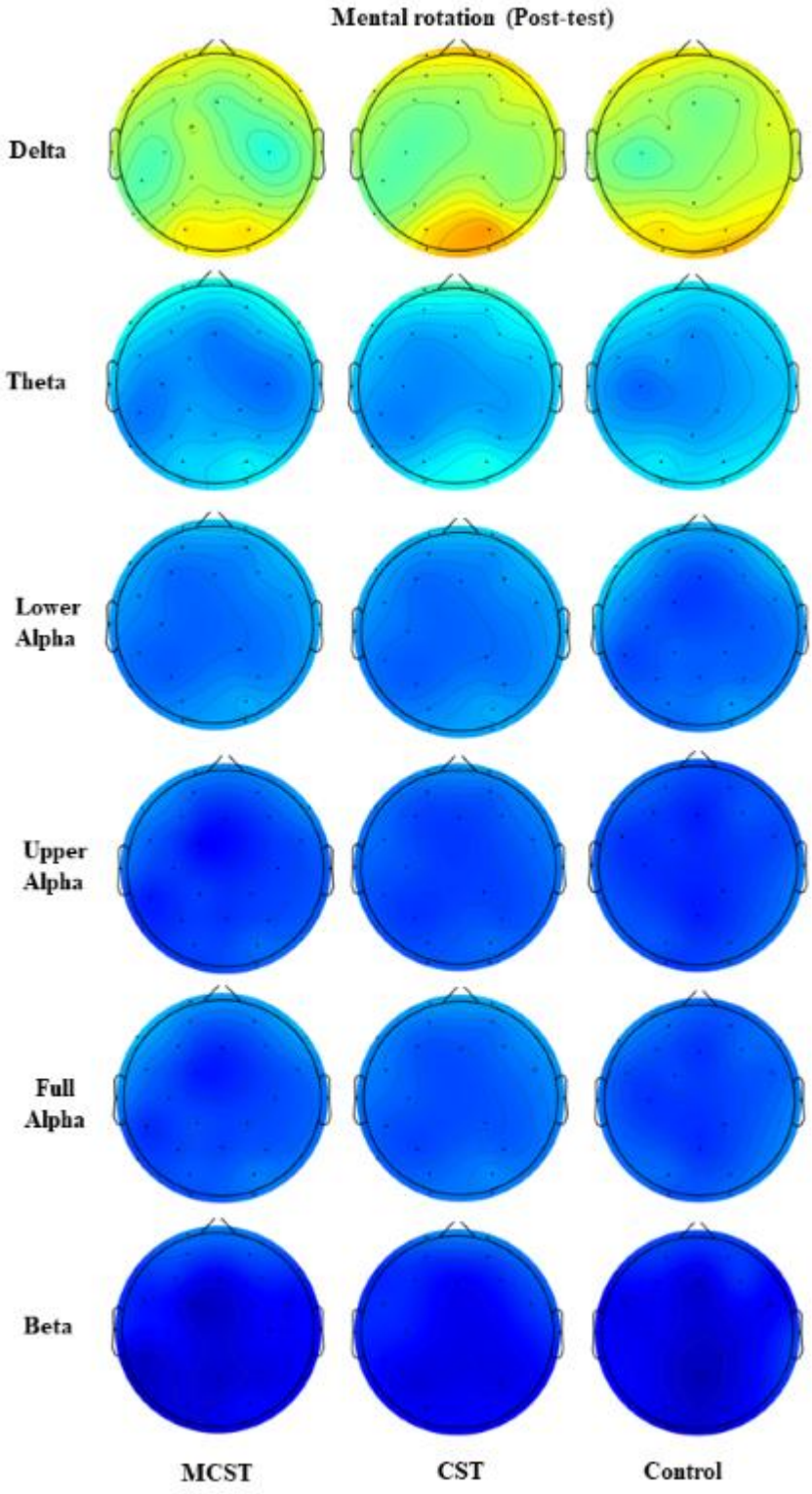

Figure 49 The topographic brain mapping of relative power during the mental rotation task at post-test

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EEG - Wisconsin card sorting test

Analysis of the relative power characteristics

In the analysis of relative spectral power of band frequencies in the Wisconsin Card Sorting Test (WCST), several parameters across different brain regions were examined, including delta, theta, lower alpha, upper alpha, full alpha, and beta bands (see Table 48).

Across brain regions, there was a consistent decrease in Delta band activity from pre-test to post-test conditions. For instance, in the frontal lobe (FL), the mean (M) Delta band power decreased from approximately 81.63% to 75.39%. Similar reductions were observed in other brain regions, reflecting a general decline in slow-wave activity following the WCST.

Theta band activity exhibited more varied patterns across brain regions. In some areas, such as the frontal lobe (FL), there was a slight increase in Theta band power from pre-test to post-test conditions (M = 8.91% to 9.22%). However, in other regions like central electrode locations (CL), Theta band power decreased (M = 5.58% to 7.44%). These changes suggest region-specific alterations in Theta band activity associated with WCST performance.

Lower Alpha band activity generally increased across brain regions from pre-test to post-test conditions. Notably, in the frontal lobe (FL), there was a substantial rise in Lower Alpha power (M = 1.43% to 2.07%). Similar trends were observed in other regions, indicating a consistent enhancement of Lower Alpha activity following WCST completion.

In contrast to Lower Alpha, Upper Alpha band activity exhibited more variable changes across brain regions. While some areas, like the frontal lobe (FL), showed an increase in Upper Alpha power (M = 1.39% to 2.37%), other regions displayed different patterns. For instance, in the occipital lobe (OL), Upper Alpha power decreased from pre-test to post-test conditions (M = 1.39% to 1.28%). These findings suggest heterogeneous alterations in Upper Alpha band activity following WCST performance.

The Full Alpha band analysis revealed overall increases in activity across brain regions from pre-test to post-test conditions. Notably, in the frontal lobe (FL), Full Alpha power exhibited a substantial rise (M = 2.81% to

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4.44%). Similar trends were observed in other areas, indicating a widespread enhancement of Alpha band activity following WCST completion.

Beta band activity demonstrated consistent increases across brain regions following WCST performance. For instance, in the frontal lobe (FL), Beta band power rose significantly from pre-test to post-test conditions (M = 6.64% to 10.95%). Comparable elevations were observed in other regions, suggesting a global augmentation of Beta band activity associated with WCST completion.

In summary, the analysis of relative spectral power of band frequencies in the WCST revealed diverse changes across different brain regions and relative power spectrum bands. While some parameters exhibited consistent trends, such as the decrease in Delta band activity and the increase in Alpha and Beta band activity, others displayed more variable patterns.

Table 48 Characteristic of relative spectral power (%) of band frequencies in the Wisconsin card sorting test

		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Delta										
FL	Pre	31	81.63	7.15	31	79.07	8.07	28	78.74	7.06
	Post	31	75.39	10.12	31	74.90	9.43	28	75.68	11.51
FM	Pre	31	87.93	7.60	31	81.48	10.73	28	81.87	9.48
	Post	31	78.46	13.34	31	75.15	13.65	28	76.86	13.24
CL	Pre	31	86.14	8.69	31	79.98	12.57	28	81.07	11.11
	Post	31	76.24	12.53	31	73.30	14.94	28	76.95	14.12
CM	Pre	31	89.59	9.07	31	84.06	12.95	28	85.36	9.77
	Post	31	80.34	14.19	31	77.32	15.77	28	78.90	16.25
PL	Pre	31	89.27	6.58	31	86.24	11.75	28	86.50	8.73
	Post	31	81.21	14.79	31	81.92	12.30	28	82.50	12.93
PM	Pre	31	90.42	7.06	31	85.81	14.29	28	88.55	9.05
	Post	31	85.82	12.87	31	86.06	12.80	28	85.16	13.99
OL	Pre	31	91.26	6.99	31	87.66	12.44	28	90.90	8.90

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	31	88.12	10.88	31	90.10	7.36	28	88.91	11.03
OM	Pre	31	91.80	7.68	31	88.04	12.59	28	90.69	7.62
	Post	31	87.92	12.24	31	89.20	10.09	28	89.00	13.29
LTL	Pre	31	82.45	9.81	31	78.78	11.36	28	77.24	10.02
	Post	31	73.31	12.85	31	73.35	12.26	28	76.21	11.77
RTL	Pre	31	83.53	8.35	31	80.11	9.94	28	81.75	7.89
	Post	31	77.73	12.15	31	77.64	11.36	28	77.89	12.96
LTPJ	Pre	31	85.78	11.14	31	82.40	15.60	28	79.35	13.14
	Post	31	75.65	16.34	31	77.72	13.94	28	79.70	12.54
RTPJ	Pre	31	87.51	8.84	31	83.90	12.15	28	88.90	8.82
	Post	31	81.73	16.25	31	82.70	13.97	28	82.90	15.94
Theta										
FL	Pre	31	8.91	2.83	31	8.80	2.88	28	9.07	2.21
	Post	31	9.22	2.24	31	9.46	2.99	28	8.45	2.31
FM	Pre	31	5.54	2.58	31	7.84	4.03	28	7.77	3.21
	Post	31	8.39	3.96	31	9.66	3.84	28	8.50	3.50
CL	Pre	31	5.58	2.46	31	6.57	2.63	28	6.56	2.44
	Post	31	7.44	2.75	31	8.12	2.89	28	7.18	2.97
CM	Pre	31	4.80	2.88	31	6.05	3.88	28	6.07	2.95
	Post	31	7.04	3.74	31	7.54	3.51	28	7.40	4.29
PL	Pre	31	4.94	1.96	31	5.39	2.87	28	5.85	2.66
	Post	31	6.41	3.15	31	6.34	2.52	28	6.13	2.66
PM	Pre	31	4.96	3.14	31	5.88	3.69	28	5.50	3.06
	Post	31	6.21	3.69	31	5.55	3.44	28	5.88	4.09
OL	Pre	31	4.60	2.91	31	5.14	3.42	28	4.52	3.09
	Post	31	5.08	2.72	31	4.62	2.50	28	4.70	2.50
OM	Pre	31	4.54	3.48	31	5.12	3.63	28	4.89	3.09
	Post	31	5.44	3.47	31	5.09	3.49	28	4.24	2.77
LTL	Pre	31	6.97	3.01	31	6.95	2.23	28	7.93	2.13

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	31	8.49	2.44	31	8.45	2.08	28	7.46	2.50
RTL	Pre	31	6.48	2.10	31	7.14	2.04	28	6.62	2.03
	Post	31	7.29	2.16	31	7.14	2.16	28	6.70	1.91
LTPJ	Pre	31	5.99	3.48	31	5.70	3.18	28	7.54	3.04
	Post	31	7.86	3.39	31	7.45	2.65	28	6.85	3.00
RTPJ	Pre	31	5.41	2.54	31	5.96	2.95	28	4.81	2.71
	Post	31	6.10	3.19	31	5.63	3.06	28	5.46	2.82
Lower Alpha										
FL	Pre	31	1.43	0.62	31	1.83	0.89	28	1.70	0.77
	Post	31	2.07	1.16	31	2.21	1.50	28	2.14	1.56
FM	Pre	31	1.20	0.80	31	2.10	1.68	28	1.91	1.48
	Post	31	2.20	1.57	31	2.97	2.72	28	2.71	2.28
CL	Pre	31	1.37	0.93	31	2.16	1.49	28	1.82	1.42
	Post	31	2.41	1.54	31	3.23	3.00	28	2.73	3.08
CM	Pre	31	1.08	1.12	31	1.96	1.88	28	1.64	1.61
	Post	31	2.32	2.02	31	3.07	3.22	28	3.09	5.15
PL	Pre	31	1.11	0.70	31	1.58	1.56	28	1.38	0.95
	Post	31	2.09	1.90	31	2.34	2.38	28	2.05	2.10
PM	Pre	31	0.99	0.82	31	1.71	2.11	28	1.19	0.88
	Post	31	1.62	1.67	31	2.11	3.33	28	1.79	2.06
OL	Pre	31	0.91	0.78	31	1.39	1.70	28	0.87	0.78
	Post	31	1.28	1.40	31	1.13	1.22	28	1.10	0.94
OM	Pre	31	0.83	0.83	31	1.31	1.69	28	0.92	0.71
	Post	31	1.31	1.59	31	1.24	1.63	28	1.08	1.17
LTL	Pre	31	1.72	1.07	31	2.21	1.41	28	2.28	1.41
	Post	31	2.73	1.79	31	2.80	1.62	28	2.73	2.55
RTL	Pre	31	1.63	0.90	31	2.11	1.22	28	1.64	0.86
	Post	31	2.36	1.83	31	2.34	1.80	28	2.33	2.20
LTPJ	Pre	31	1.41	1.16	31	1.95	2.00	28	2.21	1.94

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		MCST			CST			Control	
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	31	2.55	2.07	31	2.41	1.71	28	2.45	2.28
RTPJ	Pre	31	1.31	1.03	31	1.84	1.70	28	1.04	0.74
	Post	31	2.15	2.69	31	2.15	2.66	28	2.05	2.64
Upper Alpha										
FL	Pre	31	1.39	0.97	31	1.82	1.04	28	1.78	1.00
	Post	31	2.37	1.88	31	2.17	1.22	28	2.25	1.46
FM	Pre	31	1.16	0.94	31	2.01	1.60	28	1.82	1.19
	Post	31	2.31	1.94	31	2.70	1.95	28	2.67	2.03
CL	Pre	31	1.51	1.31	31	2.47	2.07	28	2.14	1.78
	Post	31	2.93	2.57	31	3.38	2.33	28	2.90	2.30
CM	Pre	31	1.13	1.40	31	1.98	1.79	28	1.74	1.68
	Post	31	2.51	2.81	31	2.92	2.21	28	2.66	2.25
PL	Pre	31	1.17	0.96	31	1.81	2.04	28	1.60	1.35
	Post	31	2.75	3.37	31	2.45	2.21	28	2.34	2.05
PM	Pre	31	0.98	0.97	31	1.96	2.86	28	1.31	1.24
	Post	31	1.90	3.16	31	1.87	2.11	28	2.02	2.56
OL	Pre	31	0.86	0.81	31	1.57	2.08	28	0.92	1.03
	Post	31	1.50	1.96	31	1.09	1.07	28	1.35	1.63
OM	Pre	31	0.74	0.80	31	1.44	1.96	28	0.94	0.91
	Post	31	1.40	1.90	31	1.14	1.40	28	1.38	1.95
LTL	Pre	31	1.78	1.26	31	2.44	1.88	28	2.52	1.68
	Post	31	3.21	2.57	31	2.97	1.75	28	2.79	2.16
RTL	Pre	31	1.73	1.14	31	2.26	1.58	28	1.79	1.04
	Post	31	2.70	2.40	31	2.43	1.59	28	2.54	2.20
LTPJ	Pre	31	1.57	1.55	31	2.44	2.83	28	2.63	2.42
	Post	31	3.39	3.45	31	2.90	2.49	28	2.78	2.53
RTPJ	Pre	31	1.38	1.31	31	2.10	2.29	28	1.10	0.98
	Post	31	2.62	3.48	31	2.19	2.29	28	2.34	2.82
Full Alpha										

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
FL	Pre	31	2.81	1.54	31	3.66	1.89	28	3.48	1.74
	Post	31	4.44	2.98	31	4.39	2.58	28	4.40	2.82
FM	Pre	31	2.37	1.66	31	4.11	3.18	28	3.73	2.60
	Post	31	4.51	3.46	31	5.67	4.45	28	5.38	3.99
CL	Pre	31	2.87	2.20	31	4.63	3.50	28	3.96	3.17
	Post	31	5.35	4.04	31	6.61	5.08	28	5.63	4.76
CM	Pre	31	2.21	2.50	31	3.94	3.60	28	3.38	3.26
	Post	31	4.83	4.73	31	5.99	5.17	28	5.75	6.57
PL	Pre	31	2.27	1.63	31	3.39	3.55	28	2.98	2.28
	Post	31	4.83	5.19	31	4.80	4.33	28	4.39	3.72
PM	Pre	31	1.97	1.75	31	3.67	4.92	28	2.50	2.09
	Post	31	3.51	4.74	31	3.99	5.28	28	3.82	4.44
OL	Pre	31	1.78	1.56	31	2.96	3.75	28	1.79	1.79
	Post	31	2.78	3.32	31	2.22	2.25	28	2.45	2.54
OM	Pre	31	1.57	1.59	31	2.75	3.64	28	1.86	1.61
	Post	31	2.71	3.46	31	2.38	2.99	28	2.47	3.08
LTL	Pre	31	3.50	2.29	31	4.65	3.25	28	4.80	2.97
	Post	31	5.93	4.25	31	5.77	3.16	28	5.51	4.30
RTL	Pre	31	3.36	1.99	31	4.37	2.76	28	3.43	1.88
	Post	31	5.06	4.12	31	4.77	3.23	28	4.87	3.96
LTPJ	Pre	31	2.98	2.66	31	4.39	4.78	28	4.84	4.26
	Post	31	5.95	5.46	31	5.31	4.05	28	5.23	4.48
RTPJ	Pre	31	2.70	2.28	31	3.94	3.95	28	2.14	1.71
	Post	31	4.77	6.12	31	4.34	4.75	28	4.39	4.91
Beta										
FL	Pre	31	6.64	5.83	31	8.47	6.13	28	8.71	5.18
	Post	31	10.95	7.17	31	11.26	8.26	28	11.47	8.83
FM	Pre	31	4.17	4.19	31	6.57	5.46	28	6.63	4.51
	Post	31	8.64	7.99	31	9.52	7.42	28	9.26	7.75

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		MCST			CST			Control	
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
CL	Pre	31	5.41	4.63	31	8.81	7.39	28	8.40	6.54
	Post	31	10.98	6.97	31	11.98	8.46	28	10.24	8.42
CM	Pre	31	3.39	4.19	31	5.96	5.97	28	5.20	4.43
	Post	31	7.80	6.59	31	9.15	8.14	28	7.95	8.02
PL	Pre	31	3.52	3.84	31	4.98	6.08	28	4.67	4.50
	Post	31	7.54	7.35	31	6.94	6.54	28	6.97	8.36
PM	Pre	31	2.66	3.03	31	4.65	6.21	28	3.45	4.34
	Post	31	4.45	5.50	31	4.40	4.97	28	5.15	7.28
OL	Pre	31	2.37	3.23	31	4.24	5.65	28	2.79	4.40
	Post	31	4.02	5.30	31	3.06	3.07	28	3.94	7.11
OM	Pre	31	2.08	3.37	31	4.09	5.75	28	2.56	3.40
	Post	31	3.93	5.97	31	3.33	4.06	28	4.29	8.52
LTL	Pre	31	7.08	5.84	31	9.62	6.90	28	10.02	6.44
	Post	31	12.27	8.16	31	12.43	9.42	28	10.81	7.15
RTL	Pre	31	6.64	5.13	31	8.37	6.20	28	8.20	4.75
	Post	31	9.92	7.03	31	10.45	7.74	28	10.54	8.68
LTPJ	Pre	31	5.25	6.17	31	7.51	8.43	28	8.27	7.40
	Post	31	10.55	8.98	31	9.52	9.14	28	8.22	6.96
RTPJ	Pre	31	4.38	4.75	31	6.20	6.13	28	4.15	4.81
	Post	31	7.40	8.13	31	7.32	7.58	28	7.26	9.98

Analysis of assumptions

In the Wisconsin Card Sorting Task, the assumption testing across different relative power spectrum bands reveals notable patterns. In the delta band, while normality assumptions were frequently violated (W = 0.70 - 0.95, p < 0.01), homoscedasticity was mostly observed (*K-squared* = 0.03 - 24.25, p < 0.01), except for outliers like OL and OM. Parallelism, indicating the equality of variances between groups, was generally met (F = 0.09 - 4.92, p < 0.05), except for PM, suggesting potential issues with variance across conditions.

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Moving to the theta band, normality assumptions continued to be challenged (W = 0.54 - 0.98, $p < 0.05$), particularly for variables like OL, OM, and RTPJ. However, homoscedasticity was generally observed (*K-squared* = 0.01 - 25.53, $p < 0.05$), except for outliers like OM. Parallelism, while generally supported (F = 0.00 - 11.12, $p < 0.05$), showed exceptions such as RTPJ, indicating unequal variances across groups.

In the lower alpha band, , violations of normality were common across variables (W = 0.59 - 0.85, $p < 0.01$), although homoscedasticity was mostly observed (*K-squared* = 0.01 - 22.64, $p < 0.05$). Parallelism was generally supported (F = 0.04 - 4.26, $p < 0.05$), but deviations were observed in cases like RTL, suggesting unequal variances across conditions.

Similarly, in the upper alpha band, normality assumptions were frequently challenged (W = 0.63 - 0.87, $p < 0.01$), but homoscedasticity was mostly observed (*K-squared* = 0.06 - 22.11, $p < 0.05$). However, parallelism had exceptions such as PM and OM (F = 0.15 - 11.12, $p < 0.05$), indicating potential issues with variance across conditions.

Finally, In the full alpha and beta bands, patterns of normality violations, homoscedasticity, and parallelism echoed those seen in previous bands (W = 0.54 - 0.91, $p < 0.01$; *K-squared* = 0.01 - 43.84, $p < 0.01$; F = 0.00 - 11.12, $p < 0.05$), highlighting the importance of considering these factors in subsequent data analyses.

Overall, these results underscore the variability in assumption adherence across different relative power spectrum bands in the Wisconsin Card Sorting Task, emphasizing the need for careful consideration of these factors when interpreting study outcomes.

Analysis of group comparisons

This section presents the results of ANCOVA for various parameters during the Wisconsin card sorting test to measure executive functions in older adults with MCI. Overall, all of relative bands no significant group effects were observed across any brain regions in the test. However, the results of the ANCOVA could not be interpreted due to violations of the regression slope homogeneity assumption. Therefore, separate regression analyses for each group are presented in

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the following section for the affected ROIs: Delta (OM, PM), Upper alpha (OM, PM), Full alpha , and Beta (OL, OM, PM). The following are the ANCOVA results for ROIs that met the assumption.

In the delta band, the analysis revealed no significant group effects across all regions. For example, the frontal lobe (FL) exhibited a non-significant group effect with a small effect size *(F(*2, 86*)* = 0.20, *p* = .82, partial $\omega^2 <$ .01). This non-significant pattern was consistent across the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), occipital lobe (OL), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all p > .05).

For the theta band, no significant group effects were observed in any region. The frontal lobe (FL) showed a non-significant group effect with a small effect size *(F(*2, 86*)* = 1.30, *p* = .28, partial $\omega^2 = 0.01$). Similarly, the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) all demonstrated non-significant group effects (all *p* > .05).

In the lower alpha band, no significant group effects were identified across any regions. The frontal lobe (FL) had a non-significant group effect with a small effect size *(F(*2, 86) < .01, *p* = 1.00, partial $\omega^2 <$ .01). This trend persisted in the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all *p* > .05).

The upper alpha band analysis showed no significant group effects. For instance, the frontal lobe (FL) exhibited a non-significant group effect with a small effect size *(F(*2, 86*)* = 0.56, *p* = .57, partial $\omega^2 <$ .01). Other regions, including the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), occipital lobe (OL), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) also showed non-significant group effects (all p > .05).

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In the full alpha band, no significant group effects were observed in any region. The frontal lobe (FL) exhibited a non-significant group effect with a small effect size *(F(*2, 86*)* = 0.14, *p* = .87, partial ω² < .01). This non-significant pattern was consistent across the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all p > .05).

For the beta band, the analysis revealed no significant group effects. The frontal lobe (FL) showed a non-significant group effect with a small effect size *(F(*2, 86*)* = 0.05, *p* = .95, partial ω² < .01). This non-significant trend was observed across the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all p > .05).

The ANCOVA results for the Wisconsin Card Sorting Task indicated no significant group effects across all of relative power spectrum bands in any of the brain regions examined. This suggests that group differences in spectral power were not evident in this task, as measured by the EEG parameters across the different brain regions. Please see Table 49 ANCOVA of the Wisconsin coard sorting task, for more information.

Table 49 ANCOVA of the Wisconsin coard sorting task

		df	*SS*	*MS*	*F*	*p*	ω_p^2
Delta							
FL	Pre-test	1	0.101	0.101	10.49	<.01	0.10
	Group	2	0.004	0.002	0.20	.82	<.01
	Residuals	86	0.828	0.010			
FM	Pre-test	1	0.080	0.080	4.61	.03	0.04
	Group	2	0.004	0.002	0.13	.88	<.01
	Residuals	86	1.499	0.017			
CL	Pre-test	1	0.274	0.274	16.76	<.01	0.15
	Group	2	0.020	0.010	0.60	.55	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	86	1.407	0.016			
CM	Pre-test	1	0.127	0.127	5.62	.02	0.05
	Group	2	0.003	0.001	0.06	.94	<.01
	Residuals	86	1.948	0.023			
PL	Pre-test	1	0.217	0.217	13.97	<.01	0.13
	Group	2	0.014	0.007	0.44	.65	<.01
	Residuals	86	1.333	0.016			
PM*	Pre-test	1	0.192	0.192	12.52	<.01	0.11
	Group	2	0.010	0.005	0.32	.72	<.01
	Residuals	86	1.317	0.015			
OL	Pre-test	1	0.184	0.184	24.56	<.01	0.21
	Group	2	0.023	0.011	1.52	.23	0.01
	Residuals	86	0.645	0.008			
OM*	Pre-test	1	0.292	0.292	27.19	<.01	0.23
	Group	2	0.020	0.010	0.91	.41	<.01
	Residuals	86	0.923	0.011			
LTL	Pre-test	1	0.224	0.224	18.06	<.01	0.16
	Group	2	0.045	0.023	1.83	.17	0.02
	Residuals	86	1.066	0.012			
RTL	Pre-test	1	0.296	0.296	26.00	<.01	0.22
	Group	2	0.007	0.004	0.33	.72	<.01
	Residuals	86	0.980	0.011			
LTPJ	Pre-test	1	0.288	0.288	16.81	<.01	0.15
	Group	2	0.070	0.035	2.04	.14	0.02
	Residuals	86	1.475	0.017			
RTPJ	Pre-test	1	0.243	0.243	11.55	<.01	0.10
	Group	2	0.015	0.007	0.35	.71	<.01
	Residuals	86	1.808	0.021			
Theta							
FL	Pre-test	1	<.001	<.001	0.57	.45	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	0.002	0.001	1.30	.28	0.01
	Residuals	86	0.056	0.001			
FM	Pre-test	1	0.002	0.002	1.16	.28	<.01
	Group	2	0.002	0.001	0.82	.44	<.01
	Residuals	86	0.123	0.001			
CL	Pre-test	1	0.005	0.005	6.81	.01	0.06
	Group	2	0.001	0.001	0.84	.44	<.01
	Residuals	86	0.066	0.001			
CM	Pre-test	1	0.005	0.005	3.63	.06	0.03
	Group	2	<.001	<.001	0.03	.97	<.01
	Residuals	86	0.124	0.001			
PL	Pre-test	1	0.008	0.008	12.23	<.01	0.11
	Group	2	0.001	<.001	0.44	.65	<.01
	Residuals	86	0.059	0.001			
PM	Pre-test	1	0.011	0.011	8.67	<.01	0.08
	Group	2	0.002	0.001	0.59	.55	<.01
	Residuals	86	0.110	0.001			
OL	Pre-test	1	0.007	0.007	12.85	<.01	0.12
	Group	2	0.001	<.001	0.52	.60	<.01
	Residuals	86	0.050	0.001			
OM	Pre-test	1	0.013	0.013	14.30	<.01	0.13
	Group	2	0.003	0.001	1.41	.25	0.01
	Residuals	86	0.080	0.001			
LTL	Pre-test	1	0.001	0.001	2.04	.16	0.01
	Group	2	0.003	0.001	2.45	.09	0.03
	Residuals	86	0.046	0.001			
RTL	Pre-test	1	0.003	0.003	6.17	.01	0.05
	Group	2	0.001	<.001	0.70	.50	<.01
	Residuals	86	0.035	<.001			
LTPJ	Pre-test	1	0.006	0.006	6.98	<.01	0.06

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	0.003	0.002	1.92	.15	0.02
	Residuals	86	0.072	0.001			
RTPJ	Pre-test	1	0.003	0.003	2.94	.09	0.02
	Group	2	0.001	<.001	0.35	.71	<.01
	Residuals	86	0.078	0.001			
Lower Alpha							
FL	Pre-test	1	<.001	<.001	2.00	.16	0.01
	Group	2	<.001	<.001	0.00	1	<.01
	Residuals	86	0.017	<.001			
FM	Pre-test	1	0.003	0.003	7.23	<.01	0.06
	Group	2	<.001	<.001	0.25	.78	<.01
	Residuals	86	0.041	<.001			
CL	Pre-test	1	0.006	0.006	9.86	<.01	0.09
	Group	2	<.001	<.001	0.15	.86	<.01
	Residuals	86	0.054	0.001			
CM	Pre-test	1	0.001	0.001	0.95	.33	<.01
	Group	2	0.001	<.001	0.28	.75	<.01
	Residuals	86	0.114	0.001			
PL	Pre-test	1	0.002	0.002	5.50	.02	0.05
	Group	2	<.001	<.001	0.08	.93	<.01
	Residuals	86	0.037	<.001			
PM	Pre-test	1	0.001	0.001	1.60	.21	0.01
	Group	2	<.001	<.001	0.15	.86	<.01
	Residuals	86	0.052	0.001			
OL	Pre-test	1	0.003	0.003	23.54	<.01	0.20
	Group	2	<.001	<.001	0.92	.40	<.01
	Residuals	86	0.010	<.001			
OM	Pre-test	1	0.005	0.005	30.46	<.01	0.25
	Group	2	<.001	<.001	0.74	.48	<.01
	Residuals	86	0.014	<.001			

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
LTL	Pre-test	1	0.006	0.006	17.05	<.01	0.15
	Group	2	<.001	<.001	0.28	.76	<.01
	Residuals	86	0.029	<.001			
RTL	Pre-test	1	0.005	0.005	17.30	<.01	0.15
	Group	2	<.001	<.001	0.47	.63	<.01
	Residuals	86	0.027	<.001			
LTPJ	Pre-test	1	0.005	0.005	15.70	<.01	0.14
	Group	2	<.001	<.001	0.55	.58	<.01
	Residuals	86	0.030	<.001			
RTPJ	Pre-test	1	0.004	0.004	5.79	.02	0.05
	Group	2	<.001	<.001	0.14	.87	<.01
	Residuals	86	0.058	0.001			
Upper Alpha							
FL	Pre-test	1	0.002	0.002	7.02	<.01	0.06
	Group	2	<.001	<.001	0.56	.57	<.01
	Residuals	86	0.019	<.001			
FM	Pre-test	1	0.003	0.003	8.74	<.01	0.08
	Group	2	<.001	<.001	0.01	.99	<.01
	Residuals	86	0.031	<.001			
CL	Pre-test	1	0.014	0.014	34.47	<.01	0.27
	Group	2	<.001	<.001	0.44	.65	<.01
	Residuals	86	0.036	<.001			
CM	Pre-test	1	0.004	0.004	7.36	<.01	0.07
	Group	2	<.001	<.001	0.03	.97	<.01
	Residuals	86	0.048	0.001			
PL	Pre-test	1	0.008	0.008	13.28	<.01	0.12
	Group	2	0.001	<.001	0.81	.45	<.01
	Residuals	86	0.051	0.001			
PM*	Pre-test	1	0.007	0.007	11.96	<.01	0.11
	Group	2	<.001	<.001	0.38	.68	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	86	0.053	0.001			
OL	Pre-test	1	0.004	0.004	17.30	<.01	0.15
	Group	2	0.001	<.001	2.22	.12	0.03
	Residuals	86	0.018	<.001			
OM*	Pre-test	1	0.006	0.006	26.66	<.01	0.22
	Group	2	0.001	<.001	1.82	.17	0.02
	Residuals	86	0.020	<.001			
LTL	Pre-test	1	0.009	0.009	23.75	<.01	0.20
	Group	2	0.001	0.001	1.70	.19	0.02
	Residuals	86	0.032	<.001			
RTL	Pre-test	1	0.008	0.008	24.97	<.01	0.21
	Group	2	0.001	<.001	1.14	.33	<.01
	Residuals	86	0.029	<.001			
LTPJ	Pre-test	1	0.013	0.013	18.94	<.01	0.17
	Group	2	0.002	0.001	1.76	.18	0.02
	Residuals	86	0.057	0.001			
RTPJ	Pre-test	1	0.008	0.008	10.80	<.01	0.10
	Group	2	0.001	0.001	0.88	.42	<.01
	Residuals	86	0.064	0.001			
Full Alpha							
FL	Pre-test	1	0.003	0.003	4.01	.05	0.03
	Group	2	<.001	<.001	0.14	.87	<.01
	Residuals	86	0.065	0.001			
FM	Pre-test	1	0.012	0.012	7.75	<.01	0.07
	Group	2	<.001	<.001	0.10	.91	<.01
	Residuals	86	0.128	0.001			
CL	Pre-test	1	0.036	0.036	19.88	<.01	0.17
	Group	2	<.001	<.001	0.13	.88	<.01
	Residuals	86	0.154	0.002			
CM	Pre-test	1	0.008	0.008	2.61	.11	0.02

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	0.001	<.001	0.14	.87	<.01
	Residuals	86	0.258	0.003			
PL	Pre-test	1	0.017	0.017	9.47	<.01	0.09
	Group	2	0.001	0.001	0.31	.74	<.01
	Residuals	86	0.157	0.002			
PM*	Pre-test	1	0.013	0.013	5.73	.02	0.05
	Group	2	<.001	<.001	0.02	.98	<.01
	Residuals	86	0.192	0.002			
OL	Pre-test	1	0.012	0.012	20.08	<.01	0.17
	Group	2	0.002	0.001	1.63	.20	0.01
	Residuals	86	0.052	0.001			
OM	Pre-test	1	0.022	0.022	28.93	<.01	0.24
	Group	2	0.002	0.001	1.21	.30	<.01
	Residuals	86	0.065	0.001			
LTL	Pre-test	1	0.027	0.027	21.95	<.01	0.19
	Group	2	0.002	0.001	0.97	.38	<.01
	Residuals	86	0.105	0.001			
RTL	Pre-test	1	0.025	0.025	22.10	<.01	0.19
	Group	2	0.002	0.001	0.84	.43	<.01
	Residuals	86	0.098	0.001			
LTPJ	Pre-test	1	0.033	0.033	17.97	<.01	0.16
	Group	2	0.005	0.002	1.25	.29	0.01
	Residuals	86	0.156	0.002			
RTPJ	Pre-test	1	0.022	0.022	8.50	<.01	0.08
	Group	2	0.002	0.001	0.47	.63	<.01
	Residuals	86	0.221	0.003			
Beta							
FL	Pre-test	1	0.067	0.067	11.54	<.01	0.10
	Group	2	0.001	<.001	0.05	.95	<.01
	Residuals	86	0.502	0.006			

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
FM	Pre-test	1	0.039	0.039	7.05	<.01	0.06
	Group	2	<.001	<.001	0.03	.97	<.01
	Residuals	86	0.480	0.006			
CL	Pre-test	1	0.088	0.088	16.52	<.01	0.15
	Group	2	0.008	0.004	0.72	.49	<.01
	Residuals	86	0.460	0.005			
CM	Pre-test	1	0.049	0.049	9.33	<.01	0.08
	Group	2	0.001	0.001	0.11	.90	<.01
	Residuals	86	0.455	0.005			
PL	Pre-test	1	0.074	0.074	15.80	<.01	0.14
	Group	2	0.004	0.002	0.42	.66	<.01
	Residuals	86	0.402	0.005			
PM*	Pre-test	1	0.070	0.070	25.66	<.01	0.22
	Group	2	0.004	0.002	0.69	.51	<.01
	Residuals	86	0.235	0.003			
OL*	Pre-test	1	0.052	0.052	23.11	<.01	0.20
	Group	2	0.007	0.003	1.56	.22	0.01
	Residuals	86	0.192	0.002			
OM*	Pre-test	1	0.069	0.069	21.50	<.01	0.19
	Group	2	0.008	0.004	1.18	.31	<.01
	Residuals	86	0.277	0.003			
LTL	Pre-test	1	0.094	0.094	16.03	<.01	0.14
	Group	2	0.013	0.007	1.13	.33	<.01
	Residuals	86	0.502	0.006			
RTL	Pre-test	1	0.123	0.123	25.79	<.01	0.22
	Group	2	0.001	<.001	0.08	.93	<.01
	Residuals	86	0.408	0.005			
LTPJ	Pre-test	1	0.084	0.084	13.67	<.01	0.12
	Group	2	0.020	0.010	1.59	.21	0.01
	Residuals	86	0.528	0.006			

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
RTPJ	Pre-test	1	0.096	0.096	15.19	<.01	0.14
	Group	2	0.003	0.002	0.24	.79	<.01
	Residuals	86	0.541	0.006			

*A significant interaction effect

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Analysis of regression

The following analysis explores the relationships between pre-test and post-test relative powers for specific frequency bands (delta, upper alpha, full alpha, and beta) for the OM, PM, and OL regions across the three groups, including MCST, CST, and control (see Table 50).

For the relative delta, in the OM region, the MCST group shows a moderate predictive relationship ($\beta_1 = 0.58$, $p = .04$, adjusted $R^2 = .10$). The CST group demonstrates stronger significance ($\beta_1 = 0.44$, $p < .001$, adjusted $R^2 = .28$). The control group exhibits the strongest relationship ($\beta_1 = 1.20$, $p < .001$, adjusted $R^2 = .45$), suggesting a naturally high association between pre-test and post-test values. In the PM region, the MCST group shows a significant predictive relationship ($\beta_1 = 0.89$, $p = .01$, adjusted $R^2 = .21$), while the CST group fails to reach significance ($\beta_1 = 0.16$, $p = .34$, adjusted $R^2 = .00$). In contrast, the control group demonstrates a strong relationship ($\beta_1 = 0.96$, $p < .001$, adjusted $R^2 = .36$).

For the relative upper alpha, in the OM region, The MCST group shows a marginally significant relationship ($\beta_1 = 0.66$, $p = .13$, adjusted $R^2 = .05$). The CST group demonstrates stronger predictive power ($\beta_1 = 0.50$, $p < .001$, adjusted $R^2 = .48$), while the control group shows the strongest relationship ($\beta_1 = 1.49$, $p < .001$, adjusted $R^2 = .47$) (see Figure 50). In the PM region, the MCST group demonstrates strong predictive power ($\beta_1 = 2.14$, $p < .001$, adjusted $R^2 = .41$), highlighting significant intervention effects. The CST group shows a weaker, non-significant relationship ($\beta_1 = 0.21$, $p = .12$, adjusted $R^2 = .05$), while the control group demonstrates a moderate relationship ($\beta_1 = 1.10$, $p < .001$, adjusted $R^2 = .26$).

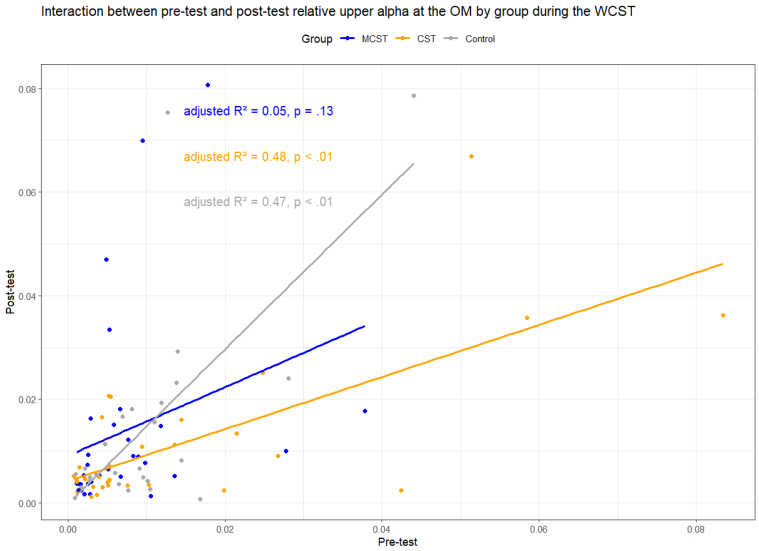

Figure 50 A scatter plot and the regression lines are shows interaction between pre-test and post-test relative upper alpha at the occipital midline (OM) area by group during the wisconsin card sorting test.

For the relative full alpha, in the PM region, the MCST group shows a strong predictive relationship (β_1 = 1.53, p < .001, adjusted R^2 = .30), indicating significant effects of the intervention. The CST group fails to show significance (β_1 = 0.13, p = .52, adjusted R^2 = −.02), while the control group exhibits a moderate relationship (β_1 = 0.92, p = .02, adjusted R^2 = .16).

For the relative beta, in the OL region, the MCST group demonstrates a significant relationship (β_1 = 0.56, p = .06, adjusted R^2 = .08), while the CST group also shows significance (β_1 = 0.30, p < .001, adjusted R^2 = .28). The control group exhibits the strongest relationship (β_1 = 1.05, p < .001, adjusted R^2 = .40)(see Figure 51). In the OM region, the MCST group demonstrates strong predictive power (β_1 = 1.30, p < .001, adjusted R^2 = .58), while the CST group shows a moderate but significant relationship (β_1 = 0.39, p < .001, adjusted R^2 = .27). The control group exhibits the strongest relationship (β_1 = 1.84, p < .001, adjusted R^2 = .52). In the PM region, the MCST group shows a significant relationship (β_1 = 1.08, p < .001, adjusted R^2 = .34). The CST group fails to reach significance (β_1 = 0.22, p = .13, adjusted R^2 = .04). However, the control group demonstrates the strongest association (β_1 = 1.25, p < .001, adjusted R^2 = .54).

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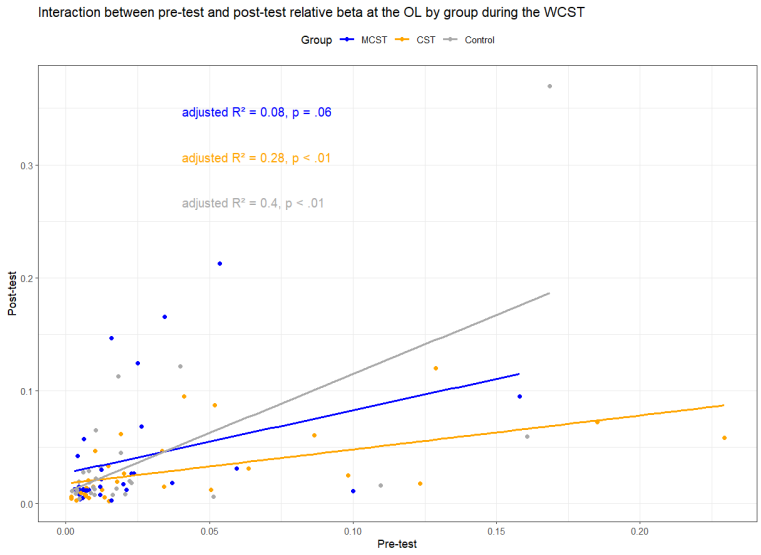

Figure 51 A scatter plot and the regression lines are shows interaction between pre-test and post-test relative delta in the occipital lobe (OL) area by group during the wisconsin card sorting test.

In summary, for the WCST task, the MCST group consistently demonstrates significant predictive relationships across, particularly in the full alpha and beta bands, highlighting the effects of the intervention (adjusted $R^2 \approx .30-0.58$). The CST group shows moderate relationships but often fails to reach the significance seen in MCST (adjusted $R^2 \approx .05-0.28$). The control group demonstrates strong predictive power across most bands and regions, suggesting high natural associations (adjusted $R^2 \approx .36-0.54$), but less intervention impact.

Table 50 Regression analysis of the Wisconsin card sorting test

ROI	Model	Variable	*β*	*SE*	*t*	*p*
Delta						
OM	MCST	Constant	0.35	0.25	1.36	.18
		Pre-test	0.58	0.28	2.11	.04
	CST	Constant	0.51	0.11	4.56	<.01
		Pre-test	0.44	0.12	3.52	<.01
	Control	Constant	-0.20	0.23	-0.88	.39
		Pre-test	1.20	0.25	4.84	<.01
PM	MCST	Constant	0.06	0.27	0.21	.84

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ROI	Model	Variable	*β*	*SE*	*t*	*p*
		Pre-test	0.89	0.30	3.00	.01
	CST	Constant	0.72	0.14	5.08	<.01
		Pre-test	0.16	0.16	0.98	.34
	Control	Constant	0.00	0.21	0.00	1
		Pre-test	0.96	0.24	4.06	<.01
Upper Alpha						
OM	MCST	Constant	0.01	0.00	1.99	.06
		Pre-test	0.66	0.42	1.56	.13
	CST	Constant	0.00	0.00	1.87	.07
		Pre-test	0.50	0.09	5.35	<.01
	Control	Constant	0.00	0.00	-0.06	.96
		Pre-test	1.49	0.30	5.01	<.01
PM	MCST	Constant	0.00	0.01	-0.31	.76
		Pre-test	2.14	0.46	4.67	<.01
	CST	Constant	0.01	0.00	3.25	<.01
		Pre-test	0.21	0.13	1.59	.12
	Control	Constant	0.01	0.01	0.95	.35
		Pre-test	1.10	0.34	3.21	<.01
Full Alpha						
PM	MCST	Constant	0.01	0.01	0.46	.65
		Pre-test	1.53	0.42	3.69	<.01
	CST	Constant	0.04	0.01	2.93	.01
		Pre-test	0.13	0.20	0.65	.52
	Control	Constant	0.02	0.01	1.25	.22
		Pre-test	0.92	0.38	2.46	.02
Beta						
OL	MCST	Constant	0.03	0.01	2.38	.02
		Pre-test	0.56	0.29	1.94	.06
	CST	Constant	0.02	0.01	3.04	.01
		Pre-test	0.30	0.08	3.59	<.01
	Control	Constant	0.01	0.01	0.82	.42
		Pre-test	1.05	0.24	4.33	<.01
OM	MCST	Constant	0.03	0.01	2.39	.02
		Pre-test	0.46	0.32	1.45	.16
	CST	Constant	0.02	0.01	2.28	.03
		Pre-test	0.39	0.11	3.51	<.01
	Control	Constant	0.00	0.01	-0.29	.77
		Pre-test	1.84	0.33	5.49	<.01
PM	MCST	Constant	0.02	0.01	1.45	.16
		Pre-test	1.08	0.27	4.02	<.01
	CST	Constant	0.03	0.01	3.08	<.01
		Pre-test	0.22	0.14	1.55	.13

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ROI	Model	Variable	*β*	*SE*	*t*	*p*
	Control	Constant	0.01	0.01	0.70	.49
		Pre-test	1.25	0.22	5.66	<.01

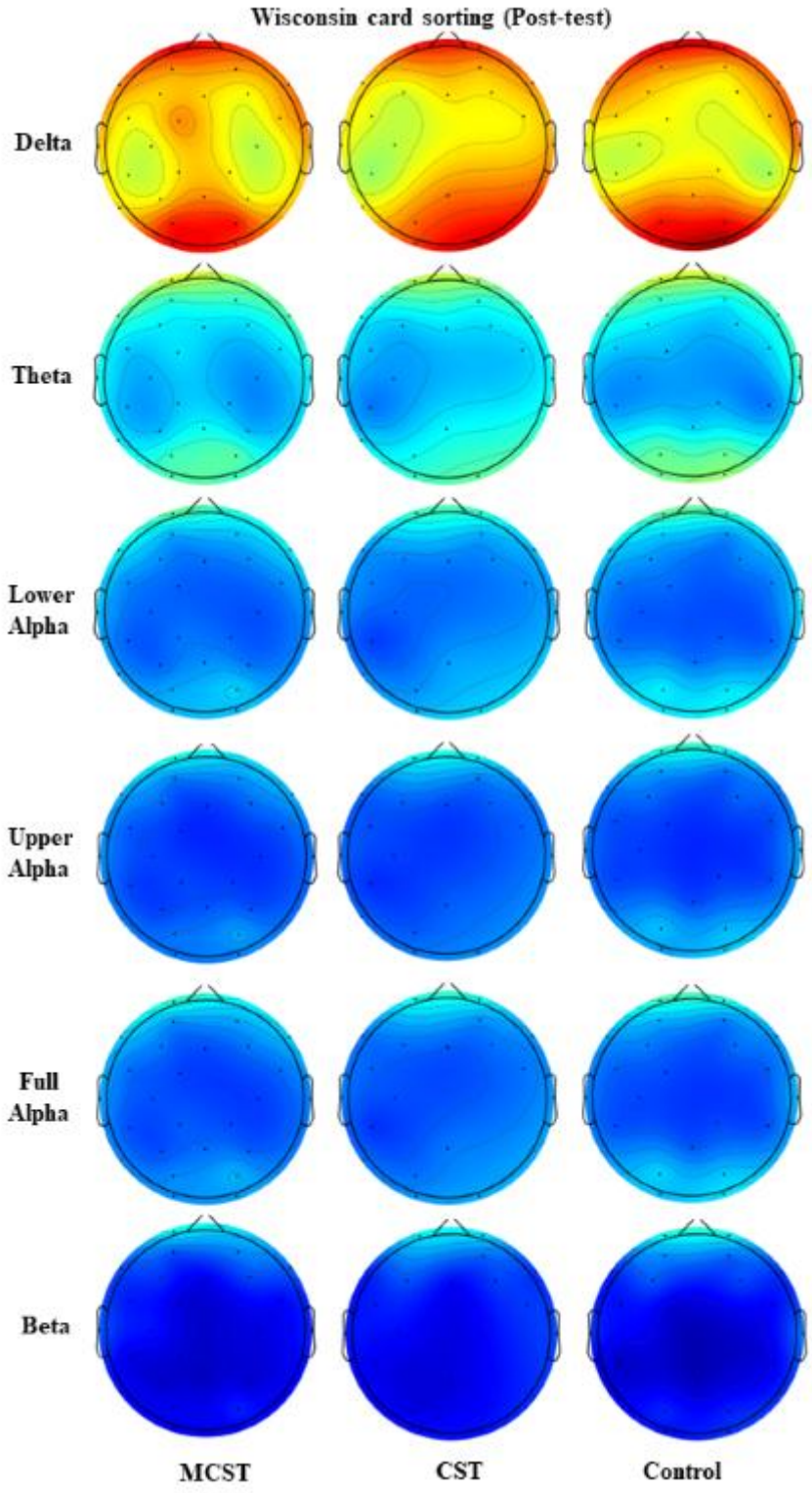

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Figure 52 The topographic brain mapping of relative power during the Wisconsin card sorting test at post-test

EEG - Simple reaction time task

Analysis of the relative power characteristics

The study investigated the relative spectral power of band frequencies in a simple reaction time task across different brain regions. The analysis included parameters such as delta, theta, lower alpha, upper alpha, full alpha, and beta band frequencies (see Table 51).

In the delta band frequency, there was a notable decrease in relative spectral power from pre- to post-test across most brain regions. For instance, in the frontal lobe (FL), there was a decrease from 74.01% to 68.14%, indicating a decrease in slow-wave activity. Similar decreases were observed in other regions such as the parietal lobe (PL) and occipital midline (OM).

Regarding the theta band frequency, there was a general increase in relative spectral power from pre- to post-test across several brain regions. For example, in the frontal midline (FM), there was an increase from 7.27% to 10.06%, suggesting an increase in activity associated with attention and cognitive processing. This pattern was consistent across other regions such as central electrode locations (CL) and central midline (CM).

In the lower alpha band, frequency, there were mixed findings observed across brain regions. While some regions showed increases in relative spectral power from pre- to post-test (e.g., frontal lobe), others exhibited decreases or minimal changes. For instance, in the occipital midline (OM), there was a slight increase from 0.95% to 1.83%, indicating a slight increase in activity related to visual processing.

Similarly, in the upper alpha band frequency, varied changes were observed across brain regions. Some regions showed increases in relative spectral power from pre- to post-test, while others displayed decreases or minimal changes. For instance, in the frontal lobe (FL), there was an increase from 2.22% to 2.76%, suggesting heightened cortical activity associated with attentional processes.

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The full alpha band frequency also exhibited diverse changes across brain regions, with some showing increases and others showing decreases or minimal changes. These changes may reflect alterations in cognitive processes such as memory and attention.

Finally, in the beta band frequency, there were notable increases in relative spectral power observed from pre- to post-test across various brain regions. For example, in the frontal lobe (FL), there was an increase from 12.48% to 16.22%, indicating heightened cortical arousal and cognitive engagement. Similar increases were observed in other regions such as the central midline (CM) and parietal midline (PM).

Overall, the study highlights dynamic changes in spectral power across different relative power spectrum bands and brain regions during a simple reaction time task, reflecting the complex interplay of neural processes underlying cognitive performance.

Table 51 Characteristic of relative spectral power (%) of band frequencies in the simple reaction time task

		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Delta										
FL	Pre	31	74.01	14.15	31	72.39	13.95	28	69.18	13.09
	Post	31	68.14	15.41	31	69.24	13.75	28	70.27	14.40
FM	Pre	31	80.79	16.29	31	75.55	17.47	28	69.77	17.29
	Post	31	71.37	16.70	31	66.81	19.92	28	71.73	17.53
CL	Pre	31	81.93	12.32	31	72.91	18.75	28	72.10	15.59
	Post	31	71.78	16.19	31	67.91	18.16	28	70.86	16.99
CM	Pre	31	86.38	12.84	31	78.84	19.98	28	77.78	17.30
	Post	31	77.08	17.25	31	71.57	22.10	28	75.32	19.18
PL	Pre	31	84.72	12.83	31	79.09	18.42	28	81.79	14.92
	Post	31	77.41	17.54	31	75.37	18.26	28	78.08	18.27
PM	Pre	31	87.34	12.38	31	81.62	19.78	28	87.52	15.13

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	31	81.33	17.42	31	77.36	20.06	28	80.65	18.27
OL	Pre	31	88.82	12.80	31	85.45	16.57	28	89.37	11.45
	Post	31	84.65	17.56	31	85.02	13.72	28	86.04	16.05
OM	Pre	31	91.25	12.24	31	85.96	17.43	28	87.72	12.60
	Post	31	84.19	17.78	31	86.21	12.87	28	85.48	16.14
LTL	Pre	31	74.05	18.24	31	68.81	18.60	28	69.85	11.98
	Post	31	67.36	15.95	31	68.49	14.15	28	69.20	16.29
RTL	Pre	31	77.10	17.09	31	73.01	16.33	28	72.87	11.12
	Post	31	71.07	16.24	31	72.40	13.94	28	70.93	18.32
LTPJ	Pre	31	79.98	16.35	31	73.55	21.28	28	76.85	17.11
	Post	31	74.16	19.55	31	72.23	18.36	28	75.66	18.23
RTPJ	Pre	31	83.77	16.15	31	75.35	21.19	28	82.80	12.86
	Post	31	76.50	21.75	31	77.37	18.68	28	79.38	21.93
Theta										
FL	Pre	31	9.30	3.13	31	8.70	2.99	28	10.61	2.84
	Post	31	10.39	3.84	31	10.91	2.99	28	9.88	3.40
FM	Pre	31	7.27	4.61	31	8.47	5.81	28	10.16	4.80
	Post	31	10.06	4.65	31	11.80	4.94	28	9.70	4.51
CL	Pre	31	6.21	3.22	31	7.29	3.61	28	7.81	2.82
	Post	31	8.15	3.53	31	9.68	4.11	28	8.40	3.91
CM	Pre	31	5.44	3.89	31	6.78	4.80	28	6.89	3.27
	Post	31	7.40	4.81	31	9.75	5.58	28	8.54	5.18
PL	Pre	31	5.36	2.99	31	5.88	3.18	28	6.06	2.76
	Post	31	6.88	3.63	31	8.05	3.98	28	6.93	3.82
PM	Pre	31	5.10	3.35	31	5.28	3.54	28	5.03	4.31
	Post	31	6.49	4.26	31	7.92	5.27	28	6.73	5.22
OL	Pre	31	4.56	3.38	31	4.84	3.36	28	4.51	3.53
	Post	31	5.29	3.50	31	6.18	3.84	28	4.82	3.82
OM	Pre	31	3.93	3.58	31	4.80	3.85	28	5.06	3.88

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	31	5.90	4.01	31	6.12	4.20	28	5.09	4.48
LTL	Pre	31	6.98	3.58	31	7.62	3.22	28	8.91	2.43
	Post	31	9.09	3.25	31	9.55	2.74	28	8.69	3.78
RTL	Pre	31	6.49	2.69	31	7.11	2.91	28	7.36	2.30
	Post	31	8.01	2.81	31	8.19	2.63	28	7.55	3.19
LTPJ	Pre	31	6.32	3.51	31	6.94	3.99	28	7.41	3.95
	Post	31	7.48	4.03	31	8.74	4.22	28	7.40	3.69
RTPJ	Pre	31	5.03	2.86	31	6.45	3.60	28	5.42	2.88
	Post	31	6.44	3.94	31	7.06	3.77	28	5.83	3.78
Lower Alpha										
FL	Pre	31	1.99	1.18	31	2.55	1.65	28	2.43	1.27
	Post	31	2.49	1.43	31	2.75	2.02	28	2.56	1.70
FM	Pre	31	1.84	1.54	31	3.14	2.97	28	3.35	3.07
	Post	31	3.20	2.37	31	4.30	3.93	28	3.57	3.11
CL	Pre	31	1.81	1.35	31	3.02	2.37	28	2.85	1.86
	Post	31	2.95	1.95	31	3.86	3.54	28	3.43	3.19
CM	Pre	31	1.34	1.33	31	2.63	2.94	28	2.46	2.04
	Post	31	2.63	2.33	31	3.55	3.76	28	3.36	4.28
PL	Pre	31	1.71	1.67	31	2.88	3.56	28	1.94	1.55
	Post	31	2.54	2.22	31	3.46	3.93	28	2.48	2.36
PM	Pre	31	1.40	1.66	31	2.91	4.52	28	1.36	1.55
	Post	31	2.05	2.06	31	3.57	5.16	28	2.02	1.99
OL	Pre	31	1.29	1.83	31	1.95	3.15	28	1.10	1.18
	Post	31	1.75	2.41	31	2.05	3.03	28	1.42	1.81
OM	Pre	31	0.95	1.66	31	1.80	2.96	28	1.24	1.19
	Post	31	1.83	2.51	31	1.79	2.50	28	1.40	1.62
LTL	Pre	31	2.59	2.08	31	3.51	2.70	28	3.09	1.70
	Post	31	3.51	2.24	31	3.84	3.32	28	3.55	2.90
RTL	Pre	31	2.30	1.80	31	3.08	2.20	28	2.46	1.51

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		MCST			CST			Control	
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	31	3.13	2.19	31	3.08	2.60	28	3.00	2.81
LTPJ	Pre	31	2.17	2.13	31	3.25	3.58	28	2.55	2.28
	Post	31	2.91	2.70	31	3.77	3.89	28	2.92	2.92
RTPJ	Pre	31	1.78	1.99	31	3.18	3.86	28	1.72	1.25
	Post	31	2.86	3.27	31	2.96	3.35	28	2.30	2.97
Upper Alpha										
FL	Pre	31	2.22	1.64	31	2.55	1.49	28	2.62	1.54
	Post	31	2.76	1.90	31	2.64	1.76	28	2.74	1.93
FM	Pre	31	2.03	1.96	31	2.76	2.11	28	3.31	2.51
	Post	31	3.12	2.62	31	3.91	3.34	28	3.40	2.63
CL	Pre	31	2.10	1.68	31	3.43	2.95	28	3.31	2.57
	Post	31	3.44	2.77	31	4.24	3.63	28	3.68	2.64
CM	Pre	31	1.43	1.57	31	2.59	3.03	28	2.76	2.79
	Post	31	2.86	2.74	31	3.65	3.44	28	3.18	3.10
PL	Pre	31	1.99	2.02	31	2.99	3.39	28	2.46	2.54
	Post	31	3.04	3.46	31	3.65	3.74	28	2.90	2.85
PM	Pre	31	1.61	2.05	31	2.70	3.60	28	1.70	2.39
	Post	31	2.33	2.71	31	3.39	3.79	28	2.58	3.14
OL	Pre	31	1.34	1.70	31	1.93	2.53	28	1.33	1.74
	Post	31	1.95	2.94	31	1.95	2.56	28	1.79	2.64
OM	Pre	31	0.90	1.43	31	1.73	2.44	28	1.52	1.81
	Post	31	1.85	2.60	31	1.69	2.21	28	1.77	2.39
LTL	Pre	31	3.13	2.53	31	3.93	2.89	28	3.44	2.12
	Post	31	3.72	2.39	31	3.78	2.51	28	3.81	3.06
RTL	Pre	31	2.73	2.34	31	3.47	2.60	28	2.93	1.95
	Post	31	3.39	2.49	31	3.26	2.39	28	3.34	2.75
LTPJ	Pre	31	2.48	2.21	31	3.78	3.82	28	3.09	3.16
	Post	31	3.32	3.21	31	3.84	3.30	28	3.45	3.54
RTPJ	Pre	31	2.17	2.48	31	3.67	3.98	28	2.13	2.13

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	31	3.29	4.19	31	3.32	3.88	28	2.66	3.63
Full Alpha										
FL	Pre	31	4.22	2.79	31	5.10	3.04	28	5.05	2.66
	Post	31	5.25	3.26	31	5.39	3.60	28	5.31	3.50
FM	Pre	31	3.87	3.46	31	5.90	4.88	28	6.66	5.35
	Post	31	6.32	4.82	31	8.21	6.73	28	6.97	5.43
CL	Pre	31	3.92	3.00	31	6.45	5.15	28	6.16	4.35
	Post	31	6.38	4.58	31	8.10	6.91	28	7.10	5.36
CM	Pre	31	2.78	2.86	31	5.22	5.75	28	5.22	4.75
	Post	31	5.49	4.91	31	7.20	6.90	28	6.54	6.85
PL	Pre	31	3.70	3.64	31	5.86	6.66	28	4.40	4.06
	Post	31	5.58	5.53	31	7.11	7.35	28	5.38	4.89
PM	Pre	31	3.01	3.70	31	5.61	7.80	28	3.06	3.91
	Post	31	4.38	4.63	31	6.96	8.64	28	4.60	4.91
OL	Pre	31	2.63	3.46	31	3.89	5.52	28	2.43	2.90
	Post	31	3.69	5.25	31	4.01	5.51	28	3.21	4.38
OM	Pre	31	1.85	3.05	31	3.53	5.33	28	2.76	2.98
	Post	31	3.68	5.06	31	3.48	4.65	28	3.16	3.92
LTL	Pre	31	5.72	4.47	31	7.44	5.43	28	6.52	3.73
	Post	31	7.23	4.56	31	7.62	5.66	28	7.37	5.62
RTL	Pre	31	5.03	4.03	31	6.55	4.74	28	5.39	3.39
	Post	31	6.53	4.61	31	6.34	4.79	28	6.34	4.91
LTPJ	Pre	31	4.65	4.21	31	7.03	7.14	28	5.63	5.38
	Post	31	6.23	5.82	31	7.61	7.00	28	6.36	6.17
RTPJ	Pre	31	3.95	4.38	31	6.85	7.57	28	3.85	3.30
	Post	31	6.14	7.38	31	6.27	7.01	28	4.95	6.06
Beta										
FL	Pre	31	12.48	11.68	31	13.80	10.56	28	15.15	11.53
	Post	31	16.22	12.81	31	14.46	11.43	28	14.55	11.26

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		MCST			CST			Control	
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
FM	Pre	31	8.07	9.46	31	10.07	8.33	28	13.41	10.95
	Post	31	12.26	10.16	31	13.18	10.57	28	11.59	9.89
CL	Pre	31	7.94	6.85	31	13.35	11.09	28	13.93	9.95
	Post	31	13.69	9.84	31	14.32	9.07	28	13.63	10.36
CM	Pre	31	5.40	6.83	31	9.16	10.63	28	10.11	10.94
	Post	31	10.03	8.57	31	11.48	11.35	28	9.60	9.53
PL	Pre	31	6.22	6.82	31	9.17	9.45	28	7.76	9.47
	Post	31	10.13	10.15	31	9.48	8.40	28	9.60	11.58
PM	Pre	31	4.54	5.98	31	7.49	9.23	28	4.39	8.25
	Post	31	7.80	10.38	31	7.75	8.02	28	8.03	10.22
OL	Pre	31	3.98	6.59	31	5.82	8.22	28	3.69	5.51
	Post	31	6.37	10.18	31	4.79	5.17	28	5.93	9.35
OM	Pre	31	2.97	6.36	31	5.72	8.83	28	4.46	6.41
	Post	31	6.23	9.85	31	4.20	4.90	28	6.27	9.35
LTL	Pre	31	13.24	12.79	31	16.13	11.47	28	14.72	8.13
	Post	31	16.31	11.77	31	14.35	8.25	28	14.74	10.21
RTL	Pre	31	11.38	11.64	31	13.33	10.15	28	14.38	7.40
	Post	31	14.40	11.62	31	13.06	8.52	28	15.18	12.81
LTPJ	Pre	31	9.06	9.59	31	12.48	11.23	28	10.11	9.88
	Post	31	12.13	11.53	31	11.42	8.79	28	10.57	10.64
RTPJ	Pre	31	7.25	10.00	31	11.35	10.96	28	7.94	8.04
	Post	31	10.91	13.29	31	9.30	9.00	28	9.84	13.83

Analysis of assumptions

In the assumption testing for the Simple Reaction Time Task across various relative power spectrum bands, several trends emerge. In the delta band, there were consistent violations of normality assumptions (W = 0.75 - 0.94, p < 0.01), while homoscedasticity was mostly observed (*K-squared* = 0.06 - 3.08, p < 0.05). Parallelism, indicating equality of variances between groups, generally held (F

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= 0.06 - 1.75, $p < 0.05$), with few exceptions such as OL and RTL, suggesting potential issues with variance across conditions.

Transitioning to the theta band, normality assumptions continued to be challenged (W = 0.84 - 0.98, $p < 0.01$), particularly for variables like FM and PL. Homoscedasticity was generally observed (*K-squared* = 0.07 - 3.54, $p < 0.05$), except for outliers like RTL. Parallelism was mostly supported (F = 0.01 - 2.87, $p < 0.05$), although deviations were seen in cases like RTL and RTPJ, indicating unequal variances across groups.

In the lower alpha band, , violations of normality were common across variables (W = 0.63 - 0.84, $p < 0.01$), but homoscedasticity was mostly observed (*K-squared* = 0.11 - 35.74, $p < 0.01$). Parallelism was generally supported (F = 0.00 - 4.52, $p < 0.05$), but exceptions like CL suggest potential issues with variance across conditions.

Similarly, in the upper alpha band, normality assumptions were frequently challenged (W = 0.65 - 0.89, $p < 0.01$), but homoscedasticity was mostly observed (*K-squared* = 0.03 - 7.31, $p < 0.05$). Parallelism was generally supported (F = 0.03 - 3.54, $p < 0.05$), although deviations were observed in cases like OL and RTL, suggesting unequal variances across groups.

In the full alpha and beta bands, patterns of normality violations, homoscedasticity, and parallelism were consistent with those seen in previous bands (W = 0.65 - 0.93, $p < 0.01$; *K-squared* = 0.03 - 14.79, $p < 0.01$; F = 0.00 - 2.31, $p < 0.05$)

Analysis of group comparisons

This section presents the results of ANCOVA for various parameters during the simple reaction time task to measure psychomotor in older adults with MCI. Overall, all of relative bands no significant group effects were observed across any brain regions in the test. To summarize, these results suggest that both interventions of MCST and CST do not have main effect on psychomotor in term of EEG freqency brain waves during performing the task of simple reaction.

In the delta band, the analysis revealed no significant group effects across all regions. For example, the frontal lobe (FL) exhibited a non-significant group effect with a small effect size ($F(2, 86) = 0.70$, $p = .50$, partial $\omega^2 <$

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.01). This non-significant pattern was consistent across the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all $p > .05$).

For the theta band, no significant group effects were observed in most regions. The frontal midline (FM) showed a non-significant group effect with a small effect size ($F(2, 86) = 2.42$, $p = .10$, partial $\omega^2 = 0.03$). The same non-significant trend was observed in the frontal lobe (FL), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all $p > .05$).

In the lower alpha band, , no significant group effects were identified across any regions. The frontal lobe (FL) had a non-significant group effect with a small effect size ($F(2, 86) = 0.09$, $p = .92$, partial $\omega^2 < .01$). This trend persisted in the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all $p > .05$).

The upper alpha band analysis showed no significant group effects. For instance, the frontal lobe (FL) exhibited a non-significant group effect with a small effect size ($F(2, 86) = 0.24$, $p = .79$, partial $\omega^2 < .01$). Other regions, including the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) also showed non-significant group effects (all $p > .05$).

In the full alpha band, no significant group effects were observed in any region. The frontal lobe (FL) exhibited a non-significant group effect with a small effect size ($F(2, 86) = 0.12$, $p = .89$, partial $\omega^2 < .01$). This non-significant pattern was consistent across the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL),

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occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all p > .05).

For the beta band, the analysis revealed no significant group effects. The frontal lobe (FL) showed a non-significant group effect with a small effect size *(F(*2, 86*)* = 0.63, *p* = .54, partial ω² < .01). This non-significant trend was observed across the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all p > .05).

The ANCOVA results for the Simple Reaction Time Task indicated no significant group effects across all relative power spectrum bands (delta, theta, lower alpha, upper alpha, full alpha, and beta) in any of the brain regions examined. This suggests that group differences in spectral power were not evident in this task, as measured by the EEG parameters across the different brain regions. Please see Table 52 ANCOVA of the simple reaction time task, for more information.

Table 52 ANCOVA of the simple reaction time task

		df	*SS*	*MS*	*F*	*p*	ω_p^2
Delta							
FL	Pre-test	1	0.277	0.277	15.45	<.01	0.14
	Group	2	0.025	0.013	0.70	.50	<.01
	Residuals	86	1.544	0.018			
FM	Pre-test	1	0.364	0.364	12.71	<.01	0.12
	Group	2	0.076	0.038	1.33	.27	0.01
	Residuals	86	2.463	0.029			
CL	Pre-test	1	0.343	0.343	13.28	<.01	0.12
	Group	2	0.019	0.009	0.36	.70	<.01
	Residuals	86	2.219	0.026			
CM	Pre-test	1	0.456	0.456	13.44	<.01	0.12
	Group	2	0.026	0.013	0.39	.68	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	86	2.919	0.034			
PL	Pre-test	1	0.597	0.597	22.99	<.01	0.20
	Group	2	0.007	0.004	0.14	.87	<.01
	Residuals	86	2.232	0.026			
PM	Pre-test	1	0.671	0.671	24.33	<.01	0.21
	Group	2	0.001	0.001	0.03	.97	<.01
	Residuals	86	2.373	0.028			
OL	Pre-test	1	0.388	0.388	18.61	<.01	0.16
	Group	2	0.006	0.003	0.15	.86	<.01
	Residuals	86	1.793	0.021			
OM	Pre-test	1	0.431	0.431	21.94	<.01	0.19
	Group	2	0.034	0.017	0.88	.42	<.01
	Residuals	86	1.689	0.020			
LTL	Pre-test	1	0.385	0.385	19.73	<.01	0.17
	Group	2	0.023	0.012	0.60	.55	<.01
	Residuals	86	1.677	0.020			
RTL	Pre-test	1	0.323	0.323	14.27	<.01	0.13
	Group	2	0.014	0.007	0.30	.74	<.01
	Residuals	86	1.948	0.023			
LTPJ	Pre-test	1	0.558	0.558	19.17	<.01	0.17
	Group	2	0.012	0.006	0.21	.81	<.01
	Residuals	86	2.502	0.029			
RTPJ	Pre-test	1	0.587	0.587	16.01	<.01	0.14
	Group	2	0.039	0.019	0.53	.59	<.01
	Residuals	86	3.152	0.037			
Theta							
FL	Pre-test	1	0.004	0.004	3.55	.06	0.03
	Group	2	0.003	0.002	1.48	.23	0.01
	Residuals	86	0.097	0.001			
FM	Pre-test	1	0.017	0.017	8.26	<.01	0.07

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	0.010	0.005	2.42	.10	0.03
	Residuals	86	0.174	0.002			
CL	Pre-test	1	0.009	0.009	6.08	.02	0.05
	Group	2	0.004	0.002	1.26	.29	0.01
	Residuals	86	0.121	0.001			
CM	Pre-test	1	0.020	0.020	8.05	<.01	0.07
	Group	2	0.006	0.003	1.10	.34	<.01
	Residuals	86	0.218	0.003			
PL	Pre-test	1	0.019	0.019	15.38	<.01	0.14
	Group	2	0.002	0.001	0.93	.40	<.01
	Residuals	86	0.108	0.001			
PM	Pre-test	1	0.020	0.020	9.09	<.01	0.08
	Group	2	0.003	0.002	0.72	.49	<.01
	Residuals	86	0.192	0.002			
OL	Pre-test	1	0.017	0.017	14.48	<.01	0.13
	Group	2	0.002	0.001	0.96	.39	<.01
	Residuals	86	0.103	0.001			
OM	Pre-test	1	0.014	0.014	8.34	<.01	0.08
	Group	2	0.003	0.001	0.79	.46	<.01
	Residuals	86	0.141	0.002			
LTL	Pre-test	1	0.003	0.003	2.41	.12	0.02
	Group	2	0.002	0.001	0.86	.42	<.01
	Residuals	86	0.090	0.001			
RTL	Pre-test	1	0.006	0.006	7.77	<.01	0.07
	Group	2	0.001	0.001	0.67	.51	<.01
	Residuals	86	0.066	0.001			
LTPJ	Pre-test	1	0.010	0.010	6.45	.01	0.06
	Group	2	0.003	0.002	1.17	.32	<.01
	Residuals	86	0.129	0.001			
RTPJ	Pre-test	1	0.016	0.016	12.34	<.01	0.11

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	0.001	0.001	0.45	.64	<.01
	Residuals	86	0.113	0.001			
Lower Alpha							
FL	Pre-test	1	0.005	0.005	20.05	<.01	0.17
	Group	2	<.001	<.001	0.09	.92	<.01
	Residuals	86	0.021	<.001			
FM	Pre-test	1	0.019	0.019	23.28	<.01	0.20
	Group	2	0.001	0.001	0.63	.53	<.01
	Residuals	86	0.071	0.001			
CL	Pre-test	1	0.008	0.008	9.67	<.01	0.09
	Group	2	<.001	<.001	0.15	.86	<.01
	Residuals	86	0.070	0.001			
CM	Pre-test	1	0.004	0.004	2.96	.09	0.02
	Group	2	0.001	<.001	0.22	.80	<.01
	Residuals	86	0.106	0.001			
PL	Pre-test	1	0.011	0.011	14.16	<.01	0.13
	Group	2	0.001	<.001	0.33	.72	<.01
	Residuals	86	0.067	0.001			
PM	Pre-test	1	0.023	0.023	24.19	<.01	0.20
	Group	2	0.001	0.001	0.56	.57	<.01
	Residuals	86	0.083	0.001			
OL	Pre-test	1	0.011	0.011	20.78	<.01	0.18
	Group	2	<.001	<.001	0.10	.90	<.01
	Residuals	86	0.044	0.001			
OM	Pre-test	1	0.012	0.012	31.89	<.01	0.26
	Group	2	0.001	<.001	0.83	.44	<.01
	Residuals	86	0.032	<.001			
LTL	Pre-test	1	0.012	0.012	18.04	<.01	0.16
	Group	2	<.001	<.001	0.06	.94	<.01
	Residuals	86	0.059	0.001			

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
RTL	Pre-test	1	0.006	0.006	10.56	<.01	0.10
	Group	2	<.001	<.001	0.21	.81	<.01
	Residuals	86	0.050	0.001			
LTPJ	Pre-test	1	0.014	0.014	14.97	<.01	0.13
	Group	2	<.001	<.001	0.25	.78	<.01
	Residuals	86	0.078	0.001			
RTPJ	Pre-test	1	0.008	0.008	8.47	<.01	0.08
	Group	2	<.001	<.001	0.25	.78	<.01
	Residuals	86	0.082	0.001			
Upper Alpha							
FL	Pre-test	1	0.005	0.005	19.24	<.01	0.17
	Group	2	<.001	<.001	0.24	.79	<.01
	Residuals	86	0.025	<.001			
FM	Pre-test	1	0.013	0.013	18.31	<.01	0.16
	Group	2	0.001	<.001	0.69	.50	<.01
	Residuals	86	0.060	0.001			
CL	Pre-test	1	0.017	0.017	23.17	<.01	0.20
	Group	2	<.001	<.001	0.28	.75	<.01
	Residuals	86	0.065	0.001			
CM	Pre-test	1	0.009	0.009	10.54	<.01	0.10
	Group	2	<.001	<.001	0.25	.78	<.01
	Residuals	86	0.075	0.001			
PL	Pre-test	1	0.017	0.017	17.38	<.01	0.15
	Group	2	<.001	<.001	0.19	.83	<.01
	Residuals	86	0.083	0.001			
PM	Pre-test	1	0.021	0.021	25.31	<.01	0.21
	Group	2	<.001	<.001	0.20	.82	<.01
	Residuals	86	0.072	0.001			
OL	Pre-test	1	0.013	0.013	21.55	<.01	0.19
	Group	2	<.001	<.001	0.16	.85	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	86	0.051	0.001			
OM	Pre-test	1	0.012	0.012	28.20	<.01	0.23
	Group	2	0.001	<.001	0.85	.43	<.01
	Residuals	86	0.037	<.001			
LTL	Pre-test	1	0.015	0.015	27.69	<.01	0.23
	Group	2	<.001	<.001	0.19	.82	<.01
	Residuals	86	0.046	0.001			
RTL	Pre-test	1	0.013	0.013	27.24	<.01	0.23
	Group	2	<.001	<.001	0.46	.63	<.01
	Residuals	86	0.042	<.001			
LTPJ	Pre-test	1	0.016	0.016	16.94	<.01	0.15
	Group	2	<.001	<.001	0.01	.99	<.01
	Residuals	86	0.082	0.001			
RTPJ	Pre-test	1	0.027	0.027	21.84	<.01	0.19
	Group	2	0.001	0.001	0.47	.62	<.01
	Residuals	86	0.106	0.001			
Full Alpha							
FL	Pre-test	1	0.018	0.018	18.34	<.01	0.16
	Group	2	<.001	<.001	0.12	.89	<.01
	Residuals	86	0.085	0.001			
FM	Pre-test	1	0.049	0.049	17.92	<.01	0.16
	Group	2	0.004	0.002	0.71	.50	<.01
	Residuals	86	0.237	0.003			
CL	Pre-test	1	0.044	0.044	15.34	<.01	0.14
	Group	2	0.001	0.001	0.19	.83	<.01
	Residuals	86	0.244	0.003			
CM	Pre-test	1	0.020	0.020	5.41	.02	0.05
	Group	2	0.001	0.001	0.19	.83	<.01
	Residuals	86	0.325	0.004			
PL	Pre-test	1	0.048	0.048	14.93	<.01	0.13

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	0.002	0.001	0.26	.77	<.01
	Residuals	86	0.274	0.003			
PM	Pre-test	1	0.081	0.081	24.56	<.01	0.21
	Group	2	0.003	0.001	0.39	.68	<.01
	Residuals	86	0.283	0.003			
OL	Pre-test	1	0.044	0.044	20.51	<.01	0.18
	Group	2	<.001	<.001	0.07	.94	<.01
	Residuals	86	0.183	0.002			
OM	Pre-test	1	0.045	0.045	28.77	<.01	0.24
	Group	2	0.003	0.001	0.80	.45	<.01
	Residuals	86	0.136	0.002			
LTL	Pre-test	1	0.051	0.051	22.68	<.01	0.19
	Group	2	<.001	<.001	0.09	.91	<.01
	Residuals	86	0.193	0.002			
RTL	Pre-test	1	0.034	0.034	18.22	<.01	0.16
	Group	2	0.001	0.001	0.35	.70	<.01
	Residuals	86	0.162	0.002			
LTPJ	Pre-test	1	0.054	0.054	15.48	<.01	0.14
	Group	2	0.001	<.001	0.09	.92	<.01
	Residuals	86	0.300	0.003			
RTPJ	Pre-test	1	0.061	0.061	14.98	<.01	0.13
	Group	2	0.003	0.001	0.36	.70	<.01
	Residuals	86	0.349	0.004			
Beta							
FL	Pre-test	1	0.232	0.232	20.18	<.01	0.18
	Group	2	0.014	0.007	0.63	.54	<.01
	Residuals	86	0.987	0.011			
FM	Pre-test	1	0.133	0.133	14.97	<.01	0.13
	Group	2	0.016	0.008	0.92	.40	<.01
	Residuals	86	0.763	0.009			

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
CL	Pre-test	1	0.136	0.136	17.22	<.01	0.15
	Group	2	0.010	0.005	0.63	.54	<.01
	Residuals	86	0.681	0.008			
CM	Pre-test	1	0.187	0.187	24.38	<.01	0.21
	Group	2	0.012	0.006	0.81	.45	<.01
	Residuals	86	0.659	0.008			
PL	Pre-test	1	0.229	0.229	30.56	<.01	0.25
	Group	2	0.009	0.005	0.61	.55	0.00
	Residuals	86	0.645	0.007			
PM	Pre-test	1	0.172	0.172	23.82	<.01	0.20
	Group	2	0.007	0.004	0.49	.61	<.01
	Residuals	86	0.620	0.007			
OL	Pre-test	1	0.087	0.087	13.99	<.01	0.13
	Group	2	0.011	0.005	0.87	.42	<.01
	Residuals	86	0.533	0.006			
OM	Pre-test	1	0.105	0.105	18.75	<.01	0.16
	Group	2	0.019	0.010	1.73	.18	0.02
	Residuals	86	0.483	0.006			
LTL	Pre-test	1	0.200	0.200	24.96	<.01	0.21
	Group	2	0.017	0.008	1.05	.35	<.01
	Residuals	86	0.691	0.008			
RTL	Pre-test	1	0.184	0.184	17.92	<.01	0.16
	Group	2	0.008	0.004	0.40	.67	<.01
	Residuals	86	0.881	0.010			
LTPJ	Pre-test	1	0.184	0.184	21.26	<.01	0.18
	Group	2	0.009	0.005	0.54	.58	<.01
	Residuals	86	0.746	0.009			
RTPJ	Pre-test	1	0.208	0.208	16.84	<.01	0.15
	Group	2	0.021	0.011	0.86	.43	<.01
	Residuals	86	1.064	0.012			

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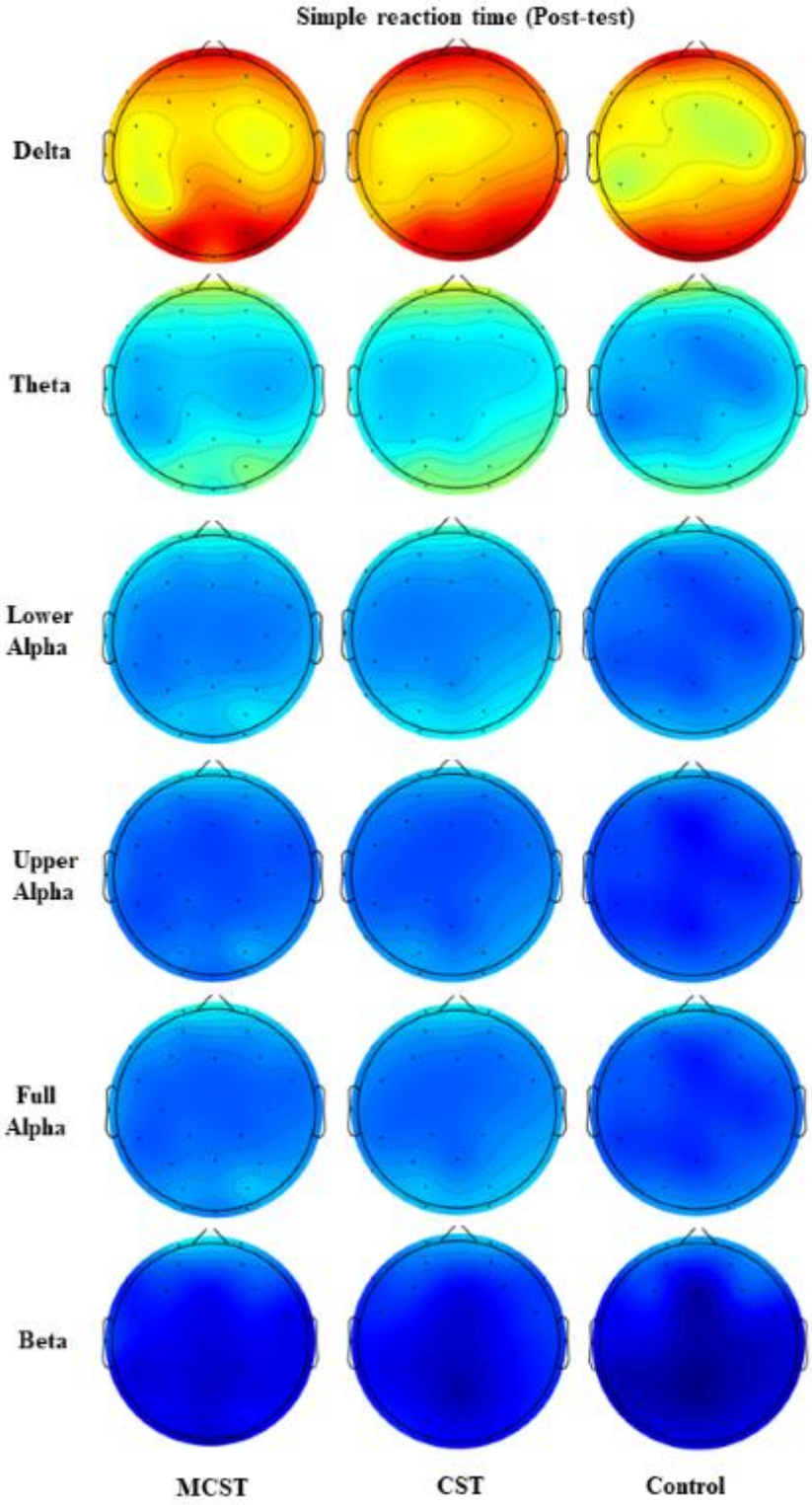

Figure 53 The topographic brain mapping of relative power during the simple reaction time task at post-test

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EEG - Choice reaction time task

Analysis of the relative power characteristics

The analysis of spectral power across different relative power spectrum bands and brain regions revealed notable patterns in the choice reaction time task. In the delta band frequency, there was a general increase in spectral power from pre to post-test across most brain regions. For example, in the frontal lobe (FL), spectral power increased from an average of M = 10.42% to M = 15.38%, indicating a significant rise in neural activity in response to the task demands. Similar trends were observed in other regions such as central electrode locations (CL) and parietal lobe (PL), with spectral power increasing from M = 10% to M = 20% or higher, suggesting heightened engagement during post-test sessions.

In contrast, the theta band frequency showed more varied changes across brain regions. While some regions exhibited increased spectral power post-test, such as the frontal lobe (FL) and frontal midline (FM), others demonstrated minimal change or even slight decreases. For instance, the occipital lobe (OL) showed relatively stable spectral power pre and post-test, with minor fluctuations observed.

Lower alpha band frequency analysis revealed consistent patterns of increase across most brain regions from pre to post-test. This increase was particularly prominent in regions such as central electrode locations (CL) and central midline (CM), with spectral power increasing from M = 5% to M = 10% or higher, indicating a potential shift towards more relaxed or passive neural states during task performance.

Similar to lower alpha, upper alpha band frequency also showed a general increase across brain regions from pre to post-test. Notably, the frontal lobe (FL) and frontal midline (FM) exhibited significant increases in spectral power, with values rising from M = 5% to M = 10% or higher, suggesting heightened cognitive processing and attentional engagement during the post-test session.

Full alpha band frequency analysis mirrored the trends observed in both lower and upper alpha bands, with widespread increases in spectral power across brain regions. This suggests a global shift towards alpha-dominant states

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during post-test sessions, with spectral power increasing from M = 5% to M = 10% or higher, possibly reflecting increased cognitive load and attentional focus.

Finally, in the beta band frequency, trends varied across brain regions, with some regions showing increased spectral power post-test (e.g., frontal lobe, FL) while others demonstrated minor fluctuations or decreases. This variability suggests differential engagement of neural networks involved in motor planning and execution during the choice reaction time task.

Overall, the analysis highlights dynamic changes in spectral power across different relative power spectrum bands and brain regions during the choice reaction time task, with significant increases observed in neural activity from pre to post-test.

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Table 53 Characteristic of relative spectral power (%) of band frequencies in the choice reaction time task

		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Delta										
FL	Pre	31	76.50	12.67	31	76.13	10.43	26	73.68	11.30
	Post	31	69.81	12.67	31	69.17	12.53	26	73.04	12.70
FM	Pre	31	82.66	14.79	31	77.40	14.52	26	75.69	12.91
	Post	31	70.35	17.09	31	69.37	18.62	26	75.43	14.98
CL	Pre	31	82.56	12.77	31	75.88	14.86	26	74.62	12.30
	Post	31	72.59	16.32	31	69.18	15.97	26	75.04	15.93
CM	Pre	31	86.91	12.13	31	81.66	14.59	26	80.69	11.95
	Post	31	79.53	17.98	31	71.76	19.29	26	78.93	18.00
PL	Pre	31	85.75	12.12	31	81.91	15.26	26	85.07	11.10
	Post	31	79.29	17.59	31	77.47	16.10	26	82.45	14.58
PM	Pre	31	87.90	11.33	31	84.64	16.56	26	90.05	9.56
	Post	31	81.90	16.92	31	81.40	17.19	26	86.86	11.76
OL	Pre	31	88.99	12.22	31	85.50	15.83	26	89.86	10.61
	Post	31	85.48	16.47	31	85.17	13.94	26	88.48	12.51

		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
OM	Pre	31	90.93	11.04	31	85.38	17.93	26	88.70	11.64
	Post	31	84.48	18.43	31	86.20	12.88	26	88.38	13.34
LTL	Pre	31	77.40	15.64	31	72.50	15.43	26	72.70	12.89
	Post	31	69.82	13.91	31	68.38	13.95	26	73.32	14.27
RTL	Pre	31	78.87	15.11	31	75.42	13.71	26	76.70	9.70
	Post	31	72.72	15.06	31	72.60	13.14	26	75.99	14.91
LTPJ	Pre	31	81.00	16.55	31	76.12	20.18	26	78.39	16.09
	Post	31	74.47	20.60	31	72.09	18.59	26	78.18	17.31
RTPJ	Pre	31	83.95	15.99	31	78.36	18.28	26	84.16	11.05
	Post	31	78.17	20.28	31	76.68	18.34	26	82.88	17.45
Theta										
FL	Pre	31	9.39	3.14	31	9.01	2.23	26	9.26	2.71
	Post	31	9.48	2.74	31	10.16	2.64	26	9.48	2.60
FM	Pre	31	7.43	5.07	31	8.65	4.28	26	8.93	3.67
	Post	31	9.97	5.31	31	11.14	5.41	26	9.47	4.08
CL	Pre	31	6.08	3.30	31	7.58	3.35	26	7.58	2.20
	Post	31	8.18	3.73	31	9.75	4.18	26	7.99	3.66
CM	Pre	31	5.38	3.90	31	7.11	4.81	26	6.86	3.02
	Post	31	6.70	4.59	31	9.69	5.02	26	7.50	4.89
PL	Pre	31	5.32	3.03	31	6.24	3.10	26	5.54	2.36
	Post	31	6.44	4.08	31	7.62	4.11	26	6.36	3.15
PM	Pre	31	4.83	3.07	31	5.63	3.68	26	4.25	2.82
	Post	31	6.55	4.53	31	6.83	5.06	26	5.55	4.01
OL	Pre	31	4.73	3.84	31	5.38	3.83	26	4.57	2.95
	Post	31	5.27	3.84	31	5.96	3.95	26	4.67	3.07
OM	Pre	31	4.24	3.82	31	5.39	4.62	26	5.19	3.51
	Post	31	5.71	4.74	31	6.04	3.98	26	4.37	3.36
LTL	Pre	31	7.00	3.49	31	8.20	2.96	26	7.94	1.96
	Post	31	8.97	2.84	31	9.26	2.76	26	8.19	2.90

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
RTL	Pre	31	6.72	2.76	31	7.63	2.27	26	7.25	1.63
	Post	31	8.23	3.13	31	8.32	2.77	26	7.39	2.49
LTPJ	Pre	31	6.33	3.93	31	6.83	3.61	26	6.52	2.65
	Post	31	7.25	4.07	31	8.36	4.31	26	6.95	3.69
RTPJ	Pre	31	5.41	3.45	31	6.63	3.43	26	5.55	2.25
	Post	31	6.32	4.26	31	7.09	4.06	26	5.82	3.58
Lower Alpha										
FL	Pre	31	1.83	1.15	31	2.08	1.25	26	2.04	0.86
	Post	31	2.53	1.45	31	2.67	1.50	26	2.21	1.36
FM	Pre	31	1.88	2.12	31	2.90	2.86	26	2.59	1.73
	Post	31	3.33	2.51	31	3.84	3.32	26	3.03	2.52
CL	Pre	31	1.77	1.40	31	2.78	2.08	26	2.46	1.21
	Post	31	3.11	2.48	31	3.61	2.78	26	2.84	2.26
CM	Pre	31	1.38	1.40	31	2.37	2.17	26	2.17	1.55
	Post	31	2.67	3.19	31	3.55	2.93	26	2.70	2.84
PL	Pre	31	1.57	1.45	31	2.07	1.92	26	1.55	1.01
	Post	31	2.52	2.56	31	2.80	2.58	26	2.03	1.96
PM	Pre	31	1.34	1.36	31	1.83	2.19	26	1.08	0.91
	Post	31	2.13	2.20	31	2.34	2.52	26	1.54	1.60
OL	Pre	31	1.23	1.69	31	1.74	2.21	26	1.03	1.11
	Post	31	1.72	2.30	31	1.83	2.50	26	1.19	1.37
OM	Pre	31	0.99	1.56	31	1.72	2.44	26	1.15	1.22
	Post	31	1.79	2.48	31	1.63	2.12	26	1.18	1.54
LTL	Pre	31	2.30	1.83	31	3.03	2.08	26	2.69	1.42
	Post	31	3.62	2.52	31	3.50	2.15	26	3.05	2.18
RTL	Pre	31	2.15	1.67	31	2.74	1.88	26	2.20	1.22
	Post	31	3.29	2.72	31	3.02	2.15	26	2.49	1.86
LTPJ	Pre	31	1.97	2.07	31	2.68	2.67	26	2.23	1.86
	Post	31	3.04	3.20	31	3.30	2.93	26	2.53	2.37

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		MCST			CST			Control	
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
RTPJ	Pre	31	1.83	2.20	31	2.54	2.58	26	1.49	1.00
	Post	31	2.91	3.58	31	2.82	3.09	26	1.92	2.20
Upper Alpha										
FL	Pre	31	1.86	1.47	31	1.98	1.14	26	2.10	1.11
	Post	31	2.79	1.71	31	2.81	1.72	26	2.46	1.77
FM	Pre	31	1.68	1.72	31	2.41	1.82	26	2.47	1.48
	Post	31	3.33	2.43	31	3.49	2.90	26	3.01	2.43
CL	Pre	31	2.07	1.95	31	3.06	2.67	26	2.79	1.61
	Post	31	3.44	2.62	31	3.94	2.71	26	3.23	2.90
CM	Pre	31	1.51	1.74	31	2.25	2.45	26	2.30	1.89
	Post	31	2.64	2.83	31	3.78	3.50	26	2.82	3.24
PL	Pre	31	1.76	1.86	31	2.42	2.99	26	1.79	1.60
	Post	31	2.89	3.04	31	3.12	2.79	26	2.42	2.77
PM	Pre	31	1.49	1.74	31	2.18	3.30	26	1.17	1.28
	Post	31	2.50	2.93	31	2.60	2.90	26	1.70	2.10
OL	Pre	31	1.22	1.48	31	1.83	2.42	26	1.11	1.37
	Post	31	1.91	2.77	31	1.92	2.48	26	1.50	2.36
OM	Pre	31	0.89	1.17	31	1.81	2.83	26	1.16	1.26
	Post	31	1.93	2.79	31	1.62	1.99	26	1.51	2.33
LTL	Pre	31	2.54	2.05	31	3.23	2.53	26	2.97	1.85
	Post	31	3.66	2.24	31	3.77	2.11	26	3.17	2.65
RTL	Pre	31	2.31	1.86	31	2.88	2.13	26	2.40	1.42
	Post	31	3.37	2.43	31	3.23	2.20	26	2.74	2.47
LTPJ	Pre	31	2.31	2.31	31	3.24	3.70	26	2.78	2.74
	Post	31	3.55	3.71	31	3.86	3.20	26	3.07	3.32
RTPJ	Pre	31	1.92	2.20	31	2.90	3.36	26	1.76	1.56
	Post	31	3.24	3.78	31	3.12	3.22	26	2.21	3.13
Full Alpha										
FL	Pre	31	3.69	2.51	31	4.06	2.30	26	4.14	1.92

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	31	5.32	3.10	31	5.47	3.06	26	4.68	3.08
FM	Pre	31	3.56	3.66	31	5.31	4.52	26	5.06	3.13
	Post	31	6.66	4.87	31	7.34	5.70	26	6.04	4.76
CL	Pre	31	3.84	3.31	31	5.84	4.61	26	5.26	2.76
	Post	31	6.55	4.98	31	7.55	5.33	26	6.07	4.95
CM	Pre	31	2.90	3.13	31	4.62	4.38	26	4.47	3.41
	Post	31	5.31	5.83	31	7.33	6.09	26	5.52	5.85
PL	Pre	31	3.33	3.25	31	4.49	4.85	26	3.34	2.57
	Post	31	5.41	5.49	31	5.92	5.28	26	4.45	4.62
PM	Pre	31	2.84	3.05	31	4.01	5.43	26	2.25	2.16
	Post	31	4.62	5.07	31	4.94	5.38	26	3.24	3.61
OL	Pre	31	2.44	3.07	31	3.57	4.55	26	2.13	2.45
	Post	31	3.63	5.04	31	3.75	4.92	26	2.69	3.69
OM	Pre	31	1.87	2.66	31	3.53	5.23	26	2.31	2.45
	Post	31	3.72	5.24	31	3.24	4.08	26	2.69	3.85
LTL	Pre	31	4.84	3.79	31	6.26	4.52	26	5.66	3.15
	Post	31	7.28	4.65	31	7.27	4.07	26	6.23	4.70
RTL	Pre	31	4.47	3.45	31	5.63	3.94	26	4.60	2.61
	Post	31	6.66	5.02	31	6.25	4.17	26	5.23	4.11
LTPJ	Pre	31	4.28	4.21	31	5.92	6.25	26	5.01	4.52
	Post	31	6.59	6.76	31	7.16	5.96	26	5.60	5.56
RTPJ	Pre	31	3.75	4.27	31	5.44	5.84	26	3.25	2.53
	Post	31	6.15	7.25	31	5.94	6.12	26	4.13	5.15
Beta										
FL	Pre	31	10.42	10.35	31	10.80	8.22	26	12.92	10.36
	Post	31	15.38	9.22	31	15.20	9.88	26	12.80	9.28
FM	Pre	31	6.35	7.93	31	8.63	7.36	26	10.32	8.72
	Post	31	13.01	9.19	31	12.16	9.27	26	9.05	7.23
CL	Pre	31	7.53	6.72	31	10.70	8.23	26	12.55	9.04

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		MCST			CST			Control	
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	31	12.68	8.79	31	13.52	7.79	26	10.90	8.69
CM	Pre	31	4.82	5.63	31	6.61	6.80	26	7.98	6.56
	Post	31	8.46	8.13	31	11.21	9.65	26	8.06	8.43
PL	Pre	31	5.61	6.32	31	7.36	8.41	26	6.04	7.00
	Post	31	8.86	8.57	31	8.99	7.57	26	6.75	7.74
PM	Pre	31	4.44	5.76	31	5.73	8.15	26	3.45	5.11
	Post	31	6.93	8.00	31	6.83	7.76	26	4.36	4.75
OL	Pre	31	3.84	5.72	31	5.55	7.88	26	3.44	5.70
	Post	31	5.62	7.95	31	5.12	5.71	26	4.17	6.38
OM	Pre	31	2.96	4.92	31	5.69	8.61	26	3.80	6.36
	Post	31	6.10	8.95	31	4.52	5.54	26	4.56	6.90
LTL	Pre	31	10.76	9.96	31	13.05	9.39	26	13.70	9.58
	Post	31	13.94	8.41	31	15.09	9.24	26	12.26	8.45
RTL	Pre	31	9.94	10.03	31	11.33	8.93	26	11.46	6.27
	Post	31	12.39	8.39	31	12.83	7.86	26	11.39	9.61
LTPJ	Pre	31	8.39	9.41	31	11.13	11.81	26	10.08	9.99
	Post	31	11.68	10.75	31	12.40	10.19	26	9.27	9.21
RTPJ	Pre	31	6.89	8.99	31	9.58	9.95	26	7.04	7.39
	Post	31	9.36	9.71	31	10.29	9.45	26	7.17	9.63

Analysis of assumptions

In the assumption testing for the Choice Reaction Time Task across various relative power spectrum bands, several patterns emerge. In the delta band, normality assumptions were frequently violated ($W = 0.76 - 0.94$, $p < 0.01$), while homoscedasticity was mostly observed (*K-squared* = 0.01 - 4.73, $p < 0.05$). Parallelism generally held ($F = 0.15 - 3.55$, $p < 0.05$), with few exceptions such as FM and PM, indicating potential issues with variance across groups.

Moving to the theta band, normality assumptions continued to be challenged ($W = 0.89 - 0.98$, $p < 0.01$), particularly for variables like RTL.

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Homoscedasticity was mostly observed (*K-squared* = 0.06 - 3.18, $p < 0.05$), except for outliers like OM. Parallelism generally held (F = 0.02 - 3.09, $p < 0.05$), although deviations were seen in cases like RTL and PM, suggesting unequal variances across groups.

In the lower alpha band, , violations of normality were common across variables (W = 0.67 - 0.89, $p < 0.01$), but homoscedasticity was mostly observed (*K-squared* = 0.07 - 9.38, $p < 0.05$). Parallelism was generally supported (F = 0.16 - 5.96, $p < 0.05$), although deviations were observed in cases like RTL and RTPJ, indicating potential issues with variance across conditions.

Similarly, in the upper alpha band, normality assumptions were frequently challenged (W = 0.66 - 0.89, $p < 0.01$), but homoscedasticity was mostly observed (*K-squared* = 0.03 - 3.37, $p < 0.05$). Parallelism was generally supported (F = 0.05 - 3.78, $p < 0.05$), although deviations were observed in cases like RTL and PM, suggesting unequal variances across groups.

In the full alpha and beta bands, patterns of normality violations, homoscedasticity, and parallelism were consistent with those seen in previous bands (W = 0.68 - 0.93, $p < 0.01$; *K-squared* = 0.02 - 7.60, $p < 0.05$; F = 0.11 - 4.90, $p < 0.05$).

Analysis of group comparisons

This section presents the results of ANCOVA for various parameters during the choice reaction time task to psychomotor in older adults with mild cognitive impairement. ANCOVA revealed significant effects of group condition on relative beta frequency in the main region of frontal mindline. However, the results of the ANCOVA could not be interpreted due to violations of the regression slope homogeneity assumption. Therefore, separate regression analyses for each group are presented in the following section for the affected ROIs: Delta (OM), Upper alpha (OM), and Beta (FL, FM, OM).

In the delta band, the analysis revealed no significant group effects across all regions. For example, the frontal lobe (FL) exhibited a non-significant group effect with a small effect size ($F(2, 84) = 1.96$, $p = .15$, partial $\omega^2 = 0.02$). This non-significant pattern was consistent across the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM),

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occipital lobe (OL), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all $p > .05$).

For the theta band, no significant group effects were observed in most regions. The central midline (CM) showed a non-significant group effect with a small effect size ($F(2, 84) = 2.42$, $p = .10$, partial $\omega^2 = 0.03$). The same non-significant trend was observed in the frontal lobe (FL), frontal midline (FM), central lobe (CL), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all $p > .05$).

In the lower alpha band, , no significant group effects were identified across any regions. The frontal lobe (FL) had a non-significant group effect with a small effect size ($F(2, 84) = 1.22$, $p = .30$, partial $\omega^2 < .01$). This trend persisted in the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all $p > .05$).

The upper alpha band analysis showed no significant group effects. For instance, the frontal lobe (FL) exhibited a non-significant group effect with a small effect size ($F(2, 84) = 0.91$, $p = .41$, partial $\omega^2 < .01$). Other regions, including the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) also showed non-significant group effects (all $p > .05$).

In the full alpha band, no significant group effects were observed in any region. The frontal lobe (FL) exhibited a non-significant group effect with a small effect size ($F(2, 84) = 1.09$, $p = .34$, partial $\omega^2 < .01$). This non-significant pattern was consistent across the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all $p > .05$).

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For the beta band, no significant group effects were observed in any region, such as the central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ), showed non-significant group effects (all $p > .05$).

The ANCOVA results for the Choice Reaction Time Task indicated no significant group effects across most relative power spectrum bands (delta, theta, lower alpha, upper alpha, and full alpha) in the brain regions examined. However, in the beta band, a significant group effect was observed in the frontal midline, indicating that the MCST group differed significantly from the control group with a moderate effect size. Other regions did not show significant group differences (See Table 54 ANCOVA of the choice reaction time task).

Table 54 ANCOVA of the choice reaction time task

		df	*SS*	*MS*	*F*	*p*	ω_p^2
Delta							
FL	Pre-test	1	0.338	0.338	28.50	<.01	0.24
	Group	2	0.046	0.023	1.96	.15	0.02
	Residuals	84	0.995	0.012			
FM	Pre-test	1	0.326	0.326	13.03	<.01	0.12
	Group	2	0.106	0.053	2.13	.13	0.02
	Residuals	84	2.103	0.025			
CL	Pre-test	1	0.378	0.378	17.69	<.01	0.16
	Group	2	0.076	0.038	1.78	.18	0.02
	Residuals	84	1.794	0.021			
CM	Pre-test	1	0.463	0.463	15.80	<.01	0.14
	Group	2	0.087	0.044	1.49	.23	0.01
	Residuals	84	2.460	0.029			
PL	Pre-test	1	0.487	0.487	23.17	<.01	0.20
	Group	2	0.021	0.010	0.50	.61	<.01
	Residuals	84	1.765	0.021			

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
PM	Pre-test	1	0.538	0.538	28.57	<.01	0.24
	Group	2	0.019	0.010	0.51	.60	<.01
	Residuals	84	1.583	0.019			
OL	Pre-test	1	0.511	0.511	33.36	<.01	0.27
	Group	2	0.010	0.005	0.31	.73	<.01
	Residuals	84	1.286	0.015			
OM*	Pre-test	1	0.586	0.586	36.58	<.01	0.29
	Group	2	0.053	0.026	1.65	.20	0.01
	Residuals	84	1.345	0.016			
LTL	Pre-test	1	0.517	0.517	38.15	<.01	0.30
	Group	2	0.056	0.028	2.06	.13	0.02
	Residuals	84	1.138	0.014			
RTL	Pre-test	1	0.528	0.528	36.42	<.01	0.29
	Group	2	0.030	0.015	1.02	.36	<.01
	Residuals	84	1.217	0.014			
LTPJ	Pre-test	1	0.750	0.750	27.22	<.01	0.23
	Group	2	0.046	0.023	0.83	.44	<.01
	Residuals	84	2.316	0.028			
RTPJ	Pre-test	1	0.909	0.909	35.97	<.01	0.28
	Group	2	0.029	0.015	0.58	.56	<.01
	Residuals	84	2.123	0.025			
Theta							
FL	Pre-test	1	0.006	0.006	9.01	<.01	0.08
	Group	2	0.001	0.001	0.93	.40	<.01
	Residuals	84	0.054	0.001			
FM	Pre-test	1	0.032	0.032	14.98	<.01	0.14
	Group	2	0.005	0.002	1.06	.35	<.01
	Residuals	84	0.181	0.002			
CL	Pre-test	1	0.008	0.008	5.57	.02	0.05
	Group	2	0.005	0.002	1.60	.21	0.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	84	0.121	0.001			
CM	Pre-test	1	0.015	0.015	6.92	.01	0.06
	Group	2	0.011	0.005	2.42	.10	0.03
	Residuals	84	0.187	0.002			
PL	Pre-test	1	0.015	0.015	11.47	<.01	0.11
	Group	2	0.002	0.001	0.56	.57	<.01
	Residuals	84	0.112	0.001			
PM	Pre-test	1	0.024	0.024	13.01	<.01	0.12
	Group	2	0.001	<.001	0.21	.81	<.01
	Residuals	84	0.156	0.002			
OL	Pre-test	1	0.026	0.026	24.77	<.01	0.21
	Group	2	0.001	0.001	0.54	.59	<.01
	Residuals	84	0.089	0.001			
OM	Pre-test	1	0.033	0.033	25.86	<.01	0.22
	Group	2	0.005	0.003	2.06	.13	0.02
	Residuals	84	0.109	0.001			
LTL	Pre-test	1	0.005	0.005	6.60	.01	0.06
	Group	2	0.002	0.001	1.26	.29	0.01
	Residuals	84	0.063	0.001			
RTL	Pre-test	1	0.009	0.009	13.33	<.01	0.12
	Group	2	0.002	0.001	1.22	.30	0.01
	Residuals	84	0.058	0.001			
LTPJ	Pre-test	1	0.022	0.022	15.37	<.01	0.14
	Group	2	0.002	0.001	0.87	.42	<.01
	Residuals	84	0.119	0.001			
RTPJ	Pre-test	1	0.020	0.020	14.60	<.01	0.13
	Group	2	0.001	<.001	0.30	.74	<.01
	Residuals	84	0.117	0.001			
Lower Alpha							
FL	Pre-test	1	0.005	0.005	34.65	<.01	0.28

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	<.001	<.001	1.22	.30	<.01
	Residuals	84	0.012	<.001			
FM	Pre-test	1	0.024	0.024	46.71	<.01	0.34
	Group	2	0.001	<.001	0.95	.39	<.01
	Residuals	84	0.044	0.001			
CL	Pre-test	1	0.015	0.015	31.66	<.01	0.26
	Group	2	0.001	<.001	1.03	.36	<.01
	Residuals	84	0.040	<.001			
CM	Pre-test	1	0.012	0.012	15.98	<.01	0.15
	Group	2	0.001	<.001	0.48	.62	0.00
	Residuals	84	0.065	0.001			
PL	Pre-test	1	0.010	0.010	20.06	<.01	0.18
	Group	2	<.001	<.001	0.38	.68	<.01
	Residuals	84	0.040	<.001			
PM	Pre-test	1	0.010	0.010	27.24	<.01	0.23
	Group	2	<.001	<.001	0.34	.71	<.01
	Residuals	84	0.031	<.001			
OL	Pre-test	1	0.008	0.008	21.93	<.01	0.19
	Group	2	<.001	<.001	0.34	.71	<.01
	Residuals	84	0.031	<.001			
OM	Pre-test	1	0.010	0.010	28.67	<.01	0.24
	Group	2	0.001	<.001	1.27	.29	0.01
	Residuals	84	0.028	<.001			
LTL	Pre-test	1	0.014	0.014	37.72	<.01	0.29
	Group	2	0.001	0.001	1.53	.22	0.01
	Residuals	84	0.031	<.001			
RTL	Pre-test	1	0.012	0.012	30.21	<.01	0.25
	Group	2	0.001	0.001	1.52	.23	0.01
	Residuals	84	0.033	<.001			
LTPJ	Pre-test	1	0.016	0.016	24.02	<.01	0.21

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	0.001	<.001	0.51	.6	<.01
	Residuals	84	0.055	0.001			
RTPJ	Pre-test	1	0.020	0.020	27.75	<.01	0.23
	Group	2	0.001	<.001	0.64	.53	<.01
	Residuals	84	0.060	0.001			
Upper Alpha							
FL	Pre-test	1	0.006	0.006	28.81	<.01	0.24
	Group	2	<.001	<.001	0.91	.41	<.01
	Residuals	84	0.019	<.001			
FM	Pre-test	1	0.010	0.010	17.70	<.01	0.16
	Group	2	0.001	<.001	0.88	.42	<.01
	Residuals	84	0.047	0.001			
CL	Pre-test	1	0.019	0.019	35.84	<.01	0.28
	Group	2	0.001	<.001	0.70	.50	<.01
	Residuals	84	0.045	0.001			
CM	Pre-test	1	0.022	0.022	28.35	<.01	0.24
	Group	2	0.001	0.001	0.93	.40	<.01
	Residuals	84	0.066	0.001			
PL	Pre-test	1	0.017	0.017	26.40	<.01	0.22
	Group	2	<.001	<.001	0.27	.77	<.01
	Residuals	84	0.054	0.001			
PM	Pre-test	1	0.018	0.018	34.33	<.01	0.27
	Group	2	0.001	<.001	0.48	.62	<.01
	Residuals	84	0.045	0.001			
OL	Pre-test	1	0.016	0.016	33.71	<.01	0.27
	Group	2	<.001	<.001	0.34	.71	<.01
	Residuals	84	0.039	<.001			
OM*	Pre-test	1	0.013	0.013	32.72	<.01	0.26
	Group	2	0.001	0.001	1.62	.20	0.01
	Residuals	84	0.034	<.001			

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
LTL	Pre-test	1	0.018	0.018	56.02	<.01	0.38
	Group	2	0.001	<.001	1.31	.28	0.01
	Residuals	84	0.027	<.001			
RTL	Pre-test	1	0.019	0.019	55.84	<.01	0.38
	Group	2	0.001	<.001	1.27	.28	0.01
	Residuals	84	0.028	<.001			
LTPJ	Pre-test	1	0.028	0.028	32.76	<.01	0.27
	Group	2	0.001	<.001	0.49	.61	<.01
	Residuals	84	0.072	0.001			
RTPJ	Pre-test	1	0.036	0.036	48.93	<.01	0.35
	Group	2	0.002	0.001	1.10	.34	<.01
	Residuals	84	0.062	0.001			
Full Alpha							
FL	Pre-test	1	0.021	0.021	30.28	<.01	0.25
	Group	2	0.002	0.001	1.09	.34	<.01
	Residuals	84	0.059	0.001			
FM	Pre-test	1	0.057	0.057	29.04	<.01	0.24
	Group	2	0.004	0.002	0.98	.38	<.01
	Residuals	84	0.166	0.002			
CL	Pre-test	1	0.063	0.063	33.67	<.01	0.27
	Group	2	0.003	0.002	0.89	.42	<.01
	Residuals	84	0.157	0.002			
CM	Pre-test	1	0.059	0.059	20.32	<.01	0.18
	Group	2	0.004	0.002	0.72	.49	<.01
	Residuals	84	0.243	0.003			
PL	Pre-test	1	0.050	0.050	23.29	<.01	0.20
	Group	2	0.001	0.001	0.33	.72	<.01
	Residuals	84	0.179	0.002			
PM	Pre-test	1	0.055	0.055	31.84	<.01	0.26
	Group	2	0.001	0.001	0.42	.66	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	84	0.145	0.002			
OL	Pre-test	1	0.046	0.046	28.21	<.01	0.24
	Group	2	0.001	<.001	0.28	.75	<.01
	Residuals	84	0.138	0.002			
OM	Pre-test	1	0.046	0.046	32.23	<.01	0.26
	Group	2	0.004	0.002	1.44	.24	0.01
	Residuals	84	0.121	0.001			
LTL	Pre-test	1	0.061	0.061	48.17	<.01	0.35
	Group	2	0.004	0.002	1.50	.23	0.01
	Residuals	84	0.107	0.001			
RTL	Pre-test	1	0.057	0.057	42.53	<.01	0.32
	Group	2	0.004	0.002	1.51	.23	0.01
	Residuals	84	0.112	0.001			
LTPJ	Pre-test	1	0.083	0.083	29.32	<.01	0.24
	Group	2	0.003	0.002	0.53	.59	<.01
	Residuals	84	0.238	0.003			
RTPJ	Pre-test	1	0.107	0.107	38.64	<.01	0.30
	Group	2	0.005	0.002	0.89	.41	<.01
	Residuals	84	0.232	0.003			
Beta							
FL*	Pre-test	1	0.197	0.197	29.85	<.01	0.25
	Group	2	0.025	0.012	1.88	.16	0.02
	Residuals	84	0.553	0.007			
FM*	Pre-test	1	0.070	0.070	10.73	<.01	0.10
	Group	2	0.043	0.022	3.31	.04	0.05
	Residuals	84	0.552	0.007			
CL	Pre-test	1	0.111	0.111	19.52	<.01	0.17
	Group	2	0.027	0.013	2.36	.10	0.03
	Residuals	84	0.476	0.006			
CM	Pre-test	1	0.121	0.121	19.23	<.01	0.17

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	0.022	0.011	1.77	.18	0.02
	Residuals	84	0.529	0.006			
PL	Pre-test	1	0.126	0.126	25.39	<.01	0.22
	Group	2	0.008	0.004	0.80	.45	<.01
	Residuals	84	0.417	0.005			
PM	Pre-test	1	0.124	0.124	33.42	<.01	0.27
	Group	2	0.006	0.003	0.77	.47	<.01
	Residuals	84	0.311	0.004			
OL	Pre-test	1	0.111	0.111	33.54	<.01	0.27
	Group	2	0.004	0.002	0.56	.57	<.01
	Residuals	84	0.278	0.003			
OM*	Pre-test	1	0.130	0.130	35.31	<.01	0.28
	Group	2	0.016	0.008	2.15	.12	0.03
	Residuals	84	0.310	0.004			
LTL	Pre-test	1	0.227	0.227	46.13	<.01	0.34
	Group	2	0.019	0.009	1.93	.15	0.02
	Residuals	84	0.413	0.005			
RTL	Pre-test	1	0.210	0.210	42.50	<.01	0.32
	Group	2	0.005	0.003	0.55	.58	<.01
	Residuals	84	0.415	0.005			
LTPJ	Pre-test	1	0.168	0.168	20.12	<.01	0.18
	Group	2	0.016	0.008	0.95	.39	<.01
	Residuals	84	0.701	0.008			
RTPJ	Pre-test	1	0.243	0.243	37.41	<.01	0.29
	Group	2	0.008	0.004	0.59	.56	<.01
	Residuals	84	0.546	0.006			

*A significant interaction effect

Analysis of regression

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This analysis examines the predictive relationships of the relative powers (i.e., pre-test and post-test) for specific frequency bands (upper alpha, beta, and delta) across regions (OM, FL, and FM) for the three groups, including MCST, CST, and control.

For the relative delta, in the OM region, the MCST group demonstrates strong predictive power ($\beta_1 = 1.09$, $p < .001$, adjusted $R^2 = .40$), indicating significant intervention effects. The CST group shows similar predictive capacity ($\beta_1 = 0.47$, $p < .001$, adjusted $R^2 = .40$). The control group exhibits moderate predictive power ($\beta_1 = 0.50$, $p = .03$, adjusted $R^2 = .15$), suggesting a weaker relationship compared to the intervention groups.

For the relative upper alpha, in the OM region, the MCST group shows strong predictive power ($\beta_1 = 1.42$, $p < .001$, adjusted $R^2 = .33$), indicating significant intervention effects. The CST group exhibits even stronger predictive power ($\beta_1 = 0.52$, $p < .001$, adjusted $R^2 = .54$), suggesting high effectiveness of this intervention. The control group shows moderate predictive capacity ($\beta_1 = 0.78$, $p = .03$, adjusted $R^2 = .14$), suggesting some natural predictive relationship in this region.

For the relative beta, in the FL region, the MCST group demonstrates significant predictive power ($\beta_1 = 0.54$, $p < .001$, adjusted $R^2 = .34$), highlighting the impact of the intervention. The CST group also shows strong predictive capacity ($\beta_1 = 0.83$, $p < .001$, adjusted $R^2 = .47$). The control group fails to reach significance ($\beta_1 = 0.25$, $p = .18$, adjusted $R^2 = .04$), suggesting limited natural predictive capacity in this region (see Figure 54). In the FM region, the MCST group fails to demonstrate significance ($\beta_1 = 0.32$, $p = .14$, adjusted $R^2 = .04$). The CST group shows significant predictive power ($\beta_1 = 0.86$, $p < .001$, adjusted $R^2 = .44$), indicating the effectiveness of this intervention. The control group fails to show significance ($\beta_1 = 0.11$, $p = .50$, adjusted $R^2 = -.02$). In the OM region, The MCST group demonstrates strong predictive power ($\beta_1 = 1.19$, $p < .001$, adjusted $R^2 = .41$). The CST group also shows significant predictive capacity ($\beta_1 = 0.41$, $p < .001$, adjusted $R^2 = .39$). The control group demonstrates moderate predictive capacity ($\beta_1 = 0.59$, $p = .01$, adjusted $R^2 = .26$).

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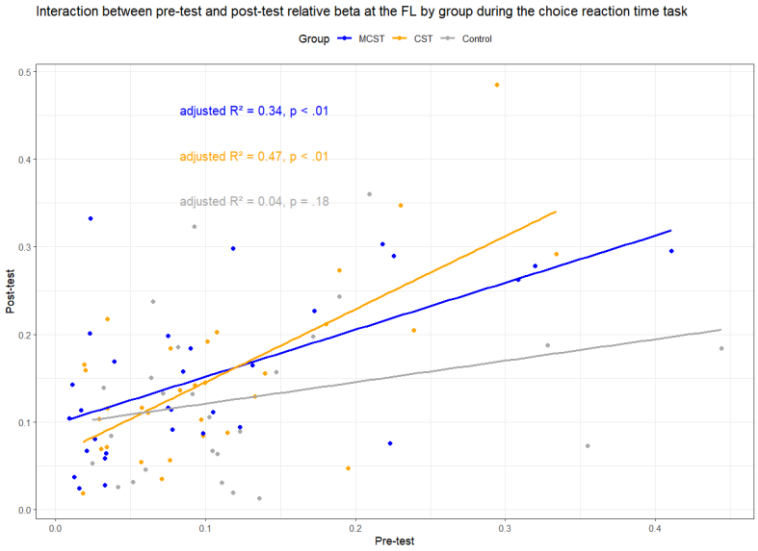

Figure 54 A scatter plot and the regression lines are shows interaction between pre-test and post-test relative beta in the frontal lobe (FL) area by group during the choice reaction time task

In summary, in the Choice Reaction Time Task, the MCST and CST groups consistently demonstrate significant predictive relationships, particularly in the upper alpha and beta, with adjusted R^2 values ranging from 0.33 to 0.54. These results suggest substantial intervention effects for both groups. The control group shows moderate predictive capacity in specific regions (adjusted $R^2 \approx .14–0.26$), indicating some natural predictive capacity, though the effects are less robust compared to the intervention groups. The delta demonstrates consistent predictive relationships across all groups, with stronger effects in the intervention groups.

Table 55 Regression analysis of the choice reaction time task

ROI	Model	Variable	*β*	*SE*	*t*	*p*
Delta						
OM	MCST	Constant	-0.14	0.22	-0.66	.51
		Pre-test	1.09	0.24	4.61	<.01
	CST	Constant	0.46	0.09	5.24	<.01
		Pre-test	0.47	0.10	4.59	<.01
	Control	Constant	0.44	0.19	2.35	.03
		Pre-test	0.50	0.21	2.35	.03
Upper Alpha						

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ROI	Model	Variable	*β*	*SE*	*t*	*p*
OM	MCST	Constant	0.01	0.01	1.29	.21
		Pre-test	1.42	0.36	4.01	<.01
	CST	Constant	0.01	0.00	2.31	.03
		Pre-test	0.52	0.09	6.02	<.01
	Control	Constant	0.01	0.01	1.05	.30
		Pre-test	0.78	0.34	2.27	.03
Beta						
FL	MCST	Constant	0.10	0.02	5.09	<.01
		Pre-test	0.54	0.13	4.07	<.01
	CST	Constant	0.06	0.02	2.86	.01
		Pre-test	0.83	0.16	5.21	<.01
	Control	Constant	0.10	0.03	3.33	<.01
		Pre-test	0.25	0.18	1.40	.18
FM	MCST	Constant	0.11	0.02	5.29	<.01
		Pre-test	0.32	0.21	1.53	.14
	CST	Constant	0.05	0.02	2.46	.02
		Pre-test	0.86	0.17	5.00	<.01
	Control	Constant	0.08	0.02	3.51	<.01
		Pre-test	0.11	0.17	0.68	.50
OM	MCST	Constant	0.03	0.01	1.78	.09
		Pre-test	1.19	0.26	4.64	<.01
	CST	Constant	0.02	0.01	2.33	.03
		Pre-test	0.41	0.09	4.45	<.01
	Control	Constant	0.02	0.01	1.71	.10
		Pre-test	0.59	0.19	3.14	<.01

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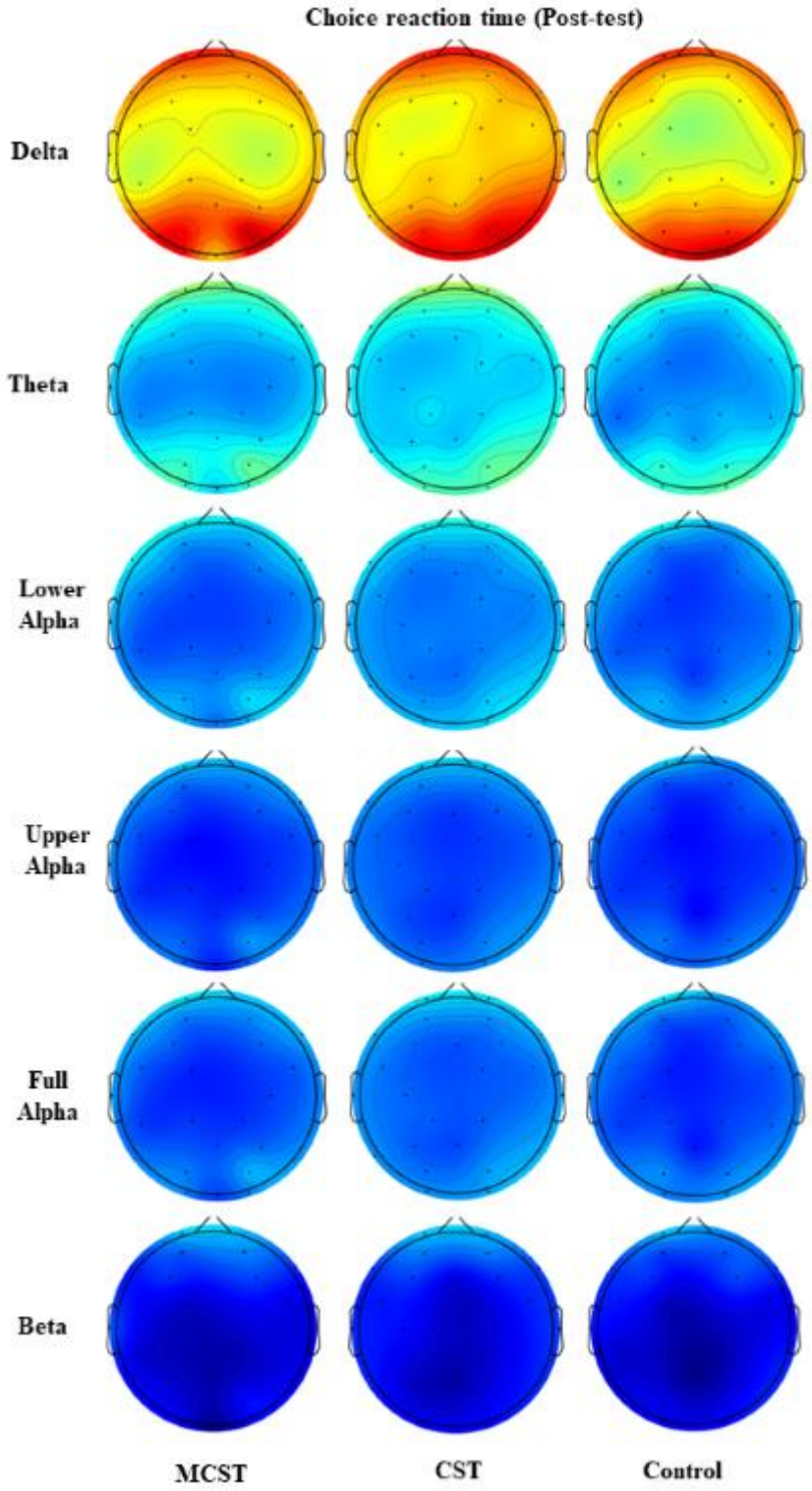

Figure 55 The topographic brain mapping of relative power during the choice reaction time task at post-test

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EEG - Sound-induced flash illusion task

Analysis of the relative power characteristics

Delta band frequency demonstrated a consistent decrease across all brain regions from pre-test to post-test. The most substantial declines were observed in central electrode locations (CL), central midline (CM), and occipital midline (OM) regions, with average reductions ranging from 5% to 20% (see Table 56).

Theta band frequency exhibited varied changes across brain regions, with some areas showing an increase (e.g., frontal lobe (FL) and frontal midline (FM)) and others displaying a decrease (e.g., parietal lobe (PL) and parietal midline (PM)). The alterations were relatively modest, with average shifts ranging from 1% to 5%.

Lower alpha band frequency demonstrated a consistent increase across all brain regions, with notable enhancements observed in central electrode locations (CL), central midline (CM), and occipital lobe (OL). Average increments ranged from 5% to 15%.

Upper alpha band frequency displayed a similar pattern of increase across brain regions, with notable enhancements in the frontal lobe (FL) and frontal midline (FM). Average increases ranged from 5% to 10%.

Full alpha band frequency exhibited uniform increases across all brain regions, with notable enhancements observed in the frontal lobe (FL), frontal midline (FM), and central lobe (CL). Average increments ranged from 5% to 10%.

Beta band frequency displayed consistent increases across brain regions, indicating heightened cortical activation during the post-test phase compared to the pre-test phase. The increases were moderate, with average increments ranging from 5% to 15%

Table 56 Characteristic of relative spectral power (%) of band frequencies in the sound-induced flash illusion task

	MCST			CST			Control		
test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Delta										
FL	Pre	31	77.74	12.08	30	76.93	12.34	27	72.84	13.35
	Post	31	70.71	13.20	30	70.09	13.06	27	72.57	11.82
FM	Pre	31	85.75	11.74	30	78.35	17.24	27	74.54	14.73
	Post	31	71.12	17.95	30	69.38	20.21	27	74.18	16.05
CL	Pre	31	85.00	9.81	30	79.20	16.28	27	74.98	14.59
	Post	31	73.00	13.67	30	67.54	17.33	27	71.90	16.38
CM	Pre	31	89.00	9.01	30	83.74	16.46	27	79.78	14.83
	Post	31	76.75	14.35	30	74.01	18.19	27	76.61	17.92
PL	Pre	31	88.59	7.96	30	84.34	16.23	27	81.96	15.67
	Post	31	77.58	15.71	30	74.51	16.60	27	78.57	15.22
PM	Pre	31	91.86	7.17	30	85.55	18.21	27	84.40	16.54
	Post	31	81.29	16.52	30	78.88	17.62	27	82.90	14.70
OL	Pre	31	91.61	8.09	30	87.40	13.30	27	86.74	14.98
	Post	31	84.51	13.24	30	84.90	11.08	27	84.68	12.73
OM	Pre	31	92.47	8.06	30	87.20	13.68	27	83.47	17.32
	Post	31	83.81	13.83	30	84.54	12.71	27	84.28	14.23
LTL	Pre	31	80.28	11.82	30	75.32	14.16	27	71.93	13.22
	Post	31	68.31	15.48	30	66.24	16.28	27	70.56	15.67
RTL	Pre	31	80.88	12.56	30	77.60	12.56	27	75.21	12.59
	Post	31	73.51	16.65	30	71.46	15.72	27	73.65	13.56
LTPJ	Pre	31	84.96	13.46	30	80.79	16.99	27	75.39	16.72
	Post	31	72.60	18.41	30	69.12	18.67	27	73.32	18.77
RTPJ	Pre	31	87.61	11.72	30	80.44	17.91	27	82.48	15.93
	Post	31	77.71	18.91	30	78.40	17.36	27	78.64	18.02
Theta										
FL	Pre	31	7.77	2.74	30	8.36	2.99	27	9.78	2.61
	Post	31	9.76	3.69	30	9.36	2.50	27	9.62	3.40
FM	Pre	31	5.67	3.65	30	8.47	6.24	27	9.52	4.33

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	31	10.71	6.61	30	9.42	3.77	27	10.32	4.92
CL	Pre	31	5.19	2.61	30	6.84	4.05	27	7.82	2.49
	Post	31	8.62	3.32	30	9.38	3.35	27	8.66	4.10
CM	Pre	31	4.40	2.57	30	6.17	4.81	27	7.00	3.15
	Post	31	7.96	3.52	30	9.07	4.76	27	7.79	4.60
PL	Pre	31	4.47	2.02	30	5.20	3.34	27	6.10	2.26
	Post	31	7.50	4.58	30	8.02	3.39	27	6.83	3.24
PM	Pre	31	3.85	2.18	30	5.10	4.15	27	5.87	3.19
	Post	31	7.34	4.91	30	7.26	4.14	27	6.02	3.58
OL	Pre	31	3.68	2.26	30	4.79	3.72	27	4.96	2.99
	Post	31	6.09	3.85	30	5.63	3.14	27	5.79	3.00
OM	Pre	31	3.46	2.28	30	5.08	4.55	27	5.97	3.18
	Post	31	6.35	3.85	30	5.96	3.67	27	5.68	3.64
LTL	Pre	31	6.26	2.88	30	7.26	2.81	27	8.84	2.64
	Post	31	9.68	4.27	30	9.46	2.71	27	8.88	3.00
RTL	Pre	31	6.11	2.29	30	6.95	2.44	27	7.52	1.98
	Post	31	8.37	4.28	30	8.22	3.22	27	7.97	2.89
LTPJ	Pre	31	5.36	3.34	30	5.48	3.60	27	7.62	2.62
	Post	31	8.53	4.84	30	8.68	2.76	27	7.64	3.35
RTPJ	Pre	31	4.49	2.67	30	5.66	3.45	27	5.62	2.39
	Post	31	7.25	5.16	30	6.74	3.91	27	6.48	3.57
Lower Alpha										
FL	Pre	31	1.67	0.86	30	2.01	1.37	27	2.12	1.04
	Post	31	2.56	1.49	30	2.97	2.56	27	2.47	1.56
FM	Pre	31	1.46	1.29	30	2.70	2.60	27	2.48	1.51
	Post	31	3.26	2.67	30	4.32	5.16	27	3.12	2.92
CL	Pre	31	1.53	1.23	30	2.41	2.13	27	2.36	1.38
	Post	31	3.04	1.92	30	4.19	3.81	27	3.60	3.78
CM	Pre	31	1.11	1.13	30	2.09	2.45	27	2.09	1.56

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		MCST			CST			Control	
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	31	2.70	1.95	30	3.60	3.72	27	3.41	4.56
PL	Pre	31	1.23	1.04	30	1.88	2.32	27	1.74	1.35
	Post	31	2.73	2.39	30	3.91	5.21	27	2.70	2.89
PM	Pre	31	0.87	0.96	30	1.91	3.03	27	1.58	1.58
	Post	31	2.22	2.19	30	3.74	6.95	27	2.07	2.06
OL	Pre	31	1.03	1.77	30	1.48	1.91	27	1.19	1.13
	Post	31	1.93	2.06	30	2.35	2.93	27	1.76	1.71
OM	Pre	31	0.89	1.66	30	1.43	1.81	27	1.48	1.28
	Post	31	1.95	2.04	30	2.49	3.46	27	1.85	2.11
LTL	Pre	31	2.01	1.44	30	2.76	1.94	27	2.88	1.77
	Post	31	3.96	2.73	30	4.39	3.50	27	3.83	3.30
RTL	Pre	31	2.00	1.58	30	2.56	1.70	27	2.32	1.43
	Post	31	3.23	2.73	30	3.53	3.14	27	3.30	3.63
LTPJ	Pre	31	1.57	1.77	30	2.14	2.13	27	2.47	1.87
	Post	31	3.41	3.19	30	4.22	3.62	27	3.30	3.41
RTPJ	Pre	31	1.52	2.27	30	2.34	2.55	27	1.60	1.33
	Post	31	3.07	3.62	30	3.04	4.15	27	2.75	3.94
Upper Alpha										
FL	Pre	31	1.89	1.29	30	2.08	1.47	27	2.46	1.63
	Post	31	2.75	1.77	30	2.81	1.66	27	2.75	1.96
FM	Pre	31	1.41	1.32	30	2.50	2.31	27	2.73	1.83
	Post	31	3.28	2.76	30	3.53	2.74	27	3.23	2.76
CL	Pre	31	1.74	1.40	30	2.64	2.40	27	2.99	2.20
	Post	31	3.38	2.28	30	4.30	2.93	27	3.96	2.94
CM	Pre	31	1.23	1.33	30	2.01	2.21	27	2.46	2.27
	Post	31	3.03	2.38	30	3.50	3.05	27	3.42	3.08
PL	Pre	31	1.40	1.27	30	2.22	2.84	27	2.24	2.40
	Post	31	3.22	3.21	30	3.80	2.90	27	3.26	2.87
PM	Pre	31	0.91	1.14	30	2.19	3.69	27	1.90	2.50

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	31	2.62	3.59	30	3.15	3.07	27	2.64	3.12
OL	Pre	31	0.99	1.22	30	1.73	2.32	27	1.56	2.07
	Post	31	2.05	2.19	30	2.06	1.79	27	2.20	2.52
OM	Pre	31	0.78	0.98	30	1.68	2.27	27	1.99	2.46
	Post	31	2.04	2.15	30	2.08	2.12	27	2.34	2.84
LTL	Pre	31	2.15	1.47	30	2.99	2.14	27	3.34	2.27
	Post	31	3.95	2.51	30	4.27	2.58	27	3.92	2.98
RTL	Pre	31	2.27	1.78	30	2.88	2.02	27	2.79	2.06
	Post	31	3.30	2.57	30	3.58	2.24	27	3.43	2.31
LTPJ	Pre	31	1.78	1.70	30	2.75	2.96	27	3.25	2.85
	Post	31	3.83	3.44	30	4.50	3.37	27	3.91	3.70
RTPJ	Pre	31	1.59	1.90	30	2.87	3.24	27	2.07	2.51
	Post	31	3.15	3.32	30	3.10	2.78	27	3.10	3.24
Full Alpha										
FL	Pre	31	3.56	2.08	30	4.09	2.78	27	4.57	2.61
	Post	31	5.31	3.16	30	5.78	3.86	27	5.22	3.39
FM	Pre	31	2.86	2.53	30	5.20	4.78	27	5.21	3.22
	Post	31	6.54	5.25	30	7.85	7.51	27	6.35	5.50
CL	Pre	31	3.27	2.60	30	5.06	4.47	27	5.35	3.55
	Post	31	6.42	4.10	30	8.49	6.40	27	7.56	6.22
CM	Pre	31	2.34	2.44	30	4.10	4.57	27	4.55	3.78
	Post	31	5.73	4.27	30	7.10	6.54	27	6.83	7.05
PL	Pre	31	2.63	2.23	30	4.10	5.09	27	3.98	3.74
	Post	31	5.95	5.48	30	7.71	7.55	27	5.96	5.40
PM	Pre	31	1.78	2.09	30	4.10	6.62	27	3.48	4.05
	Post	31	4.84	5.65	30	6.89	9.42	27	4.71	4.97
OL	Pre	31	2.02	2.79	30	3.21	4.20	27	2.75	3.18
	Post	31	3.98	4.19	30	4.40	4.55	27	3.96	4.12
OM	Pre	31	1.67	2.48	30	3.11	4.05	27	3.47	3.70

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	31	3.99	4.15	30	4.57	5.42	27	4.19	4.79
LTL	Pre	31	4.16	2.77	30	5.75	4.01	27	6.22	3.98
	Post	31	7.90	5.09	30	8.66	5.70	27	7.76	5.90
RTL	Pre	31	4.27	3.24	30	5.44	3.68	27	5.12	3.44
	Post	31	6.53	5.23	30	7.11	5.12	27	6.73	5.35
LTPJ	Pre	31	3.35	3.28	30	4.89	5.04	27	5.72	4.65
	Post	31	7.24	6.39	30	8.72	6.68	27	7.21	6.61
RTPJ	Pre	31	3.10	3.94	30	5.21	5.69	27	3.68	3.82
	Post	31	6.22	6.86	30	6.14	6.49	27	5.85	6.56
Beta										
FL	Pre	31	10.92	10.04	30	10.61	8.69	27	12.81	10.33
	Post	31	14.22	10.82	30	14.77	10.73	27	12.59	8.14
FM	Pre	31	5.71	6.65	30	7.98	7.46	27	10.74	9.06
	Post	31	11.63	10.17	30	13.35	13.67	27	9.15	7.77
CL	Pre	31	6.55	5.09	30	8.91	8.57	27	11.85	9.69
	Post	31	11.95	8.52	30	14.60	10.10	27	11.87	8.97
CM	Pre	31	4.26	4.57	30	5.99	7.57	27	8.66	9.58
	Post	31	9.56	8.25	30	9.83	8.33	27	8.77	8.97
PL	Pre	31	4.31	4.34	30	6.36	8.36	27	7.96	10.48
	Post	31	8.96	7.84	30	9.76	8.12	27	8.63	8.68
PM	Pre	31	2.51	3.32	30	5.25	7.96	27	6.25	9.93
	Post	31	6.53	7.79	30	6.97	6.63	27	6.36	7.79
OL	Pre	31	2.69	3.71	30	4.61	6.02	27	5.54	9.79
	Post	31	5.42	6.53	30	5.07	4.61	27	5.57	6.77
OM	Pre	31	2.40	4.11	30	4.61	6.05	27	7.08	11.81
	Post	31	5.84	6.96	30	4.93	4.73	27	5.86	7.21
LTL	Pre	31	9.30	7.83	30	11.66	8.59	27	13.01	8.54
	Post	31	14.11	9.59	30	15.64	10.39	27	12.81	9.19
RTL	Pre	31	8.74	7.68	30	10.02	7.69	27	12.15	8.44

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		MCST			CST			Control	
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	31	11.59	9.52	30	13.20	10.13	27	11.66	7.34
LTPJ	Pre	31	6.33	7.90	30	8.84	9.05	27	11.27	11.18
	Post	31	11.64	9.83	30	13.48	10.86	27	11.84	11.46
RTPJ	Pre	31	4.79	5.66	30	8.69	9.72	27	8.22	10.79
	Post	31	8.82	9.73	30	8.73	8.82	27	9.04	9.87

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Analysis of assumptions

the assumption testing for the Sound-Induced Flash Illusion Task across the different relative power spectrum bands, focusing on normality, homoscedasticity, and parallelism.

In the delta band, normality assumptions were generally violated (W = 0.84 - 0.96, $p < 0.01$), while homoscedasticity was mostly observed (*K-squared* = 0.01 - 1.92, $p < 0.05$). Parallelism generally held (F = 0.02 - 1.64, $p < 0.05$), with few exceptions like FM and OM, suggesting potential issues with variance across groups.

Moving to the theta band, normality assumptions continued to be challenged (W = 0.87 - 0.97, $p < 0.01$), particularly for variables like FM and LTPJ. Homoscedasticity was mostly observed (*K-squared* = 0.01 - 9.62, $p < 0.05$), except for outliers like PM. Parallelism generally held (F = 0.06 - 1.79, $p < 0.05$), although deviations were observed in cases like FM and RTL.

In the lower alpha band, , violations of normality were common across variables (W = 0.44 - 0.75, $p < 0.01$), but homoscedasticity was mostly observed (*K-squared* = 0.05 - 54.49, $p < 0.05$). Parallelism was generally supported (F = 0.08 - 2.36, $p < 0.05$), although deviations were observed in cases like FM and RTL.

Similarly, in the upper alpha band, normality assumptions were frequently challenged (W = 0.62 - 0.91, $p < 0.01$), but homoscedasticity was mostly observed (*K-squared* = 0.00 - 3.18, $p < 0.05$). Parallelism was generally supported (F

= 0.08 - 0.98, $p < 0.05$), although deviations were observed in cases like FM and RTL.

In the full alpha and beta bands, patterns of normality violations, homoscedasticity, and parallelism were consistent with those seen in previous bands (W = 0.65 - 0.91, $p < 0.01$; *K-squared* = 0.00 - 18.67, $p < 0.05$; F = 0.02 - 4.06, $p < 0.05$).

Analysis of group comparisons

This section presents the results of ANCOVA for various parameters during the sound-induced flash illusion task to measure multisensory integration in older adults with MCI. However, the results of the ANCOVA could not be interpreted due to violations of the regression slope homogeneity assumption. Therefore, a separate regression analysis for each group is presented in the following section for the affected ROI: Beta (CM). The following are the ANCOVA results for ROIs that met the assumption. Overall, all of relative bands no significant group effects were observed across any brain regions in the test.

The delta band analysis indicated no significant group effects across all regions. For example, the frontal lobe (FL) exhibited a non-significant group effect with a small effect size *(F(*2, 84*)* = 0.67, p = .52, partial $\omega^2 < .01$). Similarly, no significant group effects were found in the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all $p > .05$).

In the theta band, no significant group effects were observed in any of the regions. For instance, the frontal lobe (FL) showed a non-significant group effect with a small effect size *(F(*2, 84*)* = 0.16, p = .85, partial $\omega^2 < .01$). This pattern was consistent in the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all $p > .05$).

The lower alpha band analysis also showed no significant group effects across all regions. The frontal lobe (FL) had a non-significant group

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effect with a small effect size *(F(*2, 84*)* = 0.53, *p* = .59, partial $\omega^2 < .01$). Other regions including the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) exhibited similar non-significant group effects (all $p > .05$).

In the upper alpha band, no significant group effects were found. For example, the frontal lobe (FL) showed a non-significant group effect with a small effect size *(F(*2, 84*)* = 0.09, *p* = .92, partial $\omega^2 < .01$). This lack of significant group effects was consistent across the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all $p > .05$).

The full alpha band analysis revealed no significant group effects in any of the regions. The frontal lobe (FL) demonstrated a non-significant group effect with a small effect size *(F(*2, 84*)* = 0.26, *p* = .77, partial $\omega^2 < .01$). Similar non-significant patterns were observed in the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all $p > .05$).

In the beta band, no significant group effects were observed. For instance, the frontal lobe (FL) showed a non-significant group effect with a small effect size *(F(*2, 84*)* = 0.77, *p* = .47, partial $\omega^2 < .01$). This was consistent in the frontal midline (FM), central lobe (CL), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all $p > .05$).

The ANCOVA results for the SIFI Task indicated no significant group effects across all relative power spectrum bands (delta, theta, lower alpha, upper alpha, full alpha, and beta) in the brain regions examined. This suggests

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that the group condition did not have a significant impact on the spectral power across these frequency bands and regions in the context of the sound-induced flash illusion task. Please see the table below for more information.

Table 57 ANCOVA of the sound-induced flash illusion task

		df	*SS*	*MS*	*F*	*p*	ω_p^2
Delta							
FL	Pre-test	1	0.079	0.079	5.16	.03	0.05
	Group	2	0.021	0.010	0.67	.52	<.01
	Residuals	84	1.290	0.015			
FM	Pre-test	1	0.007	0.007	0.21	.64	<.01
	Group	2	0.039	0.020	0.59	.56	<.01
	Residuals	84	2.808	0.033			
CL	Pre-test	1	0.126	0.126	5.28	.02	0.05
	Group	2	0.046	0.023	0.97	.38	<.01
	Residuals	84	2.007	0.024			
CM	Pre-test	1	0.075	0.075	2.69	.10	0.02
	Group	2	0.017	0.008	0.30	.74	<.01
	Residuals	84	2.334	0.028			
PL	Pre-test	1	0.174	0.174	7.44	<.01	0.07
	Group	2	0.034	0.017	0.73	.48	<.01
	Residuals	84	1.961	0.023			
PM	Pre-test	1	0.149	0.149	5.87	.02	0.05
	Group	2	0.031	0.016	0.62	.54	<.01
	Residuals	84	2.125	0.025			
OL	Pre-test	1	0.182	0.182	13.68	<.01	0.13
	Group	2	0.008	0.004	0.30	.74	<.01
	Residuals	84	1.114	0.013			
OM	Pre-test	1	0.168	0.168	10.19	<.01	0.09
	Group	2	0.019	0.009	0.58	.56	<.01
	Residuals	84	1.382	0.016			

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
LTL	Pre-test	1	0.165	0.165	7.15	<.01	0.07
	Group	2	0.053	0.026	1.14	.32	<.01
	Residuals	84	1.935	0.023			
RTL	Pre-test	1	0.220	0.220	10.28	<.01	0.10
	Group	2	0.015	0.008	0.36	.70	<.01
	Residuals	84	1.801	0.021			
LTPJ	Pre-test	1	0.357	0.357	11.73	<.01	0.11
	Group	2	0.062	0.031	1.02	.36	<.01
	Residuals	84	2.555	0.030			
RTPJ	Pre-test	1	0.073	0.073	2.27	.14	0.01
	Group	2	0.008	0.004	0.12	.88	<.01
	Residuals	84	2.712	0.032			
Theta							
FL	Pre-test	1	0.001	0.001	0.49	.48	<.01
	Group	2	<.001	<.001	0.16	.85	<.01
	Residuals	84	0.088	0.001			
FM	Pre-test	1	<.001	<.001	0.00	.95	<.01
	Group	2	0.003	0.001	0.48	.62	<.01
	Residuals	84	0.235	0.003			
CL	Pre-test	1	<.001	<.001	0.09	.76	<.01
	Group	2	0.001	0.001	0.40	.67	<.01
	Residuals	84	0.109	0.001			
CM	Pre-test	1	0.001	0.001	0.29	.59	<.01
	Group	2	0.003	0.001	0.74	.48	<.01
	Residuals	84	0.157	0.002			
PL	Pre-test	1	0.002	0.002	1.25	.27	<.01
	Group	2	0.003	0.001	0.95	.39	<.01
	Residuals	84	0.121	0.001			
PM	Pre-test	1	0.001	0.001	0.61	.44	<.01
	Group	2	0.004	0.002	1.11	.33	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	84	0.153	0.002			
OL	Pre-test	1	0.001	0.001	1.10	.30	<.01
	Group	2	0.001	<.001	0.27	.77	<.01
	Residuals	84	0.095	0.001			
OM	Pre-test	1	<.001	<.001	0.18	.67	<.01
	Group	2	0.001	0.001	0.36	.70	<.01
	Residuals	84	0.117	0.001			
LTL	Pre-test	1	0.001	0.001	0.91	.34	<.01
	Group	2	0.002	0.001	0.90	.41	<.01
	Residuals	84	0.097	0.001			
RTL	Pre-test	1	0.003	0.003	2.47	.12	0.02
	Group	2	0.001	<.001	0.37	.69	<.01
	Residuals	84	0.103	0.001			
LTPJ	Pre-test	1	0.002	0.002	1.27	.26	<.01
	Group	2	0.003	0.002	1.17	.31	<.01
	Residuals	84	0.118	0.001			
RTPJ	Pre-test	1	0.001	0.001	0.43	.51	<.01
	Group	2	0.001	0.001	0.34	.71	<.01
	Residuals	84	0.156	0.002			
Lower Alpha							
FL	Pre-test	1	<.001	<.001	0.84	.36	<.01
	Group	2	<.001	<.001	0.53	.59	<.01
	Residuals	84	0.032	<.001			
FM	Pre-test	1	<.001	<.001	0.32	.57	<.01
	Group	2	0.002	0.001	0.78	.46	<.01
	Residuals	84	0.121	0.001			
CL	Pre-test	1	0.002	0.002	2.06	.15	0.01
	Group	2	0.001	0.001	0.60	.55	<.01
	Residuals	84	0.089	0.001			
CM	Pre-test	1	<.001	<.001	0.18	.68	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	0.001	0.001	0.46	.63	<.01
	Residuals	84	0.105	0.001			
PL	Pre-test	1	0.002	0.002	1.37	.24	<.01
	Group	2	0.002	0.001	0.85	.43	<.01
	Residuals	84	0.116	0.001			
PM	Pre-test	1	0.001	0.001	0.68	.41	<.01
	Group	2	0.004	0.002	1.12	.33	<.01
	Residuals	84	0.165	0.002			
OL	Pre-test	1	0.004	0.004	8.02	<.01	0.07
	Group	2	<.001	<.001	0.31	.73	<.01
	Residuals	84	0.041	<.001			
OM	Pre-test	1	0.005	0.005	8.16	<.01	0.08
	Group	2	0.001	<.001	0.50	.61	<.01
	Residuals	84	0.054	0.001			
LTL	Pre-test	1	0.008	0.008	8.99	<.01	0.08
	Group	2	0.001	<.001	0.39	.68	<.01
	Residuals	84	0.078	0.001			
RTL	Pre-test	1	0.004	0.004	4.47	.04	0.04
	Group	2	<.001	<.001	0.01	.99	<.01
	Residuals	84	0.081	0.001			
LTPJ	Pre-test	1	0.008	0.008	7.75	<.01	0.07
	Group	2	0.002	0.001	0.78	.46	<.01
	Residuals	84	0.090	0.001			
RTPJ	Pre-test	1	<.001	<.001	0.08	.77	<.01
	Group	2	<.001	<.001	0.05	.95	<.01
	Residuals	84	0.129	0.002			
Upper Alpha							
FL	Pre-test	1	0.002	0.002	5.29	.02	0.05
	Group	2	<.001	<.001	0.09	.92	<.01
	Residuals	84	0.026	<.001			

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
FM	Pre-test	1	0.002	0.002	2.29	.13	0.01
	Group	2	<.001	<.001	0.16	.85	<.01
	Residuals	84	0.063	0.001			
CL	Pre-test	1	0.008	0.008	12.87	<.01	0.12
	Group	2	<.001	<.001	0.37	.69	<.01
	Residuals	84	0.055	0.001			
CM	Pre-test	1	0.003	0.003	3.77	.06	0.03
	Group	2	<.001	<.001	0.07	.93	<.01
	Residuals	84	0.066	0.001			
PL	Pre-test	1	0.007	0.007	8.49	<.01	0.08
	Group	2	<.001	<.001	0.26	.77	<.01
	Residuals	84	0.070	0.001			
PM	Pre-test	1	0.005	0.005	4.35	.04	0.04
	Group	2	<.001	<.001	0.12	.88	<.01
	Residuals	84	0.087	0.001			
OL	Pre-test	1	0.006	0.006	14.21	<.01	0.13
	Group	2	<.001	<.001	0.19	.83	<.01
	Residuals	84	0.034	<.001			
OM	Pre-test	1	0.006	0.006	12.00	<.01	0.11
	Group	2	<.001	<.001	0.18	.84	<.01
	Residuals	84	0.042	<.001			
LTL	Pre-test	1	0.012	0.012	21.73	<.01	0.19
	Group	2	0.001	<.001	0.76	.47	<.01
	Residuals	84	0.048	0.001			
RTL	Pre-test	1	0.009	0.009	18.58	<.01	0.17
	Group	2	<.001	<.001	0.04	.96	<.01
	Residuals	84	0.040	<.001			
LTPJ	Pre-test	1	0.018	0.018	17.19	<.01	0.16
	Group	2	0.001	0.001	0.61	.54	<.01
	Residuals	84	0.086	0.001			

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
RTPJ	Pre-test	1	0.005	0.005	5.12	.03	0.04
	Group	2	<.001	<.001	0.15	.86	<.01
	Residuals	84	0.078	0.001			
Full Alpha							
FL	Pre-test	1	0.003	0.003	2.12	.15	0.01
	Group	2	0.001	<.001	0.26	.77	<.01
	Residuals	84	0.101	0.001			
FM	Pre-test	1	0.002	0.002	0.55	.46	0.00
	Group	2	0.003	0.002	0.44	.65	<.01
	Residuals	84	0.323	0.004			
CL	Pre-test	1	0.016	0.016	5.34	.02	0.05
	Group	2	0.003	0.002	0.53	.59	<.01
	Residuals	84	0.257	0.003			
CM	Pre-test	1	0.004	0.004	0.96	.33	0.00
	Group	2	0.002	0.001	0.26	.77	<.01
	Residuals	84	0.306	0.004			
PL	Pre-test	1	0.014	0.014	3.75	.06	0.03
	Group	2	0.005	0.002	0.61	.55	<.01
	Residuals	84	0.318	0.004			
PM	Pre-test	1	0.010	0.010	2.01	.16	0.01
	Group	2	0.007	0.003	0.68	.51	<.01
	Residuals	84	0.410	0.005			
OL	Pre-test	1	0.018	0.018	11.04	<.01	0.10
	Group	2	<.001	<.001	0.05	.95	<.01
	Residuals	84	0.139	0.002			
OM	Pre-test	1	0.021	0.021	10.04	<.01	0.09
	Group	2	0.001	<.001	0.15	.86	<.01
	Residuals	84	0.175	0.002			
LTL	Pre-test	1	0.036	0.036	13.48	<.01	0.12
	Group	2	0.003	0.001	0.55	.58	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	84	0.225	0.003			
RTL	Pre-test	1	0.023	0.023	9.05	<.01	0.08
	Group	2	<.001	<.001	0.02	.98	<.01
	Residuals	84	0.210	0.003			
LTPJ	Pre-test	1	0.043	0.043	11.38	<.01	0.11
	Group	2	0.005	0.003	0.72	.49	<.01
	Residuals	84	0.321	0.004			
RTPJ	Pre-test	1	0.005	0.005	1.09	.30	<.01
	Group	2	<.001	<.001	0.05	.96	<.01
	Residuals	84	0.370	0.004			
Beta							
FL	Pre-test	1	0.103	0.103	11.54	<.01	0.11
	Group	2	0.014	0.007	0.77	.47	<.01
	Residuals	84	0.748	0.009			
FM	Pre-test	1	0.031	0.031	2.71	.10	0.02
	Group	2	0.038	0.019	1.64	.20	0.01
	Residuals	84	0.965	0.011			
CL	Pre-test	1	0.115	0.115	16.20	<.01	0.15
	Group	2	0.024	0.012	1.69	.19	0.02
	Residuals	84	0.598	0.007			
CM*	Pre-test	1	0.078	0.078	12.49	<.01	0.12
	Group	2	0.011	0.006	0.89	.42	<.01
	Residuals	84	0.527	0.006			
PL	Pre-test	1	0.106	0.106	19.24	<.01	0.17
	Group	2	0.007	0.003	0.61	.55	<.01
	Residuals	84	0.461	0.005			
PM	Pre-test	1	0.090	0.090	20.19	<.01	0.18
	Group	2	0.005	0.002	0.53	.59	<.01
	Residuals	84	0.374	0.004			
OL	Pre-test	1	0.077	0.077	28.18	<.01	0.24

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	0.003	0.001	0.49	.61	<.01
	Residuals	84	0.229	0.003			
OM	Pre-test	1	0.078	0.078	24.88	<.01	0.21
	Group	2	0.006	0.003	1.02	.36	<.01
	Residuals	84	0.263	0.003			
LTL	Pre-test	1	0.077	0.077	8.89	<.01	0.08
	Group	2	0.017	0.009	1.00	.37	<.01
	Residuals	84	0.726	0.009			
RTL	Pre-test	1	0.121	0.121	17.32	<.01	0.16
	Group	2	0.009	0.005	0.67	.51	<.01
	Residuals	84	0.585	0.007			
LTPJ	Pre-test	1	0.136	0.136	13.67	<.01	0.13
	Group	2	0.011	0.005	0.54	.59	<.01
	Residuals	84	0.834	0.010			
RTPJ	Pre-test	1	0.060	0.060	7.19	<.01	0.07
	Group	2	0.002	0.001	0.15	.86	<.01
	Residuals	84	0.700	0.008			

*A significant interaction effect

Analysis of regression

This analysis examines the predictive relationships of the relative beta power (i.e., pre-test and post-test) at the CM across the three groups, including MCST, CST, and control (see Table 58). The MCST group fails to demonstrate a significant predictive relationship ($\beta_1 = -0.19$, $p = .58$, adjusted $R^2 = -.02$), indicating no meaningful intervention effects in this for this task. The CST group similarly fails to show significance ($\beta_1 = 0.26$, $p = .20$, adjusted $R^2 = .02$), suggesting the limited effectiveness of this intervention. In contrast, the control group exhibits strong predictive power ($\beta_1 = 0.71$, $p < .001$, adjusted $R^2 = .56$), indicating a robust natural predictive relationship in this and region (see Figure 56). In the SIFI task, the control group demonstrates a significant predictive relationship in the beta

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for the CM region, suggesting a strong natural predictive capacity . In contrast, both the MCST and CST groups fail to show significant relationships, highlighting limited intervention effects for these groups in this specific and region.

Table 58 Regression analysis of the sound-induced flash illusion task

ROI	Model	Variable	*B*	*SE*	*t*	*p*
Beta						
CM	MCST	Constant	0.10	0.02	5.02	<.01
		Pre-test	-0.19	0.33	-0.56	.58
	CST	Constant	0.08	0.02	4.27	<.01
		Pre-test	0.26	0.2	1.31	.20
	Control	Constant	0.03	0.02	1.67	.11
		Pre-test	0.71	0.12	5.88	<.01

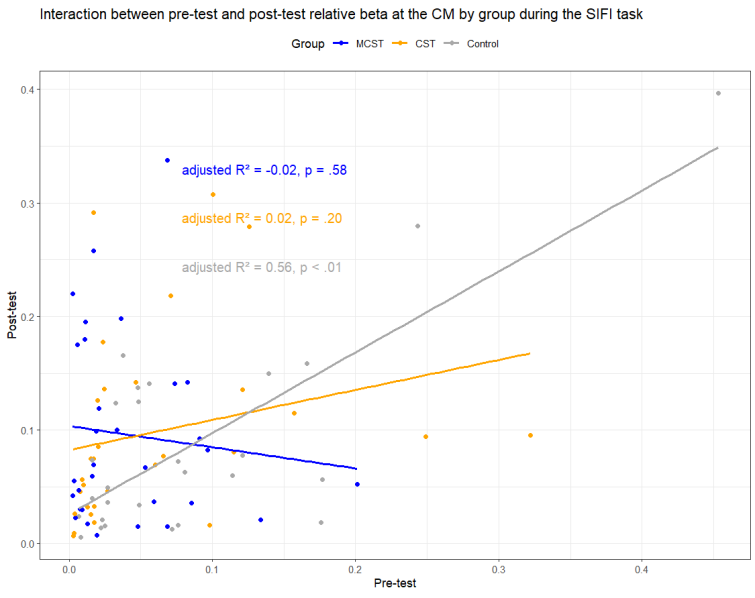

Figure 56 A scatter plot and the regression lines are shows interaction between pre-test and post-test relative beta at the central midline (CM) by group during the SIFI task

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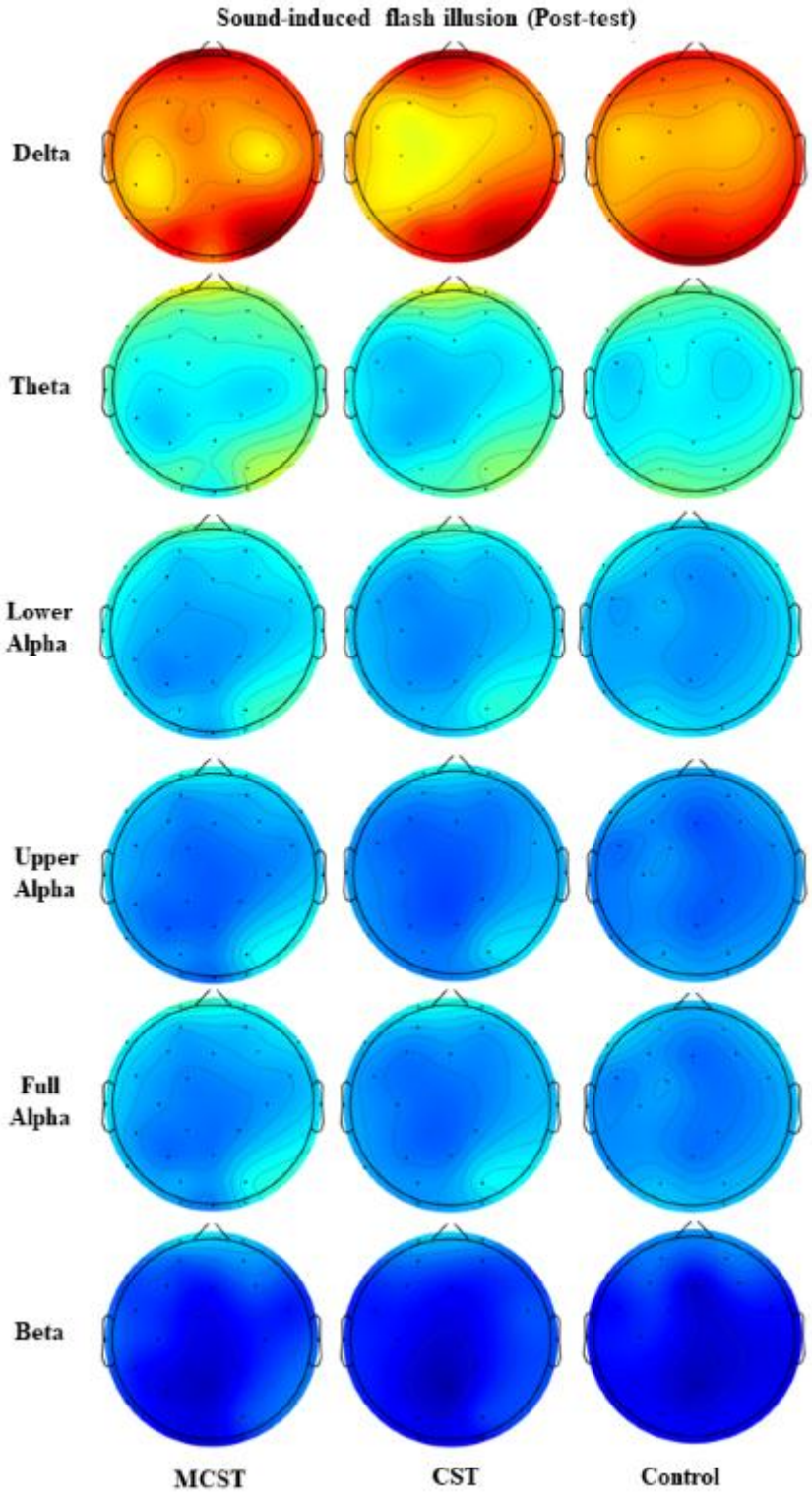

Figure 57 The topographic brain mapping of relative power during the Sound-induced flash illusion at post-test

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EEG - Overall result

In conclusion, the ANCOVA analyses across various cognitive tasks indicated that group conditions (MCST, CST, and control) generally did not produce significant effects on EEG spectral power in the majority of frequency bands and brain regions. Specifically, the eyes-open resting-state and tasks such as the Corsi block-tapping and the sound-induced flash illusion showed no significant effects across all relative power spectrum bands. On the one hand, during the eyes-closed resting-state, significant group effects were observed in the theta band in the occipital midline and the upper alpha band in the left temporal lobe, as well as in the beta band across several regions. The verbal paired associates learning task revealed significant group effects only in the theta band in the central regions, and the verbal fluency task showed significant effects in the delta, theta, and beta bands in specific frontal and central regions. The mental rotation task highlighted significant effects in the delta, upper alpha, and beta bands, particularly in the occipital midline and left temporal lobe. The choice reaction time task showed a significant effect in the beta band in the frontal midline.

Due to violations of ANCOVA assumptions (i.e., lack of parallelism) across various computer-based tasks, regression analyses were conducted. The MCST group generally exhibited the strongest and most significant predictive relationships between pre-test and post-test EEG values, particularly in the lower alpha, full alpha, and beta bands, emphasizing its efficacy as an intervention. The CST group demonstrated moderate predictive power, occasionally outperforming MCST in specific conditions, such as the upper alpha in the OL region. The control group often showed weaker or non-significant relationships but demonstrated strong natural predictive associations in certain tasks, such as the verbal PAL and SIFI tasks. MCST's strengths were evident in tasks like the eyes-closed resting-state and Corsi Block-Tapping tasks, while CST showed consistent but less robust results, particularly in the theta and upper alpha bands. The SIFI task highlighted the control group's predictive capacity in the beta band, while both interventions failed to achieve significance.

Thus, Hypotheses 3 and 4 are partially confirmed. Significant differences in EEG frequency bands (delta, theta, alpha, ,and beta) were observed

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among experimental groups in certain conditions, particularly in the eyes-closed resting-state and tasks such as verbal fluency, mental rotation, and choice reaction time, supporting the effect of the CMCS intervention. Additionally, the MCST group exhibited the strongest predictive relationships between pre-test and post-test EEG values, particularly in lower alpha, full alpha, and beta bands, indicating its efficacy. However, many tasks, including the Corsi Block-Tapping and Sound-Induced Flash Illusion tasks, did not show significant group differences, and in some cases, such as the verbal paired associates learning task, the control group exhibited comparable or stronger predictive associations. Therefore, while EEG frequency bands significantly differed in certain conditions and interventions, these findings do not fully support the hypotheses across all neuropsychological tasks.

Data analysis of ERP

This section outlines analysis of ERP components in findings from computerized neuropsychological tests included paired associates learning tasks, verbal fluentcy task, Corsi block-tapping task, mental rotation task, Wisconsin card sorting test, simple and choice reaction time task, and sound-induced flash illusion task, respectively.

ERP - Verbal paired associates learning task

Analysis of the amplitude and latency characteristics

This section provides a detailed analysis of the characteristics of amplitude and latency of Event-Related Potentials (ERPs) in a verbal paired associates learning task across three groups (see Table 59).

P300 component - Mean amplitude

In the frontal region, the MCST group showed an increase in mean amplitude post-test. Specifically, both the frontal lobe (FL) and the frontal midline (FM) increased. Conversely, the CST group experienced a decrease in the FL and a slight decrease in the FM. The control group showed a decrease in the FL and slightly improved in the FM.

In the central region, the MCST group displayed a decrease in mean amplitude post-test in central electrode locations (CL) but an increase in the central midline (CM). The CST group showed a slight decrease in the

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CL and a decrease in the CM. The control group showed a reduction in the CL but an increase in the CM.

In the parietal region, the MCST group showed a decrease in mean amplitude post-test in both the parietal lobe (PL) and the parietal midline (PM). The CST group also showed decreases in both regions. The control group showed increases in both the PL and PM.

In the temporal region, the MCST group showed a decrease in mean amplitude post-test in the left temporal lobe (LTL) but an increase in the right temporal lobe (RTL). The CST group showed decreases in both the LTL and RTL. The control group showed a decrease in the LTL but an increase in the RTL. In the left temporal-parietal junction (LTPJ), the MCST group decreased while the control group increased. In the right temporal-parietal junction (RTPJ), the MCST group slightly increased, the CST group increased, and the control group slightly increased.

P300 component - Peak amplitude

In the frontal region, the MCST group's peak amplitude increased post-test in both the frontal lobe (FL) and the frontal midline (FM). The CST group experienced a decrease in both regions. The control group also showed decreases in both regions.

In the central region, the MCST group's peak amplitude decreased in central electrode locations (CL) but increased in the central midline (CM). The CST group showed decreases in both regions. The control group showed decreases in the CL but an increase in the CM.

In the parietal region, the MCST group's peak amplitude decreased in both the parietal lobe (PL) and the parietal midline (PM). The CST group showed decreases in both regions. The control group showed increases in both regions.

In the temporal region, the MCST group's peak amplitude decreased in the left temporal lobe (LTL) but increased in the right temporal lobe (RTL). The CST group showed decreases in both the LTL and RTL. The control group showed a decrease in the LTL but an increase in the RTL. In the

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left temporal-parietal junction (LTPJ), the MCST group decreased while the control group increased. In the right temporal-parietal junction (RTPJ), the MCST group slightly increased, the CST group increased, and the control group slightly increased.

P300 component - Peak latency

In the frontal region, the MCST group showed a slight increase in peak latency post-test in both the frontal lobe (FL) and the frontal midline (FM). The CST group showed a slight decrease in both regions. The control group also showed a decrease in both areas.

In the central region, the MCST group showed an increase in peak latency in both central electrode locations (CL) and the central midline (CM). The CST group showed a decrease in both regions. The control group showed an increase in the CL and a decrease in the CM.

In the parietal region, the MCST group showed an increase in peak latency in both the parietal lobe (PL) and the parietal midline (PM). The CST group showed a decrease in both regions. The control group showed a decrease in both regions.

In the temporal region, the MCST group showed an increase in peak latency in the left temporal lobe (LTL) but a decrease in the right temporal lobe (RTL). The CST group showed a decrease in both the LTL and RTL. The control group showed a decrease in the LTL but an increase in the RTL. In the left temporal-parietal junction (LTPJ), the MCST group increased while the control group decreased. In the right temporal-parietal junction (RTPJ), the MCST group slightly decreased, the CST group increased, and the control group slightly increased.

P3/LPC component - Mean amplitude

In the frontal region, the MCST group showed an increase in mean amplitude post-test in both the frontal lobe (FL) and the frontal midline (FM). The CST group showed a decrease in both regions. The control group showed a decrease in the FL and a slight improvement in the FM.

In the central region, the MCST group showed a decrease in mean amplitude in both central electrode locations (CL) and the central midline (CM). The CST group also decreased in both regions. The control group showed a decrease in the CL but an increase in the CM.

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In the parietal region, the MCST group showed a decrease in mean amplitude in both the parietal lobe (PL) and the parietal midline (PM). The CST group showed decreases in both regions, while the control group showed increases in both regions.

In the temporal region, the MCST group showed a decrease in mean amplitude in the left temporal lobe (LTL) but an increase in the right temporal lobe (RTL). The CST group showed decreases in both the LTL and RTL. The control group showed a decrease in the LTL but an increase in the RTL. In the left temporal-parietal junction (LTPJ), the MCST group decreased while the control group increased. In the right temporal-parietal junction (RTPJ), the MCST group slightly increased, the CST group increased, and the control group slightly increased.

P3/LPC component - Peak amplitude

In the frontal region, the MCST group showed an increase in peak amplitude post-test in both the frontal lobe (FL) and the frontal midline (FM). The CST group experienced a decrease in both regions. The control group also showed decreases in both regions.

In the central region, the MCST group's peak amplitude decreased in central electrode locations (CL) but increased in the central midline (CM). The CST group showed decreases in both regions. The control group showed decreases in the CL but an increase in the CM.

In the parietal region, the MCST group's peak amplitude decreased in both the parietal lobe (PL) and the parietal midline (PM). The CST group showed decreases in both regions. The control group showed increases in both regions.

In the temporal region, the MCST group's peak amplitude decreased in the left temporal lobe (LTL) but increased in the right temporal lobe (RTL). The CST group showed decreases in both the LTL and RTL. The control group showed a decrease in the LTL but an increase in the RTL. In the left temporal-parietal junction (LTPJ), the MCST group decreased while the control group increased. In the right temporal-parietal junction (RTPJ), the MCST group slightly increased, the CST group increased, and the control group slightly increased.

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P3/LPC component - Peak latency

In the frontal region, the MCST group showed a slight decrease in peak latency post-test in both the frontal lobe (FL) and the frontal midline (FM). The CST group showed a slight decrease in both regions. The control group also showed a decrease in both regions.

In the central region, the MCST group showed increased peak latency in both central electrode locations (CL) and the central midline (CM). The CST group showed a decrease in both regions. The control group showed an increase in the CL and a decrease in the CM.

In the parietal region, the MCST group showed increased peak latency in both the parietal lobe (PL) and the parietal midline (PM). The CST group showed a decrease in both regions, and the control group showed a decline in both regions.

In the temporal region, the MCST group showed an increase in peak latency in the left temporal lobe (LTL) but a decrease in the right temporal lobe (RTL). The CST group showed a decrease in both the LTL and RTL. The control group showed a decrease in the LTL but an increase in the RTL. In the left temporal-parietal junction (LTPJ), the MCST group increased while the control group decreased. In the right temporal-parietal junction (RTPJ), the MCST group slightly decreased, the CST group increased, and the control group slightly increased.

Table 59 Characteristic of amplitude and latency of ERPs in the verbal paired associates learning task

		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
P300 – mean amplitude										
FL	Pre	20	4.10	19.26	22	10.56	12.12	21	6.06	7.85
	Post	20	14.94	18.99	22	6.63	6.89	21	1.89	11.50
FM	Pre	20	-4.34	51.65	22	7.26	21.21	21	-4.93	21.84
	Post	20	3.20	24.68	22	2.46	7.17	21	-0.68	5.92
CL	Pre	20	-1.20	19.40	22	1.34	12.95	21	-0.60	9.36
	Post	20	-8.66	14.49	22	-0.95	9.16	21	-2.28	7.27

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
CM	Pre	20	-16.31	51.96	22	13.43	50.66	21	-8.49	16.05
	Post	20	-3.34	12.93	22	-1.82	12.43	21	2.81	19.76
PL	Pre	20	-1.83	24.87	22	0.41	14.89	21	-3.30	7.14
	Post	20	-5.38	22.49	22	-1.45	8.98	21	1.19	7.15
PM	Pre	20	6.33	31.92	22	-10.18	45.62	21	-0.37	8.96
	Post	20	-26.37	89.88	22	-7.64	38.24	21	2.02	12.50
OL	Pre	20	-2.46	30.41	22	-6.79	29.65	21	2.94	13.58
	Post	20	-2.88	28.07	22	-3.55	15.00	21	1.66	12.99
OM	Pre	20	3.43	42.94	22	-1.38	37.32	21	-4.06	25.31
	Post	20	-9.85	35.72	22	-15.42	60.63	21	11.00	50.42
LTL	Pre	20	3.79	11.66	22	-0.51	5.08	21	0.33	4.15
	Post	20	1.14	8.91	22	-1.29	5.80	21	-0.16	7.85
RTL	Pre	20	-2.63	10.16	22	-4.10	11.63	21	-4.59	8.31
	Post	20	0.50	9.08	22	0.73	6.49	21	-1.88	5.91
LTPJ	Pre	20	4.88	31.28	22	4.03	9.21	21	-1.57	8.08
	Post	20	0.99	14.69	22	-3.78	6.64	21	2.95	12.61
RTPJ	Pre	20	-4.29	16.79	22	-1.50	25.34	21	-8.71	21.79
	Post	20	-2.20	10.47	22	-0.95	7.56	21	-2.01	4.93
P300 – peak amplitude										
FL	Pre	20	12.84	21.33	22	17.89	13.60	21	12.01	8.62
	Post	20	21.45	21.55	22	12.53	7.89	21	6.48	11.84
FM	Pre	20	3.01	50.41	22	12.38	22.03	21	1.13	14.95
	Post	20	6.04	26.09	22	5.94	8.21	21	2.29	6.67
CL	Pre	20	3.96	19.05	22	8.22	17.35	21	3.17	10.24
	Post	20	-3.76	14.45	22	3.43	10.47	21	0.74	7.16
CM	Pre	20	-8.74	44.63	22	24.37	65.53	21	-4.90	14.06
	Post	20	2.79	14.99	22	2.42	12.97	21	5.74	21.02
PL	Pre	20	5.20	26.55	22	6.39	15.88	21	0.89	6.64
	Post	20	-0.29	18.35	22	2.89	8.47	21	4.51	8.08
PM	Pre	20	15.25	37.80	22	-6.34	46.45	21	3.22	9.38
	Post	20	-21.88	79.98	22	-3.06	30.64	21	5.22	12.75
OL	Pre	20	4.46	31.81	22	1.17	26.93	21	7.98	16.16

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	20	6.03	31.73	22	3.00	16.79	21	7.40	16.67
OM	Pre	20	9.74	41.84	22	5.33	37.54	21	-2.42	24.90
	Post	20	-2.88	30.85	22	-4.78	66.51	21	17.80	57.46
LTL	Pre	20	10.29	13.37	22	5.46	4.99	21	4.30	3.94
	Post	20	5.73	10.50	22	2.98	5.19	21	3.33	7.94
RTL	Pre	20	3.67	11.22	22	3.38	12.42	21	-0.24	8.02
	Post	20	5.22	11.26	22	5.45	9.31	21	1.73	7.00
LTPJ	Pre	20	11.89	37.35	22	8.49	11.45	21	2.52	7.48
	Post	20	5.34	17.68	22	0.25	5.50	21	5.50	12.93
RTPJ	Pre	20	1.35	16.62	22	4.86	27.32	21	-4.68	19.56
	Post	20	1.60	10.51	22	4.18	8.80	21	1.26	6.47
P300 – peak latency										
FL	Pre	20	396	44.53	22	409	38.88	21	394	40.14
	Post	20	402	42.90	22	407	42.35	21	390	36.56
FM	Pre	20	397	62.96	22	417	63.28	21	401	60.59
	Post	20	406	49.50	22	412	57.70	21	412	56.63
CL	Pre	20	392	35.24	22	399	33.73	21	400	27.54
	Post	20	400	22.94	22	397	30.37	21	398	36.30
CM	Pre	20	371	60.57	22	402	66.44	21	368	52.21
	Post	20	417	65.53	22	410	61.33	21	397	61.31
PL	Pre	20	380	30.81	22	400	28.53	21	408	31.26
	Post	20	394	45.71	22	394	38.65	21	397	30.46
PM	Pre	20	403	71.78	22	403	51.95	21	394	62.11
	Post	20	377	66.32	22	391	65.20	21	413	59.21
OL	Pre	20	397	39.48	22	398	37.01	21	398	28.15
	Post	20	406	29.97	22	401	47.40	21	393	30.10
OM	Pre	20	401	73.36	22	407	61.96	21	377	65.99
	Post	20	399	68.99	22	415	77.92	21	399	58.30
LTL	Pre	20	398	29.64	22	410	37.46	21	409	34.29
	Post	20	402	42.91	22	397	33.50	21	400	26.25
RTL	Pre	20	386	31.10	22	401	37.85	21	398	31.26
	Post	20	388	29.48	22	401	30.72	21	397	34.19

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
LTPJ	Pre	20	390	49.88	22	413	42.70	21	405	42.51
	Post	20	405	53.93	22	398	59.44	21	388	45.66
RTPJ	Pre	20	385	38.95	22	396	42.73	21	394	44.45
	Post	20	396	41.09	22	407	46.33	21	399	44.55
P3/LPC – mean amplitude										
FL	Pre	20	-0.42	27.09	22	7.50	13.84	21	3.48	12.15
	Post	20	15.74	19.77	22	3.05	9.64	21	0.93	11.94
FM	Pre	20	-7.99	64.76	22	4.00	20.85	21	-7.15	32.43
	Post	20	1.24	44.48	22	0.15	10.09	21	0.66	5.89
CL	Pre	20	-0.98	20.66	22	0.97	19.81	21	0.33	10.57
	Post	20	-11.24	17.80	22	-0.14	12.92	21	-1.54	7.92
CM	Pre	20	-25.56	65.09	22	15.77	80.87	21	-12.08	23.90
	Post	20	-0.90	17.21	22	0.16	10.85	21	3.75	16.12
PL	Pre	20	-1.18	24.47	22	6.35	27.05	21	-3.74	8.88
	Post	20	-6.36	20.09	22	-1.23	9.83	21	2.55	8.04
PM	Pre	20	8.97	31.75	22	-2.51	40.27	21	-2.40	11.37
	Post	20	-28.48	79.27	22	-7.75	46.68	21	5.93	14.52
OL	Pre	20	4.31	33.89	22	-5.20	37.14	21	4.79	19.63
	Post	20	2.72	24.42	22	-2.48	17.47	21	0.01	14.14
OM	Pre	20	11.06	54.29	22	-0.58	44.54	21	-1.60	31.70
	Post	20	-15.38	66.93	22	-14.32	84.05	21	1.78	50.89
LTL	Pre	20	4.79	10.94	22	-0.28	9.91	21	0.69	4.80
	Post	20	1.06	9.82	22	-0.08	5.55	21	0.22	9.36
RTL	Pre	20	-6.22	13.70	22	-7.73	17.38	21	-4.74	10.87
	Post	20	-1.77	7.20	22	0.74	5.88	21	-1.85	8.86
LTPJ	Pre	20	5.09	36.79	22	10.57	14.62	21	-1.56	10.57
	Post	20	0.60	18.33	22	-2.32	7.26	21	3.76	16.29
RTPJ	Pre	20	-2.38	25.54	22	-3.04	22.47	21	-10.02	26.18
	Post	20	-2.10	11.16	22	0.21	11.38	21	-0.90	7.73
P3/LPC – peak amplitude										
FL	Pre	20	7.68	27.23	22	15.22	14.20	21	8.46	10.98
	Post	20	26.02	27.72	22	9.80	11.02	21	6.18	12.36

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
FM	Pre	20	-2.55	58.90	22	10.88	22.18	21	-4.03	32.90
	Post	20	10.11	37.32	22	4.36	10.64	21	3.79	6.85
CL	Pre	20	6.64	20.27	22	7.21	23.10	21	3.99	11.34
	Post	20	-5.41	15.14	22	4.16	15.20	21	2.32	8.13
CM	Pre	20	-13.05	63.14	22	25.82	87.24	21	-9.85	24.40
	Post	20	5.24	23.54	22	4.19	13.24	21	7.92	17.12
PL	Pre	20	7.10	28.01	22	13.19	31.41	21	-0.34	7.92
	Post	20	-1.66	17.52	22	2.79	10.15	21	6.15	9.89
PM	Pre	20	22.63	36.33	22	5.31	35.32	21	1.41	10.19
	Post	20	-22.45	70.93	22	-4.30	46.71	21	9.20	15.14
OL	Pre	20	12.91	34.82	22	3.44	36.57	21	10.79	21.93
	Post	20	10.53	21.94	22	5.19	22.91	21	4.55	13.78
OM	Pre	20	21.29	51.00	22	6.56	45.07	21	3.31	31.59
	Post	20	-10.23	75.71	22	-4.52	82.13	21	6.03	54.97
LTL	Pre	20	11.68	14.10	22	5.59	8.44	21	4.79	4.91
	Post	20	6.62	12.97	22	3.98	5.09	21	4.87	10.66
RTL	Pre	20	0.65	10.54	22	-0.32	16.57	21	-0.88	10.64
	Post	20	4.01	10.46	22	5.32	8.02	21	2.68	11.36
LTPJ	Pre	20	10.46	40.16	22	16.42	18.96	21	2.36	11.20
	Post	20	6.52	22.30	22	1.31	6.50	21	6.86	17.20
RTPJ	Pre	20	3.84	25.82	22	3.81	22.21	21	-6.75	25.08
	Post	20	2.27	11.86	22	4.85	12.60	21	2.51	9.57
P3/LPC – peak latency										
FL	Pre	20	596	39.43	22	559	38.56	21	586	47.14
	Post	20	586	42.19	22	579	50.00	21	599	42.30
FM	Pre	20	590	67.01	22	566	61.39	21	586	63.52
	Post	20	591	64.40	22	572	68.74	21	595	70.31
CL	Pre	20	587	31.17	22	591	31.87	21	611	30.37
	Post	20	604	20.03	22	594	31.92	21	606	37.25
CM	Pre	20	580	81.13	22	602	67.09	21	599	56.07
	Post	20	621	62.94	22	579	58.85	21	609	71.53
PL	Pre	20	586	31.54	22	608	35.01	21	592	33.54

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		MCST			CST			Control	
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	20	587	37.43	22	582	32.10	21	602	36.74
PM	Pre	20	602	74.27	22	624	59.27	21	574	67.58
	Post	20	591	62.76	22	588	58.42	21	616	51.16
OL	Pre	20	601	29.23	22	600	37.44	21	587	29.93
	Post	20	609	44.38	22	600	41.99	21	593	38.88
OM	Pre	20	602	69.90	22	600	64.76	21	593	70.27
	Post	20	615	60.32	22	585	71.56	21	582	66.75
LTL	Pre	20	588	47.93	22	599	36.30	21	594	52.24
	Post	20	591	40.35	22	585	29.06	21	581	46.82
RTL	Pre	20	595	42.13	22	583	33.58	21	598	29.99
	Post	20	601	35.75	22	600	32.91	21	619	33.26
LTPJ	Pre	20	588	45.94	22	614	38.17	21	591	55.70
	Post	20	576	55.35	22	581	33.20	21	588	52.60
RTPJ	Pre	20	586	62.97	22	601	37.32	21	591	43.12
	Post	20	586	43.63	22	592	49.38	21	616	31.35

Analysis of assumptions

In analyzing the verbal paired associates learning task, focusing on the amplitude and latency of the P300 and P3/LPC components, several key findings regarding assumption testing emerged.

P300 component

For the mean amplitude of P300, normality assumptions were generally violated across most regions of interest (ROIs), with Shapiro-Wilk W values ranging from 0.54 to 0.95 (all $p < .01$), except for OL and OM. However, homoscedasticity was predominantly observed, as indicated by Levene's test for equality of variances (K-squared range = 0.11 - 56.52, all $p > .05$), except for CL and RTL. Parallelism, assessing the homogeneity of regression slopes, was generally met across ROIs (F range = 0.01 - 4.73, all $p > .05$), except for LTPJ.

Similarly, normality assumptions were generally violated for the peak amplitude of P300 (W range = 0.56 - 0.96, all $p < .01$), except for LTL and RTPJ. Homoscedasticity was mainly observed (K-squared range = 0.11 -

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53.93, all p > .05), except for CL, CM, and LTPJ. Parallelism was generally met (F range = 0.01 - 4.78, all p > .05), except for LTPJ.

Concerning the peak latency of P300, normality assumptions were violated in several ROIs (W range = 0.93 - 0.98, all p < .01), except for FL and FM. Homoscedasticity was mostly observed (K-squared range = 0.11 - 6.94, all p > .05), except for PL and RTL. Parallelism was generally met (F range = 0.23 - 2.46, all p > .05), except for LTPJ.

P3/LPC component

Regarding mean amplitude, normality assumptions were violated in some ROIs (W range = 0.56 - 0.96, all p < .05), except for OL and RTPJ. Except for RTL, homoscedasticity was generally observed (K-squared range = 0.16 - 76.80, all p > .05). Parallelism was mostly met (F range = 0.04 - 4.78, all p > .05), except for LTPJ.

For the peak amplitude of P3/LPC, normality assumptions were generally violated (W range = 0.68 - 0.96, all p < .01), except for LTL, RTL, and RTPJ. Homoscedasticity was predominantly observed (K-squared range = 0.16 - 57.36, all p > .05), except for CL, CM, and PL. Parallelism was generally met (F range = 0.23 - 4.78, all p > .05), except for LTPJ.

Regarding the peak latency of P3/LPC, normality assumptions were generally violated (W range = 0.79 - 0.99, all p < .05), except for FM and RTL. Except for RTL, homoscedasticity was mostly observed (K-squared range = 0.33 - 6.94, all p > .05). Parallelism was generally met (F range = 0.25 - 1.93, all p > .05), except for CL.

While normality assumptions were frequently violated, homoscedasticity and parallelism were generally observed across most ROIs and contrasts, indicating that the assumptions for conducting subsequent analyses were reasonably met in the verbal paired associates learning task.

Analysis of group comparisons

The study investigated the effects of group conditions on various parameters of ERP components during a verbal paired associate learning task to measure learning and memory in older adults with MCI. The parameters analyzed

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included mean amplitude, peak amplitude, and peak latency of both P300 and P3/LPC components across different brain regions (see Table 60, Figure 59, and Figure 60).

P300 component

The results of the ANCOVA for the P300 ERP component could not be interpreted due to violations of the regression slope homogeneity assumption. Therefore, a separate regression analysis for each group is presented in the following section for the affected ROI: peak amplitude (LTPJ). The following are the ANCOVA results for ROIs that met the assumption.

The mean amplitude of the P300 ERP component showed a significant group effect in the frontal lobe (FL) with a large effect size *(F(*2, 59*)* = 5.90, $p < .01$, partial $\omega^2 = 0.13$). Post hoc comparisons indicated that the MCST group had a significantly higher mean amplitude than the control group *(t(59)* = 3.34, $p < .01$, Cohen's $d = 1.05$), and the CST group did not differ significantly from the control group. In addition, in central electrode locations (CL), the group effect was not significant *(F(*2, 59*)* = 2.91, $p = .06$, partial $\omega^2 = 0.06$), indicating a trend but not reaching statistical significance. Other regions, including the frontal midline (FM), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ), did not show significant group effects (all $p > .05$).

The peak amplitude of the P300 ERP component showed a significant group effect in the frontal lobe (FL) with a large effect size *(F(*2, 59*)* = 5.78, $p < .01$, partial $\omega^2 = 0.13$). Post hoc comparisons revealed that the MCST group had a significantly higher peak amplitude than the control group *(t(59)* = 3.32, $p < .01$, Cohen's $d = 1.04$). Other regions, including the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), and right temporal-parietal junction (RTPJ), did not show significant group effects (all $p > .05$).

The peak latency of the P300 ERP component did not show significant group effects in any region, including the frontal lobe (FL), frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal

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midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all p > .05).

P3/LPC component

The results of the ANCOVA for the P3/LPC ERP component could not be interpreted due to violations of the regression slope homogeneity assumption. Therefore, separate regression analyses for each group are presented in the following section for the affected ROI: mean amplitude (LTPJ) and peak amplitude (LTPJ). The following are the ANCOVA results for ROIs that met the assumption.

The mean amplitude of the P3/LPC ERP component showed a significant group effect in the frontal lobe (FL) with a large effect size *(F(*2, 59*)* = 6.89, *p* < .01, partial $\omega^2 = 0.16$). Post hoc comparisons indicated that the MCST group had a significantly higher mean amplitude than the control group *(t(59)* = 3.41, *p* < .01, Cohen's *d* = 1.07), and the CST group did not differ significantly from the control group. Central electrode locations (CL) also showed a significant group effect with a moderate effect size *(F(*2, 59*)* = 4.06, *p* = .02, partial $\omega^2 = 0.09$). Post hoc comparisons indicated that the MCST group had a significantly lower mean amplitude than the CST group *(t(59)* = -2.64, *p* = .03, Cohen's *d* = -0.82). Other regions, including the frontal midline (FM), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), and right temporal-parietal junction (RTPJ), did not show significant group effects (all p > .05).

The peak amplitude of the P3/LPC ERP component showed a significant group effect in the frontal lobe (FL) with a large effect size *(F(*2, 59*)* = 7.13, *p* < .01, partial $\omega^2 = 0.16$). Post hoc comparisons indicated that the MCST group had a significantly higher peak amplitude than the control group *(t(59)* = 3.49, *p* < .01, Cohen's *d* = 1.09). Other regions, including the frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), and right temporal-parietal junction (RTPJ), did not show significant group effects (all p > .05).

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The peak latency of the P3/LPC ERP component did not show significant group effects in any region, including the frontal lobe (FL), frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all $p > .05$).

The ANCOVA results for the Verbal Paired Associates Learning Task indicated significant group effects for the P300 mean, and peak amplitudes and the P3/LPC mean and peak amplitudes in the frontal lobe (FL) with large effect sizes. Central electrode locations (CL) also showed a significant group effect for the P3/LPC mean amplitude with a moderate effect size. Post hoc analyses revealed that the MCST group generally had higher amplitudes compared to the control group, indicating enhanced neural activity in these conditions. No significant group effects were found across all regions for the peak latency measures.

Table 60 ANCOVA of amplitude and latency of ERPs in the verbal paired associates learning task

		df	*SS*	*MS*	*F*	*p*	ω_p^2
P300 – mean amplitude							
FL	Pre-test	1	446.75	446.75	2.67	.11	0.03
	Group	2	1,973.34	986.67	5.90	<.01	0.13
	Residuals	59	9,859.96	167.12			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	59	9.84	4.07	2.42	.06	0.76
	MCST-Control	59	13.52	4.05	3.34	<.01	1.05
	CST-Control	59	3.68	3.98	0.92	1	0.28
FM	Pre-test	1	42.25	42.25	0.19	.67	<.01
	Group	2	166.29	83.15	0.37	.69	<.01
	Residuals	59	13,317.05	225.71			
CL	Pre-test	1	297.15	297.15	2.67	.11	0.03
	Group	2	648.02	324.01	2.91	.06	0.06

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	59	6,561.67	111.21			
CM	Pre-test	1	5.75	5.75	0.02	.88	<.01
	Group	2	423.78	211.89	0.88	.42	<.01
	Residuals	59	14,223.96	241.08			
PL	Pre-test	1	419.73	419.73	2.08	.15	0.02
	Group	2	427.46	213.73	1.06	.35	<.01
	Residuals	59	11,922.05	202.07			
PM	Pre-test	1	9,886.82	9,886.82	3.26	.08	0.03
	Group	2	6,885.46	3,442.73	1.13	.33	<.01
	Residuals	59	179,071.21	3,035.11			
OL	Pre-test	1	594.05	594.05	1.55	.22	0.01
	Group	2	224.73	112.36	0.29	.75	<.01
	Residuals	59	22,592.24	382.92			
OM	Pre-test	1	3,947.11	3,947.11	1.56	.22	0.01
	Group	2	7,661.76	3,830.88	1.52	.23	0.02
	Residuals	59	148,904.44	2,523.80			
LTL	Pre-test	1	174.71	174.71	3.12	.08	0.03
	Group	2	25.45	12.73	0.23	.80	<.01
	Residuals	59	3,308.78	56.08			
RTL	Pre-test	1	6.01	6.01	0.11	.74	<.01
	Group	2	86.06	43.03	0.81	.45	<.01
	Residuals	59	3,144.61	53.30			
LTPJ	Pre-test	1	146.24	146.24	1.06	.31	<.01
	Group	2	469.52	234.76	1.71	.19	0.02
	Residuals	59	8,103.74	137.35			
RTPJ	Pre-test	1	263.93	263.93	4.47	.04	0.05
	Group	2	39.81	19.90	0.34	.72	<.01
	Residuals	59	3,481.52	59.01			
P300 – peak amplitude							
FL	Pre-test	1	1,008.29	1,008.29	4.99	.03	0.06
	Group	2	2,333.90	1,166.95	5.78	<.01	0.13
	Residuals	59	11,909.76	201.86			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	MCST-CST	59	9.84	4.07	2.42	.06	0.76
	MCST-Control	59	13.52	4.05	3.34	<.01	1.05
	CST-Control	59	3.68	3.98	0.92	1	0.28
FM	Pre-test	1	3.31	3.31	0.01	.91	<.01
	Group	2	188.74	94.37	0.37	.70	<.01
	Residuals	59	15,233.53	258.20			
CL	Pre-test	1	144.04	144.04	1.18	.28	<.01
	Group	2	500.88	250.44	2.05	.14	0.03
	Residuals	59	7,198.85	122.01			
CM	Pre-test	1	6.76	6.76	0.02	.88	<.01
	Group	2	133.71	66.85	0.24	.79	<.01
	Residuals	59	16,641.77	282.06			
PL	Pre-test	1	129.64	129.64	0.84	.36	<.01
	Group	2	219.15	109.58	0.71	.50	<.01
	Residuals	59	9,103.79	154.30			
PM	Pre-test	1	8,659.88	8,659.88	3.70	.06	0.04
	Group	2	5,582.18	2,791.09	1.19	.31	0.01
	Residuals	59	138,144.66	2,341.43			
OL	Pre-test	1	1,448.76	1,448.76	2.92	.09	0.03
	Group	2	115.85	57.92	0.12	.89	<.01
	Residuals	59	29,264.06	496.00			
OM	Pre-test	1	5,077.50	5,077.50	1.73	.19	0.01
	Group	2	5,308.05	2,654.03	0.90	.41	<.01
	Residuals	59	173,255.59	2,936.54			
LTL	Pre-test	1	246.10	246.10	3.89	.05	0.04
	Group	2	30.38	15.19	0.24	.79	<.01
	Residuals	59	3,735.48	63.31			
RTL	Pre-test	1	3.30	3.30	0.04	.85	<.01
	Group	2	179.74	89.87	1.02	.37	<.01
	Residuals	59	5,210.01	88.31			
LTPJ	Pre-test	1	49.63	49.63	0.30	.59	<.01
*	Group	2	375.31	187.65	1.12	.33	<.01
	Residuals	59	9,877.93	167.42			

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
RTPJ	Pre-test	1	143.30	143.30	1.93	.17	0.01
	Group	2	158.16	79.08	1.07	.35	<.01
	Residuals	59	4,371.25	74.09			
P300 – peak latency							
FL	Pre-test	1	1,148.33	1,148.33	0.69	.41	<.01
	Group	2	2,932.11	1,466.05	0.88	.42	<.01
	Residuals	59	98,673.92	1,672.44			
FM	Pre-test	1	951.11	951.11	0.31	.58	<.01
	Group	2	398.39	199.19	0.07	.94	<.01
	Residuals	59	179,753.76	3,046.67			
CL	Pre-test	1	426.36	426.36	0.46	.50	<.01
	Group	2	114.25	57.12	0.06	.94	<.01
	Residuals	59	55,246.64	936.38			
CM	Pre-test	1	11,341.57	11,341.57	2.98	.09	0.03
	Group	2	3,963.84	1,981.92	0.52	.60	<.01
	Residuals	59	224,660.59	3,807.81			
PL	Pre-test	1	1.01	1.01	0.00	.98	<.01
	Group	2	228.43	114.21	0.08	.93	<.01
	Residuals	59	89,607.17	1,518.77			
PM	Pre-test	1	1,446.63	1,446.63	0.35	.55	<.01
	Group	2	13,281.29	6,640.64	1.62	.21	0.02
	Residuals	59	242,011.62	4,101.89			
OL	Pre-test	1	3,187.52	3,187.52	2.38	.13	0.02
	Group	2	1,745.97	872.99	0.65	.53	<.01
	Residuals	59	79,097.23	1,340.63			
OM	Pre-test	1	10,759.09	10,759.09	2.30	.13	0.02
	Group	2	2,316.62	1,158.31	0.25	.78	<.01
	Residuals	59	276,312.53	4,683.26			
LTL	Pre-test	1	21.72	21.72	0.02	.89	<.01
	Group	2	276.08	138.04	0.11	.89	<.01
	Residuals	59	72,322.02	1,225.80			
RTL	Pre-test	1	1,980.63	1,980.63	2.00	.16	0.02
	Group	2	1,214.94	607.47	0.61	.54	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	59	58,360.84	989.17			
LTPJ	Pre-test	1	1,925.98	1,925.98	0.67	.42	<.01
	Group	2	2,441.85	1,220.92	0.42	.66	<.01
	Residuals	59	169,680.53	2,875.94			
RTPJ	Pre-test	1	836.52	836.52	0.42	.52	<.01
	Group	2	1,122.00	561.00	0.28	.75	<.01
	Residuals	59	116,196.57	1,969.43			
P3/LPC – mean amplitude							
FL	Pre-test	1	74.57	74.57	0.37	.55	<.01
	Group	2	2,795.04	1,397.52	6.89	<.01	0.16
	Residuals	59	11,973.75	202.94			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	59	13.55	4.47	3.03	.01	0.95
	MCST-Control	59	15.23	4.47	3.41	<.01	1.07
	CST-Control	59	1.68	4.36	0.38	1	0.12
FM	Pre-test	1	363.87	363.87	0.54	.47	<.01
	Group	2	34.91	17.45	0.03	.97	<.01
	Residuals	59	40,031.14	678.49			
CL	Pre-test	1	90.91	90.91	0.50	.48	<.01
	Group	2	1,473.10	736.55	4.06	.02	0.09
	Residuals	59	10,714.94	181.61			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	59	-11.00	4.17	-2.64	.03	-0.82
	MCST-Control	59	-9.63	4.21	-2.29	.08	-0.71
	CST-Control	59	1.37	4.11	0.33	1	0.10
CM	Pre-test	1	235.63	235.63	1.07	.31	<.01
	Group	2	264.77	132.39	0.60	.55	<.01
	Residuals	59	13,047.68	221.15			
PL	Pre-test	1	317.04	317.04	1.75	.19	0.01
	Group	2	797.32	398.66	2.20	.12	0.04
	Residuals	59	10,697.12	181.31			
PM	Pre-test	1	16,191.98	16,191.98	6.08	.02	0.07
	Group	2	8,443.82	4,221.91	1.59	.21	0.02

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	59	157,015.46	2,661.28			
OL	Pre-test	1	0.63	0.63	0.00	.97	<.01
	Group	2	291.39	145.69	0.40	.67	<.01
	Residuals	59	21,722.66	368.18			
OM	Pre-test	1	2,111.94	2,111.94	0.44	.51	<.01
	Group	2	3,482.63	1,741.32	0.36	.70	<.01
	Residuals	59	283,514.55	4,805.33			
LTL	Pre-test	1	79.69	79.69	1.13	.29	<.01
	Group	2	2.86	1.43	0.02	.98	<.01
	Residuals	59	4,164.97	70.59			
RTL	Pre-test	1	240.11	240.11	4.70	.03	0.06
	Group	2	119.66	59.83	1.17	.32	0.01
	Residuals	59	3,013.70	51.08			
LTPJ	Pre-test	1	122.13	122.13	0.57	.46	<.01
*	Group	2	322.01	161.00	0.75	.48	<.01
	Residuals	59	12,749.72	216.10			
RTPJ	Pre-test	1	137.00	137.00	1.32	.26	<.01
	Group	2	57.12	28.56	0.27	.76	<.01
	Residuals	59	6,145.60	104.16			
P3/LPC – peak amplitude							
FL	Pre-test	1	253.62	253.62	0.76	.39	<.01
	Group	2	4,771.58	2,385.79	7.13	<.01	0.16
	Residuals	59	19,734.85	334.49			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	59	17.36	5.73	3.03	.01	0.95
	MCST-Control	59	19.96	5.72	3.49	<.01	1.09
	CST-Control	59	2.60	5.65	0.46	1	0.14
FM	Pre-test	1	195.72	195.72	0.39	.53	<.01
	Group	2	544.42	272.21	0.54	.58	<.01
	Residuals	59	29,531.92	500.54			
CL	Pre-test	1	8.81	8.81	0.05	.82	<.01
	Group	2	1,064.93	532.46	2.99	.06	0.06
	Residuals	59	10,515.09	178.22			

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
CM	Pre-test	1	220.66	220.66	0.65	.42	<.01
	Group	2	106.31	53.15	0.16	.85	<.01
	Residuals	59	19,896.80	337.23			
PL	Pre-test	1	228.27	228.27	1.38	.25	0.01
	Group	2	562.99	281.49	1.70	.19	0.02
	Residuals	59	9,787.79	165.89			
PM	Pre-test	1	15,445.76	15,445.76	6.70	.01	0.08
	Group	2	4,798.10	2,399.05	1.04	.36	<.01
	Residuals	59	136,056.98	2,306.05			
OL	Pre-test	1	4.40	4.40	0.01	.92	<.01
	Group	2	450.40	225.20	0.55	.58	<.01
	Residuals	59	23,957.62	406.06			
OM	Pre-test	1	5,878.50	5,878.50	1.13	.29	<.01
	Group	2	1,774.73	887.37	0.17	.84	<.01
	Residuals	59	306,157.40	5,189.11			
LTL	Pre-test	1	273.95	273.95	2.79	.10	0.03
	Group	2	23.00	11.50	0.12	.89	<.01
	Residuals	59	5,790.62	98.15			
RTL	Pre-test	1	162.36	162.36	1.64	.21	0.01
	Group	2	71.31	35.65	0.36	.70	<.01
	Residuals	59	5,851.19	99.17			
LTPJ	Pre-test	1	96.38	96.38	0.35	.56	<.01
*	Group	2	355.72	177.86	0.65	.53	<.01
	Residuals	59	16,215.10	274.83			
RTPJ	Pre-test	1	168.93	168.93	1.30	.26	<.01
	Group	2	118.31	59.15	0.46	.64	<.01
	Residuals	59	7,640.17	129.49			
P3/LPC – peak latency							
FL	Pre-test	1	12,823.04	12,823.04	6.82	.01	0.08
	Group	2	2,738.88	1,369.44	0.73	.49	<.01
	Residuals	59	110,949.55	1,880.50			
FM	Pre-test	1	5,988.53	5,988.53	1.30	.26	<.01
	Group	2	4,799.68	2,399.84	0.52	.60	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	59	272,574.31	4,619.90			
CL	Pre-test	1	3,431.70	3,431.70	3.90	.05	0.04
	Group	2	3,066.52	1,533.26	1.74	.18	0.02
	Residuals	59	51,950.66	880.52			
CM	Pre-test	1	1,135.32	1,135.32	0.27	.61	<.01
	Group	2	19,140.01	9,570.01	2.26	.11	0.04
	Residuals	59	250,016.69	4,237.57			
PL	Pre-test	1	116.33	116.33	0.09	.76	<.01
	Group	2	4,358.32	2,179.16	1.71	.19	0.02
	Residuals	59	75,259.56	1,275.59			
PM	Pre-test	1	535.77	535.77	0.16	.69	<.01
	Group	2	9,310.24	4,655.12	1.38	.26	0.01
	Residuals	59	198,820.16	3,369.83			
OL	Pre-test	1	379.92	379.92	0.22	.64	<.01
	Group	2	3,185.03	1,592.52	0.90	.41	<.01
	Residuals	59	103,840.08	1,760.00			
OM	Pre-test	1	12,127.40	12,127.40	2.81	.10	0.03
	Group	2	12,799.84	6,399.92	1.48	.24	0.02
	Residuals	59	254,588.89	4,315.07			
LTL	Pre-test	1	1.76	1.76	0.00	.97	<.01
	Group	2	902.38	451.19	0.29	.75	<.01
	Residuals	59	92,495.17	1,567.71			
RTL	Pre-test	1	4,203.90	4,203.90	3.76	.06	0.04
	Group	2	3,738.23	1,869.12	1.67	.20	0.02
	Residuals	59	65,951.00	1,117.81			
LTPJ	Pre-test	1	2,185.80	2,185.80	0.96	.33	<.01
	Group	2	1,654.60	827.30	0.36	.70	<.01
	Residuals	59	134,370.16	2,277.46			
RTPJ	Pre-test	1	1,810.42	1,810.42	1.02	.32	<.01
	Group	2	10,408.43	5,204.21	2.92	.06	0.06
	Residuals	59	105,158.00	1,782.34			

*A significant interaction effect

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Analysis of regression

This section provides an analysis of ERP parameters (mean amplitude and peak amplitude) for the P300 and P3/LPC components in the LTPJ region across intervention conditions (MCST, CST, and control) during the verbal paired associates learning task.

The analysis of mean and peak amplitudes for P300 and P3/LPC components reveals distinct patterns across groups. For the P3/LPC component's mean amplitude, neither the MCST (β_1 = -0.10, p = .38, adjusted R^2 = -.01) nor the CST group (β_1 = -0.04, p = .75, adjusted R^2 = -.04) exhibited significant predictive relationships, while the control group showed a significant positive relationship (β_1 = 0.71, p = .04, adjusted R^2 = .17) (see Figure 58).

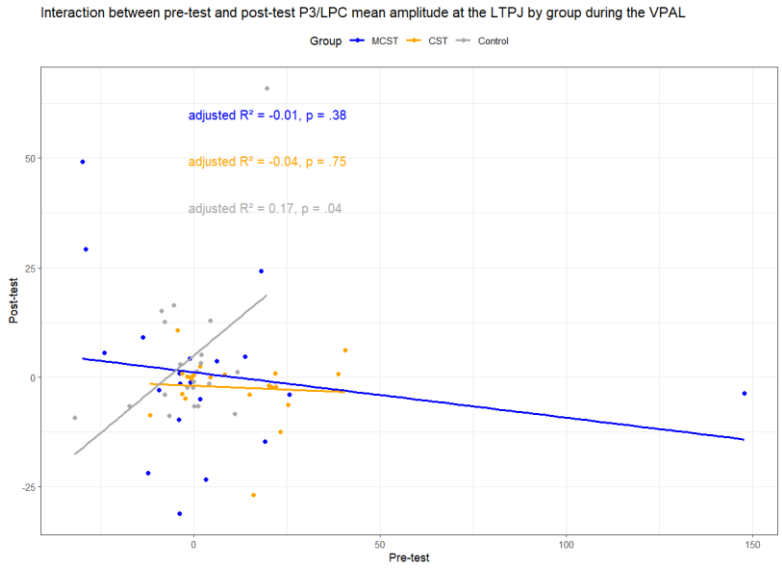

Figure 58 A scatter plot and the regression lines are shows interaction between pre-test and post-test P3/LPC mean amplitude at the left TPJ (LTPJ) by group during the verbal paired associates learning (VPAL) task

Regarding the P300 component's peak amplitude, significant predictive power was only observed in the control group (β_1 = 1.06, p < .001, adjusted R^2 = .34), with no significant effects in the MCST (β_1 = -0.08, p = .46, adjusted R^2 = -.02) or CST group (β_1 = -0.05, p = .67, adjusted R^2 = -.04).

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Similarly, for the P3/LPC component's peak amplitude, only the control group demonstrated significance (β_1 = 0.88, p = .01, adjusted R^2 = .30), while the MCST (β_1 = -0.11, p = .38, adjusted R^2 = -.01) and CST groups (β_1 = 0.01, p = .89, adjusted R^2 = -.05) showed no predictive effects. These findings suggest that the control group has a naturally stronger association between pre-test performance and amplitude metrics, while the MCST and CST interventions show limited impact.

In summary, the results indicate that the control group consistently exhibits significant predictive relationships for both mean and peak amplitude in the P300 and P3/LPC components, particularly for pre-test performance. The MCST and CST groups do not demonstrate significant relationships, suggesting that these interventions might not substantially affect ERP parameters in this task. The control group's significant results imply that natural learning effects or baseline cognitive abilities might explain their predictive relationships.

Table 61 Regression analysis of the verbal paired associates learning task

ROI	Model	Variable	*β*	*SE*	*t*	*p*
P300 - Peak ampitude						
LTPJ	MCST	Constant	6.32	4.21	1.50	.15
		Pre-test	-0.08	0.11	-0.75	.46
	CST	Constant	0.65	1.50	0.43	.67
		Pre-test	-0.05	0.11	-0.44	.67
	Control	Constant	2.83	2.42	1.17	.26
		Pre-test	1.06	0.31	3.39	<.01
P3/LPC - Mean amplitude						
LTPJ	MCST	Constant	1.12	4.16	0.27	.79
		Pre-test	-0.1	0.11	-0.9	.38
	CST	Constant	-1.94	1.97	-0.99	.34
		Pre-test	-0.04	0.11	-0.32	.75
	Control	Constant	4.86	3.28	1.48	.16
		Pre-test	0.71	0.31	2.25	.04
P3/LPC - Peak ampitude						
LTPJ	MCST	Constant	7.72	5.19	1.49	.15
		Pre-test	-0.11	0.13	-0.90	.38
	CST	Constant	1.14	1.9	0.60	.55
		Pre-test	0.01	0.08	0.13	.89

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ROI	Model	Variable	*β*	*SE*	*t*	*p*
	Control	Constant	4.77	3.22	1.48	.15
		Pre-test	0.88	0.29	3.07	.01

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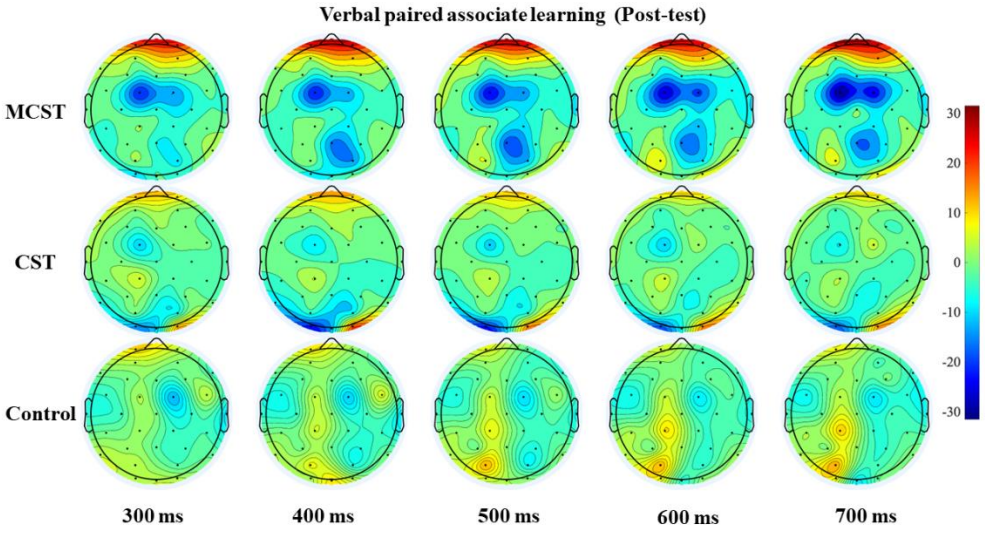

Figure 59 The topographic brain mapping of mean amplitude for each 100 ms latency window during the verbal paired associate learning task at post-test

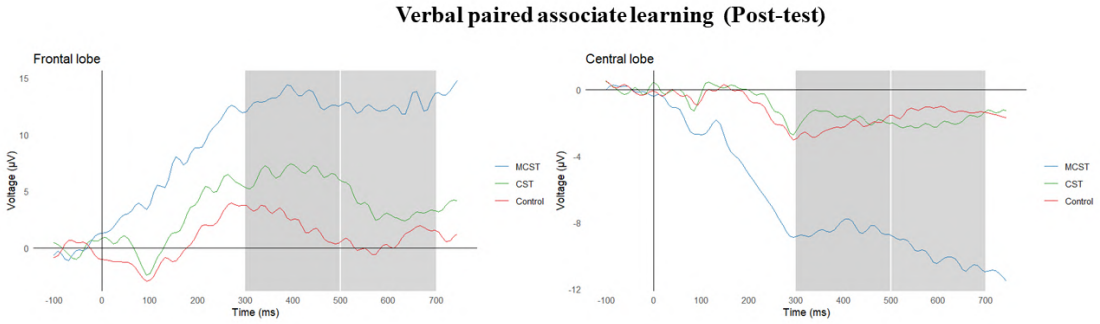

Figure 60 Grand-average ERP waveforms over the frontal and central regions across three groups in the verbal paired associate learning task

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ERP - Non-verbal paired associates learning task

Analysis of the amplitude and latency characteristics

P300 component Mean amplitude

In the frontal region, the MCST group showed a slight decrease in mean amplitude post-test. Specifically, the frontal lobe (FL) and the frontal midline (FM) both decreased. Conversely, the CST group experienced an increase in the FL and a slight increase in the FM. The control group showed a slight increase in the FL and a slight decrease in the FM.

In the central region, the MCST group displayed an increase in mean amplitude post-test in central electrode locations (CL) and the central midline (CM). The CST group showed a slight increase in the CL and a slight decrease in the CM. The control group showed a slight increase in the CL but a decrease in the CM.

In the parietal region, the MCST group showed a decrease in mean amplitude post-test in both the parietal lobe (PL) and the parietal midline (PM). The CST group also showed decreases in both regions. The control group showed a slight decrease in both the PL and PM.

In the temporal region, the MCST group showed a slight decrease in mean amplitude post-test in the left temporal lobe (LTL) and the right temporal lobe (RTL). The CST group showed slight decreases in both the LTL and RTL. The control group showed a slight decrease in the LTL and a slight decrease in the RTL. In the left temporal-parietal junction (LTPJ), the MCST group decreased

while the control group slightly increased. In the right temporal-parietal junction (RTPJ), the MCST group slightly decreased, the CST group slightly decreased, and the control group increased.

P300 component - Peak amplitude

In the frontal region, the MCST group's peak amplitude decreased post-test in both the frontal lobe (FL) and the frontal midline (FM). The CST group experienced a slight increase in both regions. The control group also showed slight decreases in both regions.

In the central region, the MCST group's peak amplitude increased in central electrode locations (CL) and the central midline (CM). The CST group showed slight increases in both regions. The control group showed slight decreases in the CL and the CM.

In the parietal region, the MCST group's peak amplitude decreased in both the parietal lobe (PL) and the parietal midline (PM). The CST group showed slight decreases in both regions. The control group showed slight increases in both regions.

In the temporal region, the MCST group's peak amplitude decreased in the left temporal lobe (LTL) and the right temporal lobe (RTL). The CST group showed slight decreases in both the LTL and RTL. The control group showed a slight decrease in the LTL and a slight increase in the RTL. In the left temporal-parietal junction (LTPJ), the MCST group decreased while the control group slightly increased. In the right temporal-parietal junction (RTPJ), the MCST group slightly decreased, the CST group slightly decreased, and the control group increased.

P300 component - Peak latency

In the frontal region, the MCST group showed a slight increase in peak latency post-test in both the frontal lobe (FL) and the frontal midline (FM). The CST group showed a slight decrease in both regions. The control group also showed a slight decrease in both regions.

In the central region, the MCST group showed a slight increase in peak latency in central electrode locations (CL) and the central midline

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(CM). The CST group showed a slight decrease in both regions. The control group showed a slight increase in the CL and a decrease in the CM.

In the parietal region, the MCST group showed a slight increase in peak latency in the parietal lobe (PL) and the parietal midline (PM). The CST group showed a slight decrease in both regions. The control group showed a slight decrease in both regions.

In the temporal region, the MCST group showed a slight increase in peak latency in the left temporal lobe (LTL) and the right temporal lobe (RTL). The CST group showed a slight decrease in both the LTL and RTL. The control group showed a slight decrease in the LTL and a slight increase in the RTL. In the left temporal-parietal junction (LTPJ), the MCST group slightly increased while the control group decreased. In the right temporal-parietal junction (RTPJ), the MCST group slightly decreased, the CST group increased, and the control group slightly decreased.

P3/LPC component - Mean amplitude

In the frontal region, the MCST group showed a slight decrease in mean amplitude post-test in both the frontal lobe (FL) and the frontal midline (FM). The CST group showed a slight increase in both regions. The control group showed a slight decrease in the FL and a slight decrease in the FM.

In the central region, the MCST group showed a slight increase in mean amplitude in both central electrode locations (CL) and the central midline (CM). The CST group showed a slight increase in both regions. The control group showed a slight decrease in the CL but a decrease in the CM.

In the parietal region, the MCST group showed a decrease in mean amplitude in both the parietal lobe (PL) and the parietal midline (PM). The CST group showed slight decreases in both regions. The control group showed slight decreases in both regions.

In the temporal region, the MCST group showed a slight decrease in mean amplitude in the left temporal lobe (LTL) and the right temporal lobe (RTL). The CST group showed slight decreases in both the LTL and RTL. The control group showed a slight decrease in the LTL and a slight increase in the RTL. In the left temporal-parietal junction (LTPJ), the MCST group slightly

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decreased while the control group slightly increased. In the right temporal-parietal junction (RTPJ), the MCST group slightly decreased, the CST group slightly decreased, and the control group increased.

P3/LPC component - Peak amplitude

In the frontal region, the MCST group showed a slight decrease in peak amplitude post-test in both the frontal lobe (FL) and the frontal midline (FM). The CST group experienced a slight increase in both regions. The control group also showed slight decreases in both regions.

In the central region, the MCST group's peak amplitude slightly increased in central electrode locations (CL) and the central midline (CM). The CST group showed slight increases in both regions. The control group showed slight decreases in the CL and the CM.

In the parietal region, the MCST group's peak amplitude slightly decreased in both the parietal lobe (PL) and the parietal midline (PM). The CST group showed slight decreases in both regions. The control group showed slight increases in both regions.

In the temporal region, the MCST group's peak amplitude slightly decreased in the left temporal lobe (LTL) and the right temporal lobe (RTL). The CST group showed slight decreases in both the LTL and RTL. The control group showed a slight decrease in the LTL and a slight increase in the RTL. In the left temporal-parietal junction (LTPJ), the MCST group slightly decreased while the control group slightly increased. In the right temporal-parietal junction (RTPJ), the MCST group slightly decreased, the CST group slightly decreased, and the control group increased.

P3/LPC component - Peak latency

In the frontal region, the MCST group showed a slight decrease in peak latency post-test in both the frontal lobe (FL) and the frontal midline (FM). The CST group showed a slight decrease in both regions. The control group also showed a slight decrease in both regions.

In the central region, the MCST group showed a slight increase in peak latency in central electrode locations (CL) and the central midline

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(CM). The CST group showed a slight decrease in both regions. The control group showed a slight increase in the CL and a slight decrease in the CM.

In the parietal region, the MCST group showed a slight increase in peak latency in the parietal lobe (PL) and the parietal midline (PM). The CST group showed a slight decrease in both regions. The control group showed a slight decrease in both regions.

In the temporal region, the MCST group showed a slight increase in peak latency in the left temporal lobe (LTL) and the right temporal lobe (RTL). The CST group showed a slight decrease in both the LTL and RTL. The control group showed a slight decrease in the LTL and a slight increase in the RTL. In the left temporal-parietal junction (LTPJ), the MCST group slightly increased while the control group slightly decreased. In the right temporal-parietal junction (RTPJ), the MCST group slightly decreased, the CST group increased, and the control group slightly decreased.

Table 62 Characteristic of amplitude and latency of ERPs in the non-verbal paired associates learning task

		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
P300 – mean amplitude										
FL	Pre	21	5.29	11.51	22	3.37	17.23	24	4.26	8.88
	Post	21	4.12	10.77	22	6.49	7.63	24	5.14	9.29
FM	Pre	21	7.17	16.77	22	-13.07	39.84	24	1.90	8.17
	Post	21	-8.63	19.16	22	0.61	5.54	24	1.16	8.62
CL	Pre	21	-2.44	13.47	22	-7.17	12.97	24	0.93	5.49
	Post	21	1.53	6.71	22	-0.17	8.92	24	0.97	7.30
CM	Pre	21	-18.08	44.87	22	-4.18	45.97	24	-0.12	9.73
	Post	21	6.10	16.90	22	-2.55	12.17	24	-4.08	10.16
PL	Pre	21	1.46	12.91	22	-4.01	22.88	24	0.94	7.24
	Post	21	-0.94	8.05	22	-2.06	8.32	24	-0.33	5.88
PM	Pre	21	0.84	26.71	22	2.64	27.40	24	7.71	27.61
	Post	21	-3.47	16.51	22	-4.82	20.02	24	-1.13	11.64
OL	Pre	21	0.66	15.02	22	1.48	18.83	24	-4.72	11.78

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	21	-2.21	14.23	22	-2.86	8.09	24	-2.50	10.99
OM	Pre	21	8.13	37.91	22	-20.23	63.66	24	2.68	45.58
	Post	21	-15.96	53.56	22	-8.17	89.14	24	-1.10	30.30
LTL	Pre	21	-1.53	8.93	22	2.49	8.51	24	0.70	4.34
	Post	21	-0.14	5.63	22	-0.22	6.60	24	-1.31	6.79
RTL	Pre	21	-2.62	11.45	22	2.79	17.89	24	-1.87	4.50
	Post	21	-1.94	6.13	22	-0.94	4.42	24	-1.43	3.60
LTPJ	Pre	21	0.47	13.97	22	-3.38	20.86	24	-1.07	7.77
	Post	21	-1.23	8.41	22	-2.45	6.57	24	-1.10	6.00
RTPJ	Pre	21	1.49	11.66	22	-5.48	36.97	24	-2.29	5.35
	Post	21	-1.34	8.83	22	-5.05	11.16	24	1.39	7.09
P300 – peak amplitude										
FL	Pre	21	11.13	12.98	22	11.79	16.67	24	9.49	9.65
	Post	21	9.12	12.32	22	12.99	10.38	24	10.25	11.02
FM	Pre	21	11.23	16.95	22	-8.12	38.79	24	5.24	8.02
	Post	21	-6.58	26.07	22	4.80	8.52	24	4.66	8.85
CL	Pre	21	5.28	14.06	22	0.19	16.97	24	4.85	7.22
	Post	21	5.87	9.16	22	3.96	8.93	24	4.23	8.69
CM	Pre	21	-9.38	37.30	22	5.44	52.20	24	3.10	9.30
	Post	21	10.61	19.71	22	1.96	9.09	24	-1.12	11.36
PL	Pre	21	6.48	14.99	22	6.28	21.05	24	4.49	7.76
	Post	21	2.78	7.17	22	2.43	8.06	24	2.57	5.83
PM	Pre	21	7.78	27.01	22	10.77	41.19	24	11.31	27.68
	Post	21	0.15	17.24	22	-1.47	20.04	24	1.54	11.59
OL	Pre	21	7.72	16.22	22	10.56	21.23	24	1.07	10.95
	Post	21	1.56	13.92	22	4.91	10.97	24	1.55	9.31
OM	Pre	21	14.42	40.80	22	-12.51	66.26	24	7.68	46.03
	Post	21	-12.01	53.76	22	0.19	89.12	24	4.86	28.19
LTL	Pre	21	3.40	9.94	22	9.20	11.32	24	4.55	5.67
	Post	21	3.93	5.65	22	4.39	7.22	24	2.54	6.69
RTL	Pre	21	3.70	10.70	22	10.60	21.17	24	2.10	3.99
	Post	21	1.69	7.73	22	4.02	5.34	24	1.95	4.18

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
LTPJ	Pre	21	5.14	15.12	22	3.74	22.49	24	2.52	9.05
	Post	21	2.75	7.12	22	2.24	5.42	24	2.34	5.74
RTPJ	Pre	21	6.72	15.36	22	4.01	33.76	24	1.26	5.04
	Post	21	1.72	9.66	22	-0.68	9.96	24	4.14	7.42
P300 – peak latency										
FL	Pre	21	403	33.91	22	409	33.58	24	416	31.55
	Post	21	410	47.73	22	408	37.95	24	413	28.47
FM	Pre	21	425	55.01	22	430	52.12	24	433	43.69
	Post	21	438	64.89	22	407	68.20	24	429	44.83
CL	Pre	21	403	37.28	22	402	32.16	24	421	38.02
	Post	21	418	29.92	22	393	37.74	24	411	23.39
CM	Pre	21	391	82.28	22	395	63.13	24	428	53.95
	Post	21	432	45.33	22	404	62.38	24	402	63.54
PL	Pre	21	407	39.15	22	393	37.30	24	407	27.92
	Post	21	391	25.64	22	387	35.48	24	398	36.75
PM	Pre	21	396	65.06	22	389	67.27	24	409	58.07
	Post	21	372	58.65	22	378	49.79	24	385	58.93
OL	Pre	21	402	28.47	22	399	32.53	24	391	36.90
	Post	21	383	31.67	22	392	35.50	24	392	33.51
OM	Pre	21	408	53.79	22	393	72.06	24	390	62.67
	Post	21	418	61.50	22	396	62.15	24	390	73.64
LTL	Pre	21	393	30.42	22	388	31.69	24	394	37.35
	Post	21	378	38.89	22	383	41.14	24	395	36.64
RTL	Pre	21	403	38.92	22	405	32.91	24	400	31.79
	Post	21	407	33.55	22	399	32.12	24	391	33.64
LTPJ	Pre	21	403	43.20	22	387	45.09	24	394	39.58
	Post	21	371	42.32	22	374	38.33	24	399	45.31
RTPJ	Pre	21	396	38.41	22	400	53.32	24	398	36.19
	Post	21	395	45.03	22	383	38.61	24	388	42.87
P3/LPC – mean amplitude										
FL	Pre	21	8.50	14.34	22	4.26	22.29	24	6.02	10.23
	Post	21	7.00	12.35	22	6.85	7.30	24	5.89	8.96

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
FM	Pre	21	0.75	31.83	22	-16.62	51.25	24	2.85	9.37
	Post	21	-8.72	22.69	22	0.28	6.61	24	0.95	11.45
CL	Pre	21	-3.51	22.73	22	-8.21	18.80	24	1.20	7.49
	Post	21	2.51	10.90	22	-1.67	9.32	24	1.34	7.23
CM	Pre	21	-21.04	65.50	22	-3.59	55.53	24	0.83	14.54
	Post	21	10.10	26.42	22	-5.28	23.68	24	-4.59	15.82
PL	Pre	21	1.35	13.74	22	-0.22	33.85	24	0.51	9.36
	Post	21	-2.94	11.52	22	-3.12	7.59	24	-1.31	8.26
PM	Pre	21	-2.34	36.14	22	14.61	53.46	24	4.50	23.69
	Post	21	-4.35	22.61	22	-6.44	22.11	24	-2.95	15.07
OL	Pre	21	-0.21	19.64	22	-0.11	30.78	24	-6.60	17.66
	Post	21	-2.98	22.54	22	-2.23	11.70	24	-2.38	12.80
OM	Pre	21	6.38	40.74	22	-20.70	71.01	24	5.46	65.34
	Post	21	-16.10	64.97	22	-12.54	101.6	24	-5.21	40.62
LTL	Pre	21	-3.30	11.14	22	0.97	14.45	24	-1.37	5.16
	Post	21	-2.16	5.32	22	-2.22	7.47	24	-3.27	10.37
RTL	Pre	21	-1.80	11.37	22	2.60	16.46	24	0.43	4.81
	Post	21	-0.83	6.51	22	2.36	7.70	24	0.33	4.62
LTPJ	Pre	21	-0.50	14.38	22	0.09	22.54	24	-1.52	8.67
	Post	21	-1.69	7.12	22	-3.90	9.62	24	-1.15	6.80
RTPJ	Pre	21	3.51	15.96	22	-6.14	53.80	24	-0.92	7.93
	Post	21	-1.44	12.18	22	-4.31	11.99	24	1.52	9.60
P3/LPC – peak amplitude										
FL	Pre	21	16.18	16.41	22	14.81	20.41	24	11.64	11.41
	Post	21	14.23	14.11	22	13.83	9.37	24	11.55	11.35
FM	Pre	21	6.10	35.72	22	-9.83	48.85	24	5.78	9.30
	Post	21	-4.97	20.71	22	4.57	8.68	24	3.93	11.82
CL	Pre	21	2.52	22.85	22	-0.35	20.10	24	5.44	9.39
	Post	21	6.48	11.79	22	2.85	9.67	24	4.41	8.29
CM	Pre	21	-15.19	56.80	22	7.93	66.88	24	4.29	14.71
	Post	21	13.96	35.04	22	-2.48	22.47	24	-1.61	17.20
PL	Pre	21	7.73	14.35	22	8.16	36.08	24	4.61	8.74

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	21	0.11	10.60	22	0.70	6.56	24	1.85	7.24
PM	Pre	21	4.76	34.82	22	24.76	60.90	24	9.28	30.11
	Post	21	-2.44	20.68	22	-3.59	22.34	24	-0.59	15.28
OL	Pre	21	6.06	22.16	22	14.13	38.04	24	-1.68	18.25
	Post	21	2.61	22.18	22	5.68	14.93	24	2.10	12.78
OM	Pre	21	11.88	43.36	22	-3.75	79.58	24	12.94	67.71
	Post	21	-8.50	59.62	22	-2.19	99.59	24	-1.92	41.55
LTL	Pre	21	3.06	11.86	22	8.89	15.93	24	3.53	6.30
	Post	21	2.35	5.67	22	2.52	7.98	24	0.31	9.65
RTL	Pre	21	4.44	9.15	22	12.26	19.80	24	5.90	7.51
	Post	21	3.73	7.41	22	8.81	10.55	24	3.86	5.29
LTPJ	Pre	21	5.29	16.92	22	7.42	24.77	24	2.82	9.31
	Post	21	2.15	7.27	22	0.48	7.81	24	1.48	7.05
RTPJ	Pre	21	10.16	17.75	22	2.73	50.70	24	3.88	8.81
	Post	21	1.99	13.26	22	0.33	12.30	24	4.26	10.13
P3/LPC – peak latency										
FL	Pre	21	604	45.45	22	591	48.37	24	612	36.74
	Post	21	590	49.21	22	598	44.30	24	582	37.49
FM	Pre	21	593	68.88	22	602	71.42	24	611	59.99
	Post	21	570	57.68	22	611	62.32	24	570	61.08
CL	Pre	21	587	39.87	22	600	36.00	24	592	34.65
	Post	21	588	36.91	22	586	35.24	24	589	32.58
CM	Pre	21	581	66.14	22	588	67.66	24	584	78.78
	Post	21	582	75.69	22	578	54.54	24	588	72.33
PL	Pre	21	586	38.10	22	610	31.48	24	599	31.87
	Post	21	601	45.38	22	584	34.64	24	597	36.85
PM	Pre	21	583	62.73	22	612	65.38	24	590	69.29
	Post	21	604	67.95	22	586	64.93	24	586	65.77
OL	Pre	21	590	38.43	22	599	37.65	24	597	29.65
	Post	21	608	33.35	22	591	42.00	24	605	32.09
OM	Pre	21	595	70.32	22	616	69.90	24	602	69.24
	Post	21	591	70.25	22	601	74.73	24	589	62.69

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		MCST			CST			Control	
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
LTL	Pre	21	574	35.57	22	596	43.40	24	575	30.52
	Post	21	584	32.63	22	587	40.51	24	594	32.07
RTL	Pre	21	605	34.33	22	605	37.09	24	624	32.18
	Post	21	602	43.71	22	615	41.41	24	608	27.03
LTPJ	Pre	21	572	36.45	22	607	46.68	24	589	35.20
	Post	21	598	49.08	22	610	47.96	24	624	36.93
RTPJ	Pre	21	590	36.87	22	617	41.01	24	622	39.26
	Post	21	606	47.14	22	605	47.73	24	606	43.66

Analysis of assumptions

In the non-verbal paired associates learning task, assumption testing was conducted for the amplitude and latency of the P300 and P3/LPC components across various regions of interest (ROIs).

P300 component

For the mean amplitude of P300, normality assumptions were generally violated (W range = 0.70 - 0.99, all $p < .05$), except for OL. Homoscedasticity was observed in most cases (K-squared range = 0.06 - 31.54, all $p > .05$), except for PM and RTL. Parallelism was generally met (F range = 0.01 - 2.76, all $p > .05$), except for RTL, LTPJ, and PM.

Similarly, for the peak amplitude of P300, normality assumptions were violated across ROIs (W range = 0.69 - 0.97, all $p < .05$), except for OL. Homoscedasticity was predominantly observed (K-squared range = 0.06 - 35.49, all $p > .05$), except for CM and RTL. Parallelism was generally met (F range = 0.01 - 3.11, all $p > .05$), except for RTL and LTPJ.

Regarding the peak latency of P300, normality assumptions were generally violated (W range = 0.70 - 0.99, all $p < .05$), except for FL, FM, and OL. Except for RTL, homoscedasticity was mostly observed (K-squared range = 0.04 - 5.50, all $p > .05$). Parallelism was generally met (F range = 0.01 - 3.08, all $p > .05$), except for CL.

P3/LPC component

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Moving to the P3/LPC component, for the mean amplitude, normality assumptions were violated in some ROIs (W range = 0.79 - 0.97, all p < .05), except for OL. Homoscedasticity was observed in most cases (K-squared range = 1.45 - 28.93, all p > .05), except for RTL and LTPJ. Parallelism was generally met (F range = 0.08 - 3.37, all p > .05), except for RTL and RTPJ.

Concerning the peak amplitude of P3/LPC, normality assumptions were violated across ROIs (W range = 0.69 - 0.97, all p < .05), except for OL. Homoscedasticity was predominantly observed (K-squared range = 0.06 - 25.36, all p > .05), except for RTL and OM. Parallelism was generally met (F range = 0.02 - 3.11, all p > .05), except for LTPJ.

For the peak latency of P3/LPC, normality assumptions were violated (W range = 0.74 - 0.99, all p < .05), except for OM. Homoscedasticity was mostly observed (K-squared range = 0.04 - 17.03, all p > .05), except for RTL. Parallelism was generally met (F range = 0.01 - 3.08, all p > .05), except for RTL.

Overall, while normality assumptions were frequently violated, homoscedasticity and parallelism were generally observed across most ROIs and contrasts, indicating that the assumptions for conducting subsequent analyses were reasonably met in the non-verbal paired associates learning task.

Analysis of group comparisons

The study investigated the effects of group conditions on various parameters of ERP components during the non-verbal paired associates learning task to measure non-semantic learning and memory in older adults with MCI. The parameters analyzed included mean amplitude, peak amplitude, and peak latency of both P300 and P3/LPC components across different brain regions. The one-way ANCOVA indicated that mean amplitude difference in the frontal and central midline and central midline, as well as peak amplitude, also differed in the central midline among P300.

P300 component

The mean amplitude of the P300 ERP component showed a significant group effect in the frontal midline (FM) with a moderate effect size ($F(2, 63) = 4.26$, $p = .02$, partial $\omega^2 = 0.09$). Post hoc comparisons indicated that

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the MCST group had a significantly lower mean amplitude than the control group *(t(63)* = -2.66, *p* = .03, Cohen's *d* = -0.80). The central midline (CM) also showed a significant group effect with a moderate effect size *(F(*2, 63*)* = 3.68, *p* = .03, partial $\omega^2 = 0.07$). Post hoc comparisons revealed that the MCST group had a significantly higher mean amplitude than the control group *(t(63)* = 2.56, *p* = .04, Cohen's *d* = 0.78).

Other regions, including the frontal lobe (FL), central lobe (CL), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ), did not show significant group effects (all $p > .05$).

The peak amplitude of the P300 ERP component showed a significant group effect in the central midline (CM) with a moderate effect size *(F(*2, 63*)* = 4.23, *p* = .02, partial $\omega^2 = 0.09$). Post hoc comparisons revealed that the MCST group had a significantly higher peak amplitude than The control group *(t(63)* = 2.83, *p* = .02, Cohen's *d* = 0.85).

Other regions, including the frontal lobe (FL), frontal midline (FM), central lobe (CL), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ), did not show significant group effects (all $p > .05$).

The peak latency of the P300 ERP component showed a significant group effect in central electrode locations (CL) with a moderate effect size *(F(*2, 63*)* = 3.44, *p* = .04, partial $\omega^2 = 0.07$). Post hoc comparisons indicated that the MCST group had a significantly longer peak latency than the CST group *(t(63)* = 2.61, *p* = .03, Cohen's *d* = 0.80).

Other regions, including the frontal lobe (FL), frontal midline (FM), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ), did not show significant group effects (all $p > .05$).

P3/LPC component

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The mean amplitude of the P3/LPC ERP component showed a significant group effect in the central midline (CM) with a moderate effect size *(F(*2, 63*)* = 4.07, *p* = .02, partial ω² = 0.08). Post hoc comparisons indicated that the MCST group had a significantly higher mean amplitude than the control group *(t(63)* = 2.49, *p* = .05, Cohen's *d* = 0.76).

Other regions, including the frontal lobe (FL), frontal midline (FM), central lobe (CL), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ), did not show significant group effects (all p > .05).

The peak amplitude of the P3/LPC ERP component showed a significant group effect in the central midline (CM) with a moderate effect size *(F(*2, 63*)* = 3.52, *p* = .04, partial ω² = 0.07). Post hoc comparisons revealed that the MCST group had a significantly higher peak amplitude than the control group *(t(63)* = 2.37, *p* = .06, Cohen's *d* = 0.74).

Other regions, including the frontal lobe (FL), frontal midline (FM), central lobe (CL), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ), did not show significant group effects (all p > .05).

The peak latency of the P3/LPC ERP component showed a significant group effect in the frontal midline (FM) with a moderate effect size *(F(*2, 63*)* = 3.32, *p* = .04, partial ω² = 0.06). Post hoc comparisons indicated that the MCST group had a non-significantly shorter peak latency than the CST group *(t(63)* = -2.17, *p* = .10, Cohen's *d* = -0.66).

Other regions, including the frontal lobe (FL), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ), did not show significant group effects (all p > .05).

The ANCOVA results for the non-verbal paired associates learning task indicated significant group effects for the P300 and P3/LPC

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mean, peak amplitudes, and peak latency in specific regions. The frontal midline (FM) and central midline (CM) showed significant effects with moderate effect sizes, suggesting differential neural activity associated with the MCST condition compared to the control group. Post hoc analyses revealed that the MCST group generally had higher or lower amplitudes and latencies compared to the control group, indicating variations in neural processing in these conditions.

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Table 63 ANCOVA of amplitude and latency of ERPs in the non-verbal paired associates learning task

		df	*SS*	*MS*	*F*	*p*	ω_p^2
P300 – mean amplitude							
FL	Pre-test	1	369.03	369.03	4.52	.04	0.05
	Group	2	80.87	40.43	0.50	.61	<.01
	Residuals	63	5,138.10	81.56			
FM	Pre-test	1	15.96	15.96	0.10	.75	<.01
	Group	2	1,309.53	654.77	4.26	.02	0.09
	Residuals	63	9,681.14	153.67			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	63	-9.62	3.98	-2.41	.06	-0.78
	MCST-Control	63	-9.89	3.72	-2.66	.03	-0.80
	CST-Control	63	-0.27	3.77	-0.07	1	-0.02
CL	Pre-test	1	50.12	50.12	0.84	.36	<.01
	Group	2	19.81	9.90	0.17	.85	<.01
	Residuals	63	3,758.91	59.67			
CM	Pre-test	1	16.67	16.67	0.09	.76	<.01
	Group	2	1,308.13	654.07	3.68	.03	0.07
	Residuals	63	11,184.85	177.54			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	63	8.81	4.11	2.14	.11	0.66
	MCST-Control	63	10.39	4.06	2.56	.04	0.78
	CST-Control	63	1.58	3.94	0.40	1	0.12
PL	Pre-test	1	8.54	8.54	0.15	.70	<.01
	Group	2	41.02	20.51	0.37	.70	<.01

		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	63	3,531.47	56.06			
PM	Pre-test	1	50.44	50.44	0.19	.67	<.01
	Group	2	179.35	89.68	0.33	.72	<.01
	Residuals	63	16,913.20	268.46			
OL	Pre-test	1	143.36	143.36	1.12	.29	<.01
	Group	2	11.49	5.74	0.04	.96	<.01
	Residuals	63	8,055.86	127.87			
OM	Pre-test	1	73.45	73.45	0.02	.89	<.01
	Group	2	2,444.67	1,222.34	0.31	.73	<.01
	Residuals	63	245,280.97	3,893.35			
LTL	Pre-test	1	44.01	44.01	1.08	.30	<.01
	Group	2	23.14	11.57	0.28	.75	<.01
	Residuals	63	2,563.55	40.69			
RTL	Pre-test	1	0.22	0.22	0.01	.92	<.01
	Group	2	10.44	5.22	0.23	.80	<.01
	Residuals	63	1,461.86	23.20			
LTPJ	Pre-test	1	180.31	180.31	3.84	.05	0.04
	Group	2	39.63	19.82	0.42	.66	<.01
	Residuals	63	2,956.00	46.92			
RTPJ	Pre-test	1	3.47	3.47	0.04	.84	<.01
	Group	2	474.34	237.17	2.80	.07	0.05
	Residuals	63	5,331.63	84.63			
P300 – peak amplitude							
FL	Pre-test	1	472.48	472.48	3.90	.05	0.04
	Group	2	153.54	76.77	0.63	.53	<.01
	Residuals	63	7,638.01	121.24			
FM	Pre-test	1	176.73	176.73	0.66	.42	<.01
	Group	2	1,679.42	839.71	3.13	.05	0.06
	Residuals	63	16,911.86	268.44			
CL	Pre-test	1	80.53	80.53	1.01	.32	<.01
	Group	2	34.96	17.48	0.22	.80	<.01
	Residuals	63	5,017.05	79.64			
CM	Pre-test	1	0.01	0.01	0.00	.99	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	1,667.32	833.66	4.23	.02	0.09
	Residuals	63	12,429.59	197.30			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	63	8.98	4.34	2.07	.13	0.64
	MCST-Control	63	12.00	4.24	2.83	.02	0.85
	CST-Control	63	3.02	4.15	0.73	1	0.22
PL	Pre-test	1	16.32	16.32	0.33	.57	<.01
	Group	2	1.52	0.76	0.02	.98	<.01
	Residuals	63	3,156.11	50.10			
PM	Pre-test	1	267.37	267.37	0.98	.33	<.01
	Group	2	106.77	53.39	0.20	.82	<.01
	Residuals	63	17,202.10	273.05			
OL	Pre-test	1	254.79	254.79	1.96	.17	0.01
	Group	2	109.08	54.54	0.42	.66	<.01
	Residuals	63	8,197.20	130.11			
OM	Pre-test	1	714.97	714.97	0.19	.67	<.01
	Group	2	3,093.86	1,546.93	0.40	.67	<.01
	Residuals	63	242,391.96	3,847.49			
LTL	Pre-test	1	63.41	63.41	1.47	.23	0.01
	Group	2	32.15	16.08	0.37	.69	<.01
	Residuals	63	2,709.64	43.01			
RTL	Pre-test	1	31.04	31.04	0.90	.35	<.01
	Group	2	53.43	26.71	0.77	.47	<.01
	Residuals	63	2,182.51	34.64			
LTPJ	Pre-test	1	102.05	102.05	2.81	.10	0.03
	Group	2	5.44	2.72	0.07	.93	<.01
	Residuals	63	2,284.57	36.26			
RTPJ	Pre-test	1	0.07	0.07	0.00	.98	<.01
	Group	2	267.39	133.69	1.62	.21	0.02
	Residuals	63	5,212.55	82.74			
P300 – peak latency							
FL	Pre-test	1	1,506.20	1,506.20	1.02	.32	<.01
	Group	2	220.04	110.02	0.07	.93	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	63	93,046.18	1,476.92			
FM	Pre-test	1	2,758.27	2,758.27	0.77	.38	<.01
	Group	2	11,456.12	5,728.06	1.60	.21	0.02
	Residuals	63	225,052.54	3,572.26			
CL	Pre-test	1	4,200.98	4,200.98	4.65	.03	0.05
	Group	2	6,213.41	3,106.70	3.44	.04	0.07
	Residuals	63	56,862.94	902.59			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	63	23.95	9.17	2.61	.03	0.80
	MCST-Control	63	10.27	9.18	1.12	.80	0.34
	CST-Control	63	-13.68	9.11	-1.50	.41	-0.46
CM	Pre-test	1	2,993.77	2,993.77	0.90	.35	<.01
	Group	2	15,152.63	7,576.32	2.27	.11	0.04
	Residuals	63	210,115.15	3,335.16			
PL	Pre-test	1	342.97	342.97	0.31	.58	<.01
	Group	2	1,218.72	609.36	0.54	.58	<.01
	Residuals	63	70,484.37	1,118.80			
PM	Pre-test	1	2,597.56	2,597.56	0.82	.37	<.01
	Group	2	1,442.41	721.20	0.23	.80	<.01
	Residuals	63	198,502.50	3,150.83			
OL	Pre-test	1	0.58	0.58	0.00	.98	<.01
	Group	2	1,172.82	586.41	0.51	.60	<.01
	Residuals	63	72,329.03	1,148.08			
OM	Pre-test	1	5,874.16	5,874.16	1.35	.25	0.01
	Group	2	11,699.91	5,849.96	1.35	.27	0.01
	Residuals	63	273,489.90	4,341.11			
LTL	Pre-test	1	838.65	838.65	0.55	.46	<.01
	Group	2	3,448.68	1,724.34	1.13	.33	<.01
	Residuals	63	95,907.41	1,522.34			
RTL	Pre-test	1	1,305.54	1,305.54	1.19	.28	<.01
	Group	2	2,896.38	1,448.19	1.32	.27	0.01
	Residuals	63	69,041.92	1,095.90			
LTPJ	Pre-test	1	782.24	782.24	0.44	.51	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	10,693.38	5,346.69	2.98	.06	0.06
	Residuals	63	112,954.89	1,792.93			
RTPJ	Pre-test	1	0.21	0.21	0.00	.99	<.01
	Group	2	1,671.78	835.89	0.46	.63	<.01
	Residuals	63	114,116.81	1,811.38			
P3/LPC – mean amplitude							
FL	Pre-test	1	231.88	231.88	2.53	.12	0.02
	Group	2	16.75	8.37	0.09	.91	<.01
	Residuals	63	5,785.53	91.83			
FM	Pre-test	1	35.07	35.07	0.16	.69	<.01
	Group	2	1,240.07	620.04	2.75	.07	0.05
	Residuals	63	14,213.88	225.62			
CL	Pre-test	1	0.65	0.65	0.01	.93	<.01
	Group	2	203.96	101.98	1.19	.31	0.01
	Residuals	63	5,403.07	85.76			
CM	Pre-test	1	564.80	564.80	1.18	.28	<.01
	Group	2	3,913.67	1,956.84	4.07	.02	0.08
	Residuals	63	30,269.57	480.47			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	63	16.93	6.76	2.50	.04	0.77
	MCST-Control	63	16.62	6.66	2.49	.05	0.76
	CST-Control	63	-0.31	6.47	-0.05	1	-0.01
PL	Pre-test	1	83.57	83.57	0.98	.32	<.01
	Group	2	46.12	23.06	0.27	.76	<.01
	Residuals	63	5,345.92	84.86			
PM	Pre-test	1	4.44	4.44	0.01	.92	<.01
	Group	2	137.19	68.60	0.17	.85	<.01
	Residuals	63	25,717.11	408.21			
OL	Pre-test	1	54.21	54.21	0.20	.65	<.01
	Group	2	9.34	4.67	0.02	.98	<.01
	Residuals	63	16,752.70	265.92			
OM	Pre-test	1	189.02	189.02	0.04	.85	<.01
	Group	2	1,370.05	685.02	0.13	.88	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	63	338,986.64	5,380.74			
LTL	Pre-test	1	61.33	61.33	0.93	.34	<.01
	Group	2	19.12	9.56	0.15	.87	<.01
	Residuals	63	4,150.28	65.88			
RTL	Pre-test	1	1.65	1.65	0.04	.84	<.01
	Group	2	111.67	55.83	1.36	.26	0.01
	Residuals	63	2,582.46	40.99			
LTPJ	Pre-test	1	0.72	0.72	0.01	.92	<.01
	Group	2	94.78	47.39	0.74	.48	<.01
	Residuals	63	4,021.00	63.83			
RTPJ	Pre-test	1	19.04	19.04	0.15	.70	<.01
	Group	2	403.52	201.76	1.57	.22	0.02
	Residuals	63	8,075.16	128.18			
P3/LPC – peak amplitude							
FL	Pre-test	1	125.60	125.60	0.91	.34	<.01
	Group	2	72.73	36.37	0.26	.77	<.01
	Residuals	63	8,689.16	137.92			
FM	Pre-test	1	86.67	86.67	0.41	.52	<.01
	Group	2	1,167.38	583.69	2.76	.07	0.05
	Residuals	63	13,346.02	211.84			
CL	Pre-test	1	33.64	33.64	0.34	.56	<.01
	Group	2	135.59	67.79	0.68	.51	<.01
	Residuals	63	6,295.76	99.93			
CM	Pre-test	1	680.72	680.72	1.06	.31	<.01
	Group	2	4,515.17	2,257.58	3.52	.04	0.07
	Residuals	63	40,449.79	642.06			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	63	18.65	7.87	2.37	.06	0.74
	MCST-Control	63	17.43	7.67	2.27	.08	0.69
	CST-Control	63	-1.22	7.48	-0.16	1	-0.05
PL	Pre-test	1	19.21	19.21	0.28	.60	<.01
	Group	2	32.32	16.16	0.23	.79	<.01
	Residuals	63	4,340.24	68.89			

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
PM	Pre-test	1	20.07	20.07	0.05	.82	<.01
	Group	2	96.54	48.27	0.12	.88	<.01
	Residuals	63	24,390.13	387.14			
OL	Pre-test	1	4.91	4.91	0.02	.90	<.01
	Group	2	163.91	81.95	0.28	.75	<.01
	Residuals	63	18,275.47	290.09			
OM	Pre-test	1	447.42	447.42	0.09	.77	<.01
	Group	2	559.59	279.79	0.06	.95	<.01
	Residuals	63	318,687.50	5,058.53			
LTL	Pre-test	1	33.61	33.61	0.52	.47	<.01
	Group	2	60.90	30.45	0.47	.63	<.01
	Residuals	63	4,097.03	65.03			
RTL	Pre-test	1	170.23	170.23	2.68	.11	0.02
	Group	2	274.02	137.01	2.15	.12	0.03
	Residuals	63	4,008.02	63.62			
LTPJ	Pre-test	1	15.26	15.26	0.28	.60	<.01
	Group	2	27.98	13.99	0.25	.78	<.01
	Residuals	63	3,468.31	55.05			
RTPJ	Pre-test	1	9.05	9.05	0.06	.80	<.01
	Group	2	179.75	89.87	0.63	.54	<.01
	Residuals	63	9,041.54	143.52			
P3/LPC – peak latency							
FL	Pre-test	1	737.40	737.40	0.38	.54	<.01
	Group	2	2,514.44	1,257.22	0.65	.53	<.01
	Residuals	63	121,696.48	1,931.69			
FM	Pre-test	1	433.68	433.68	0.12	.73	<.01
	Group	2	24,628.94	12,314.47	3.32	.04	0.06
	Residuals	63	233,432.43	3,705.28			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	63	-40.31	18.60	-2.17	.10	-0.66
	MCST-Control	63	0.96	18.30	0.05	1	0.02
	CST-Control	63	41.27	18.00	2.29	.08	0.68
CL	Pre-test	1	6,354.15	6,354.15	5.63	.02	0.06

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	481.54	240.77	0.21	.81	<.01
	Residuals	63	71,051.60	1,127.80			
CM	Pre-test	1	162.59	162.59	0.03	.85	<.01
	Group	2	1,270.29	635.15	0.13	.87	<.01
	Residuals	63	297,217.39	4,717.74			
PL	Pre-test	1	756.89	756.89	0.49	.49	<.01
	Group	2	2,826.86	1,413.43	0.91	.41	<.01
	Residuals	63	97,455.66	1,546.92			
PM	Pre-test	1	1,870.99	1,870.99	0.42	.52	<.01
	Group	2	3,792.77	1,896.39	0.43	.65	<.01
	Residuals	63	279,079.54	4,429.83			
OL	Pre-test	1	767.68	767.68	0.59	.45	<.01
	Group	2	3,940.95	1,970.48	1.52	.23	0.02
	Residuals	63	81,879.10	1,299.67			
OM	Pre-test	1	2,993.75	2,993.75	0.62	.43	<.01
	Group	2	1,396.09	698.05	0.14	.87	<.01
	Residuals	63	303,771.50	4,821.77			
LTL	Pre-test	1	1,257.85	1,257.85	1.01	.32	<.01
	Group	2	1,109.06	554.53	0.45	.64	<.01
	Residuals	63	78,166.44	1,240.74			
RTL	Pre-test	1	16.62	16.62	0.01	.91	<.01
	Group	2	1,946.29	973.14	0.67	.51	<.01
	Residuals	63	91,013.44	1,444.66			
LTPJ	Pre-test	1	45.27	45.27	0.02	.88	<.01
	Group	2	7,302.53	3,651.27	1.80	.17	0.02
	Residuals	63	127,809.07	2,028.72			
RTPJ	Pre-test	1	66.23	66.23	0.03	.86	<.01
	Group	2	29.99	14.99	0.01	.99	<.01
	Residuals	63	136,064.90	2,159.76			

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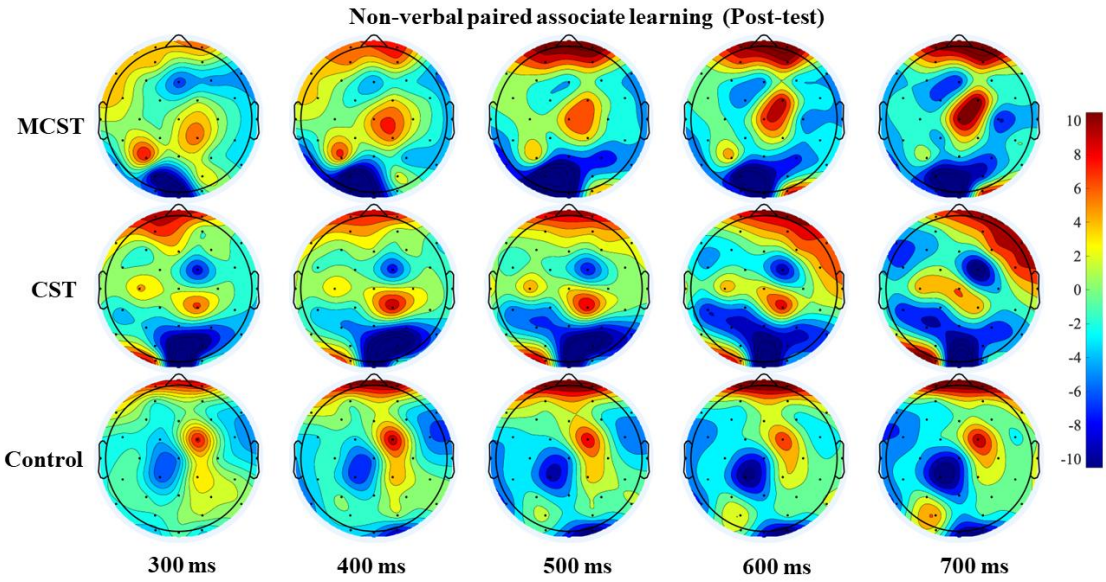

Figure 61 The topographic brain mapping of mean amplitude for each 100 ms latency window during the non-verbal paired associate learning task at post-test

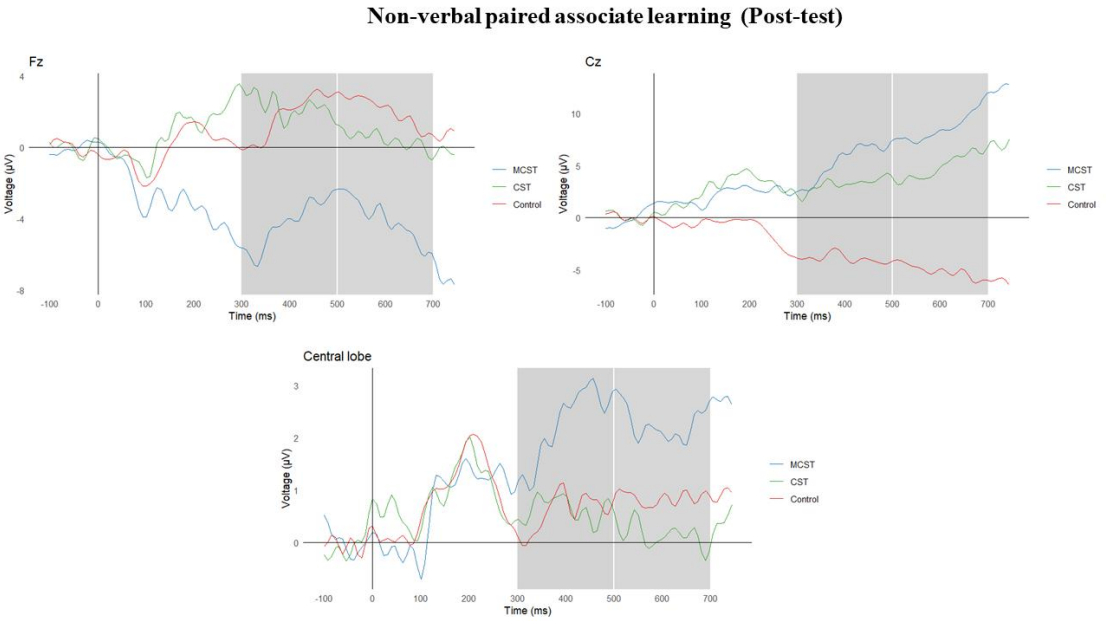

Figure 62 Grand-average ERP waveforms over the frontal and central regions across three groups in the non-verbal paired associate learning task

ERP - Verbal fluency task

Analysis of the amplitude and latency characteristics

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N4 component - Mean amplitude

In the frontal region, the MCST group showed a slight decrease in mean amplitude post-test. The CST group experienced a notable increase, while the control group showed a slight decrease.

In the central region, the MCST group showed a substantial increase in mean amplitude post-test. The CST group showed a decrease, whereas The control group exhibited a slight increase.

In the parietal region, the MCST group displayed a slight decrease in mean amplitude post-test. The CST group showed a significant increase, and the control group experienced a slight increase.

In the temporal region, the MCST group showed mixed changes: for example, the left temporal lobe (LTL) increased from -0.73 to 4.51, while the right temporal lobe (RTL) decreased from 7.39 to -3.04. The CST group showed slight decreases in most regions, while the control group experienced slight increases or remained stable.

N4 component - Peak amplitude

In the frontal region, the MCST group showed a decrease in peak amplitude post-test. The CST group experienced a slight increase, and the control group remained relatively stable.

In the central region, the MCST group showed an increase in peak amplitude post-test. The CST group showed a slight increase, while the control group experienced a slight increase.

In the parietal region, the MCST group showed mixed changes with slight decreases in some areas. For instance, the parietal midline (PM) increased from -13.03 to -5.21, while the parietal lobe (PL) increased from 4.04 to 5.45. The CST group experienced a significant increase, and the control group remained relatively stable.

In the temporal region, the MCST group showed mixed changes: the left temporal lobe (LTL) increased from 10.66 to 11.51, while the right temporal lobe (RTL) decreased from 17.38 to 4.39. The CST group experienced slight decreases, while the control group showed slight increases or remained stable.

N4 component - Peak latency

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In the frontal region, the MCST group showed a slight decrease in peak latency post-test. The CST group showed a slight increase, and the control group exhibited a slight decrease.

In the central region, the MCST group showed a slight increase in peak latency post-test. The CST group showed a slight decrease, while the control group remained relatively stable.

In the parietal region, the MCST group showed slight increases in peak latency. The CST group experienced slight decreases, and the control group remained stable.

In the temporal region, the MCST group showed mixed changes: for example, the left temporal lobe (LTL) decreased from 410 to 401, while the right temporal lobe (RTL) decreased from 408 to 396. The CST group experienced slight decreases, while the control group showed slight increases or remained stable.

P6 component - Mean amplitude

In the frontal region, the MCST group showed a slight decrease in mean amplitude post-test. The CST group experienced a slight decrease, while the control group showed a substantial increase.

In the central region, the MCST group showed a substantial increase in mean amplitude post-test. The CST group showed a slight decrease, whereas the control group exhibited a slight increase.

In the parietal region, the MCST group displayed a slight decrease in mean amplitude post-test. The CST group showed a slight increase, and the control group experienced a slight decrease.

In the temporal region, the MCST group showed mixed changes: for example, the left temporal lobe (LTL) increased from 0.88 to 5.00, while the right temporal lobe (RTL) decreased from 2.40 to -2.71. The CST group showed slight increases in some regions, while the control group experienced slight decreases or remained stable.

P6 component - Peak amplitude

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In the frontal region, the MCST group showed a decrease in peak amplitude post-test. The CST group experienced a slight increase, and the control group remained relatively stable.

In the central region, the MCST group showed a substantial increase in peak amplitude post-test. The CST group showed a slight increase, while the control group experienced a slight increase.

In the parietal region, the MCST group showed mixed changes with slight decreases in some areas. For instance, the parietal midline (PM) decreased from -20.05 to -5.86, while the parietal lobe (PL) decreased from 13.35 to 2.69. The CST group experienced a slight increase, and the control group remained relatively stable.

In the temporal region, the MCST group showed mixed changes: the left temporal lobe (LTL) decreased from 12.87 to 12.01, while the right temporal lobe (RTL) decreased from 12.08 to 4.25. The CST group experienced slight decreases, while the control group showed slight increases or remained stable.

P6 component - Peak latency

In the frontal region, the MCST group showed a slight decrease in peak latency post-test. The CST group showed a slight increase, and the control group exhibited a slight decrease.

In the central region, the MCST group showed a slight increase in peak latency post-test. The CST group showed a slight decrease, while the control group remained relatively stable.

In the parietal region, the MCST group showed slight increases in peak latency. The CST group experienced slight decreases, and the control group remained stable.

In the temporal region, the MCST group showed mixed changes: for example, the left temporal lobe (LTL) remained stable from 583 to 585, while the right temporal lobe (RTL) increased from 608 to 611. The CST group experienced slight decreases, while the control group showed slight increases or remained stable.

Table 64 Characteristic of amplitude and latency of ERPs in the verbal fluency task

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
N4 – mean amplitude										
FL	Pre	12	-4.80	35.80	10	-15.32	27.47	18	8.76	38.90
	Post	12	-5.94	27.11	10	-3.61	27.63	18	5.06	43.73
FM	Pre	12	6.88	36.55	10	-30.03	59.81	18	6.67	24.03
	Post	12	-12.40	21.74	10	13.20	36.92	18	3.36	32.35
CL	Pre	12	0.80	12.89	10	5.82	17.25	18	-5.33	41.30
	Post	12	10.45	17.54	10	-3.41	24.24	18	6.57	11.30
CM	Pre	12	4.98	58.26	10	-4.25	45.56	18	-3.87	36.77
	Post	12	43.16	93.96	10	-13.13	78.54	18	4.74	36.96
PL	Pre	12	-3.56	25.04	10	-0.02	25.14	18	-3.31	19.54
	Post	12	-1.31	13.64	10	10.50	24.17	18	2.88	32.82
PM	Pre	12	-23.93	61.03	10	-4.78	21.08	18	7.66	33.87
	Post	12	-11.15	39.13	10	24.86	54.48	18	11.93	77.60
OL	Pre	12	-0.43	25.17	10	9.65	40.97	18	8.43	37.43
	Post	12	-4.96	17.19	10	1.62	31.35	18	-0.98	39.45
OM	Pre	12	6.03	65.88	10	-0.73	44.01	18	39.09	88.06
	Post	12	-9.73	54.23	10	-9.32	25.21	18	9.21	86.25
LTL	Pre	12	-0.73	25.23	10	-4.46	17.97	18	0.20	25.51
	Post	12	4.51	11.72	10	3.18	13.83	18	-1.86	15.12
RTL	Pre	12	7.39	12.68	10	4.34	15.89	18	-7.33	29.16
	Post	12	-3.04	13.02	10	-7.44	7.79	18	-9.42	20.49
LTPJ	Pre	12	-5.55	33.91	10	3.38	23.81	18	-3.00	20.79
	Post	12	0.97	12.98	10	7.94	17.00	18	3.32	34.81
RTPJ	Pre	12	2.13	28.50	10	5.21	22.94	18	-22.52	59.06
	Post	12	-1.27	14.28	10	5.33	15.02	18	-15.36	32.85
N4 – peak amplitude										
FL	Pre	12	11.82	43.89	10	-3.07	25.64	18	26.89	52.03
	Post	12	4.66	29.51	10	12.20	35.16	18	26.39	53.59
FM	Pre	12	16.64	37.49	10	-19.85	58.22	18	21.96	44.70
	Post	12	-2.03	19.87	10	25.46	52.74	18	15.90	28.88
CL	Pre	12	11.09	15.67	10	15.24	18.18	18	8.74	39.32

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	12	19.07	19.43	10	12.55	17.31	18	17.27	14.12
CM	Pre	12	17.10	57.27	10	0.26	48.86	18	7.18	32.99
	Post	12	52.83	94.63	10	2.73	61.27	18	15.46	39.48
PL	Pre	12	4.04	28.34	10	8.51	26.98	18	9.47	18.28
	Post	12	5.45	11.85	10	23.01	34.61	18	13.05	36.23
PM	Pre	12	-13.03	61.74	10	1.02	19.86	18	22.31	31.68
	Post	12	-5.21	38.92	10	42.03	73.99	18	22.07	83.67
OL	Pre	12	13.03	25.51	10	23.25	43.35	18	26.62	47.56
	Post	12	4.57	20.52	10	17.95	32.84	18	14.88	46.26
OM	Pre	12	23.24	77.70	10	11.73	48.80	18	61.69	107.03
	Post	12	0.21	50.56	10	2.07	24.69	18	24.74	90.59
LTL	Pre	12	10.66	26.12	10	7.50	18.82	18	11.06	25.01
	Post	12	11.51	12.50	10	16.12	24.86	18	9.23	17.12
RTL	Pre	12	17.38	12.11	10	13.92	18.82	18	4.75	27.35
	Post	12	4.39	13.88	10	5.60	8.83	18	2.39	18.77
LTPJ	Pre	12	2.53	34.45	10	12.84	23.43	18	5.66	19.39
	Post	12	7.76	11.94	10	19.80	28.03	18	15.34	40.99
RTPJ	Pre	12	11.05	28.61	10	15.76	26.14	18	-9.09	57.57
	Post	12	5.43	13.74	10	15.74	24.86	18	-3.27	25.76
N4 – peak latency										
FL	Pre	12	427	39.76	10	397	33.54	18	409	39.83
	Post	12	410	32.33	10	419	35.60	18	396	44.53
FM	Pre	12	418	63.96	10	373	54.01	18	403	64.86
	Post	12	391	75.63	10	395	80.93	18	380	64.94
CL	Pre	12	378	24.67	10	382	27.51	18	385	40.90
	Post	12	390	37.01	10	381	38.62	18	388	40.66
CM	Pre	12	386	69.40	10	392	61.93	18	391	68.63
	Post	12	388	75.88	10	350	54.99	18	390	63.48
PL	Pre	12	384	33.13	10	392	27.71	18	391	26.78
	Post	12	390	46.96	10	375	32.99	18	391	29.96
PM	Pre	12	385	61.60	10	409	49.41	18	398	64.43
	Post	12	398	59.99	10	359	67.39	18	394	63.08

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
OL	Pre	12	404	25.95	10	429	26.54	18	404	29.92
	Post	12	418	32.67	10	412	41.19	18	424	40.50
OM	Pre	12	411	70.93	10	412	68.05	18	438	55.79
	Post	12	427	70.00	10	404	66.93	18	436	58.29
LTL	Pre	12	410	33.17	10	397	31.74	18	399	24.97
	Post	12	401	28.71	10	411	26.71	18	393	29.29
RTL	Pre	12	408	32.00	10	421	28.21	18	396	35.28
	Post	12	396	26.14	10	377	25.36	18	391	35.76
LTPJ	Pre	12	410	46.61	10	397	58.94	18	403	41.76
	Post	12	409	49.65	10	400	24.00	18	394	41.21
RTPJ	Pre	12	403	35.12	10	421	47.14	18	385	36.90
	Post	12	404	47.50	10	396	41.72	18	397	56.47
P6 – mean amplitude										
FL	Pre	10	0.65	18.99	4	15.86	24.53	12	5.78	20.70
	Post	10	0.37	30.81	4	-1.57	40.70	12	23.53	45.09
FM	Pre	10	2.26	41.78	4	-17.07	15.70	12	-9.72	28.25
	Post	10	-12.25	26.87	4	4.84	33.31	12	-1.02	28.92
CL	Pre	10	-2.18	19.12	4	7.05	22.87	12	-4.64	18.15
	Post	10	9.30	26.95	4	-2.86	7.70	12	1.32	9.35
CM	Pre	10	3.97	58.58	4	11.19	23.35	12	3.71	37.18
	Post	10	59.82	123.2	4	5.74	13.20	12	-4.03	40.98
PL	Pre	10	2.30	34.66	4	-3.61	21.98	12	-1.84	12.83
	Post	10	-4.07	18.36	4	0.87	9.97	12	-8.99	15.41
PM	Pre	10	-31.78	57.97	4	-4.63	12.08	12	-4.10	25.84
	Post	10	-11.68	44.18	4	2.81	14.59	12	-23.95	36.53
OL	Pre	10	-4.70	36.90	4	-1.65	16.71	12	-0.36	35.23
	Post	10	-8.36	15.10	4	2.88	28.44	12	-1.31	45.19
OM	Pre	10	6.66	28.06	4	-40.91	60.99	12	66.98	121.2
	Post	10	-6.50	53.98	4	-26.99	56.75	12	37.78	84.33
LTL	Pre	10	0.88	32.41	4	-6.53	19.53	12	3.38	12.05
	Post	10	5.00	13.69	4	3.50	7.58	12	-6.67	13.23
RTL	Pre	10	2.40	25.65	4	-8.19	15.84	12	-2.50	15.15

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	10	-2.71	15.71	4	-2.93	2.47	12	-5.46	14.01
LTPJ	Pre	10	7.07	27.47	4	-12.59	25.51	12	0.01	13.22
	Post	10	0.63	18.69	4	5.36	15.23	12	-5.39	14.21
RTPJ	Pre	10	3.56	23.14	4	-1.07	15.38	12	-3.76	24.85
	Post	10	-3.53	13.12	4	-0.62	12.86	12	-10.37	32.22
P6 – peak amplitude										
FL	Pre	10	16.63	15.83	4	30.83	28.11	12	28.79	40.27
	Post	10	11.69	33.02	4	13.71	50.32	12	40.34	58.53
FM	Pre	10	10.27	44.90	4	-8.85	13.84	12	-0.33	23.00
	Post	10	-7.53	26.69	4	10.50	32.86	12	9.97	32.22
CL	Pre	10	7.67	18.06	4	13.42	23.48	12	3.93	19.27
	Post	10	15.56	26.08	4	1.76	7.98	12	10.31	11.04
CM	Pre	10	15.69	56.69	4	18.59	20.92	12	11.24	39.57
	Post	10	68.25	121.7	4	11.41	12.53	12	8.60	35.50
PL	Pre	10	13.35	37.39	4	0.91	17.88	12	9.70	12.79
	Post	10	2.69	19.34	4	6.59	8.31	12	-0.61	12.62
PM	Pre	10	-20.05	59.88	4	0.31	10.48	12	9.84	28.87
	Post	10	-5.86	44.39	4	8.16	12.58	12	-14.87	39.00
OL	Pre	10	8.94	42.41	4	9.89	17.83	12	15.99	39.09
	Post	10	-0.42	14.55	4	13.41	28.73	12	10.36	48.17
OM	Pre	10	23.13	36.32	4	-33.71	60.81	12	77.07	124.9
	Post	10	0.05	53.60	4	-8.86	44.65	12	51.77	90.03
LTL	Pre	10	12.87	33.04	4	1.43	17.56	12	14.94	12.22
	Post	10	12.01	14.89	4	10.52	6.99	12	2.88	13.76
RTL	Pre	10	12.08	24.29	4	0.56	18.14	12	10.18	15.10
	Post	10	4.25	16.08	4	5.33	2.69	12	4.38	13.28
LTPJ	Pre	10	17.43	30.06	4	-7.00	26.73	12	10.65	12.57
	Post	10	5.55	18.86	4	11.90	12.41	12	1.77	9.82
RTPJ	Pre	10	13.92	23.86	4	2.59	10.97	12	8.24	24.84
	Post	10	3.03	13.92	4	5.79	10.68	12	0.41	30.10
P6 – peak latency										
FL	Pre	10	633	19.64	4	605	66.68	12	602	58.38

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		MCST			CST			Control	
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	10	620	34.03	4	597	21.83	12	617	38.40
FM	Pre	10	637	69.89	4	589	103.4	12	606	56.47
	Post	10	586	66.60	4	593	72.86	12	636	57.01
CL	Pre	10	595	42.80	4	564	32.06	12	590	32.66
	Post	10	564	29.64	4	612	35.02	12	586	35.44
CM	Pre	10	566	62.66	4	572	77.87	12	592	61.96
	Post	10	588	66.16	4	657	14.67	12	569	62.93
PL	Pre	10	574	35.37	4	578	27.04	12	595	43.77
	Post	10	587	29.15	4	588	51.02	12	571	46.51
PM	Pre	10	574	67.58	4	550	31.65	12	593	61.88
	Post	10	595	63.19	4	589	82.28	12	575	70.49
OL	Pre	10	585	26.42	4	592	32.97	12	594	34.13
	Post	10	582	45.72	4	619	54.89	12	587	35.94
OM	Pre	10	578	67.21	4	618	68.28	12	599	48.95
	Post	10	599	64.97	4	593	95.68	12	583	61.41
LTL	Pre	10	583	26.98	4	604	33.96	12	601	28.76
	Post	10	585	34.35	4	604	29.22	12	594	37.38
RTL	Pre	10	608	45.77	4	579	27.54	12	607	24.94
	Post	10	611	26.27	4	606	42.56	12	595	41.44
LTPJ	Pre	10	559	37.39	4	569	19.72	12	593	53.50
	Post	10	577	46.51	4	625	54.49	12	582	55.98
RTPJ	Pre	10	586	45.96	4	568	22.27	12	596	48.91
	Post	10	583	47.22	4	597	50.33	12	587	59.84

Analysis of assumptions

In the verbal fluency task, assumption testing was conducted for the amplitude and latency of the N4 and P6 components across various regions of interest (ROIs).

N4 component

For the mean amplitude of N4, normality assumptions were generally violated (W range = 0.69 - 0.97, all $p < .05$), except for OL.

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Homoscedasticity was observed in most cases (K-squared range = 0.02 - 21.35, all p > .05), except for CM and RTL. Parallelism was generally met (F range = 0.01 - 3.95, all p > .05), except for CL.

Similarly, for the peak amplitude of N4, normality assumptions were violated across ROIs (W range = 0.69 - 0.97, all p < .05), except for OL. Homoscedasticity was predominantly observed (K-squared range = 0.02 - 20.96, all p > .05), except for CM and RTL. Parallelism was generally met (F range = 0.01 - 3.95, all p > .05), except for CL.

Regarding the peak latency of N4, normality assumptions were frequently violated (W range = 0.89 - 0.99, all p < .05), except for FM, PL, and PM. Homoscedasticity was mostly observed (K-squared range = 0.05 - 5.42, all p > .05), except for CL and PM. Parallelism was generally met (F range = 0.11 - 3.95, all p > .05), except for CL.

P6 component

Moving to the P6 component, for the mean amplitude, normality assumptions were generally met (W range = 0.80 - 0.98, all p > .05). Homoscedasticity was observed in most cases (K-squared range = 0.03 - 17.60, all p > .05), except for CL and CM. Parallelism was generally met (F range = 0.01 - 2.27, all p > .05), except for CL.

Concerning the peak amplitude of P6, normality assumptions were violated across ROIs (W range = 0.73 - 0.98, all p < .05), except for OL. Homoscedasticity was predominantly observed (K-squared range = 0.01 - 19.90, all p > .05), except for CL and RTL. Parallelism was generally met (F range = 0.01 - 1.90, all p > .05), except for CL and RTL.

For the peak latency of P6, normality assumptions were generally met (W range = 0.93 - 0.98, all p > .05). Homoscedasticity was observed in most cases (K-squared range = 0.11 - 5.42, all p > .05), except for CL and OM. Parallelism was generally met (F range = 0.01 - 3.95, all p > .05), except for CL and OM.

In summary, while there were some violations of normality assumptions, homoscedasticity, and parallelism were generally observed across most

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ROIs and contrasts in the verbal fluency task, indicating that the assumptions for subsequent analyses were reasonably met.

Analysis of group comparisons

The study investigated the effects of group condition on various parameters of ERPs components during the verbal fluency task to measure language skills in older adults with MCI. The parameters analyzed included mean amplitude, peak amplitude, and peak latency of both N4 and P6 components across different brain regions. Although the one-way ANOCOVA indicated that peak latency of P6 in the central area was shown significant group effect *(F(*2, 22*)* = 3.59, *p* = .04), the pairwise comparison showed no significant difference among pairs of means (all p > .05). In summary, MCST and CST program do not show effect to change on language skills in terms of event-related potential when performing the verbal fluency task (see Table 65).

N4 component

In the verbal fluency task, the mean amplitude of the N4 ERP component did not show significant group effects across most regions, including the frontal lobe (FL), frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all p > .05). However, the RTPJ showed a trend towards significance with a small effect size *(F(*2, 36*)* = 2.82, *p* = .07, partial $\omega^2 = 0.08$), suggesting some potential group differences that did not reach statistical significance.

The peak amplitude of the N4 ERP component also showed no significant group effects across most regions. This includes the frontal lobe (FL), frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all p > .05). In addition, The RTPJ again showed a trend towards significance with a small effect size *(F(*2, 36*)* = 2.91, *p* = .07, partial $\omega^2 = 0.09$), indicating possible group differences that warrant further investigation.

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The peak latency of the N4 ERP component did not demonstrate significant group effects in any region, including the frontal lobe (FL), frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all $p > .05$).

P6 component

For the mean amplitude of the P6 ERP component, no significant group effects were observed across regions, including the frontal lobe (FL), frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all $p > .05$).

The peak amplitude of the P6 ERP component did not show significant group effects across regions. This includes the frontal lobe (FL), frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all $p > .05$).

The peak latency of the P6 ERP component indicated a significant group effect in central electrode locations (CL) with a moderate effect size *(F(*2, 22*)* = 3.59, $p = .04$, partial $\omega^2 = 0.17$). Post hoc comparisons revealed that the MCST group had a significantly different latency compared to the CST group *(t(22)* = -2.61, $p = .05$, Cohen's $d = -1.61$). Other regions, including the frontal lobe (FL), frontal midline (FM), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ), did not show significant group effects (all $p > .05$).

In summary, the ANCOVA results for the verbal fluency task showed limited significant group effects. The most notable finding was in the peak latency of the P6 component in central electrode locations (CL), where a significant difference was found between groups with a moderate effect size. The other ERP

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components and regions did not show significant group effects, indicating that the verbal fluency task did not elicit strong differential neural responses across the groups in these specific measures. Further research with larger sample sizes and more sensitive measures might be needed to uncover subtle differences in neural processing during verbal fluency tasks.

Table 65 ANCOVA of amplitude and latency of ERPs in the verbal fluency task

		df	*SS*	*MS*	*F*	*p*	ω_p^2
N4 – mean amplitude							
FL	Pre-test	1	293.41	293.41	0.22	.64	<.01
	Group	2	816.06	408.03	0.31	.74	<.01
	Residuals	36	47,360.81	1,315.58			
FM	Pre-test	1	9,929.76	9,929.76	13.11	<.01	0.23
	Group	2	1,805.52	902.76	1.19	.32	0.01
	Residuals	36	27,268.04	757.45			
CL	Pre-test	1	6.01	6.01	0.02	.89	<.01
	Group	2	1,100.88	550.44	1.83	.18	0.04
	Residuals	36	10,841.29	301.15			
CM	Pre-test	1	1,739.33	1,739.33	0.36	.55	<.01
	Group	2	18,053.19	9,026.59	1.86	.17	0.04
	Residuals	36	174,970.64	4,860.30			
PL	Pre-test	1	46.63	46.63	0.07	.80	<.01
	Group	2	802.75	401.37	0.57	.57	<.01
	Residuals	36	25,544.63	709.57			
PM	Pre-test	1	3,127.62	3,127.62	0.81	.38	<.01
	Group	2	10,750.84	5,375.42	1.39	.26	0.02
	Residuals	36	139,566.64	3,876.85			
OL	Pre-test	1	2,793.15	2,793.15	2.83	.10	0.04
	Group	2	495.81	247.90	0.25	.78	<.01
	Residuals	36	35,516.57	986.57			
OM	Pre-test	1	8,408.58	8,408.58	1.91	.18	0.02
	Group	2	1,414.78	707.39	0.16	.85	<.01
	Residuals	36	158,195.67	4,394.32			

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
LTL	Pre-test	1	15.77	15.77	0.08	.78	0.00
	Group	2	346.27	173.14	0.88	.42	<.01
	Residuals	36	7,097.02	197.14			
RTL	Pre-test	1	4.67	4.67	0.02	.89	<.01
	Group	2	340.85	170.43	0.65	.53	<.01
	Residuals	36	9,499.63	263.88			
LTPJ	Pre-test	1	1,067.32	1,067.32	1.59	.21	0.01
	Group	2	149.75	74.88	0.11	.89	<.01
	Residuals	36	24,105.11	669.59			
RTPJ	Pre-test	1	4.21	4.21	0.01	.93	<.01
	Group	2	3,481.95	1,740.97	2.82	.07	0.08
	Residuals	36	22,258.68	618.30			
N4 – peak amplitude							
FL	Pre-test	1	319.63	319.63	0.17	.69	<.01
	Group	2	3,343.54	1,671.77	0.87	.43	<.01
	Residuals	36	69,486.44	1,930.18			
FM	Pre-test	1	10,179.04	10,179.04	10.50	<.01	0.19
	Group	2	2,889.12	1,444.56	1.49	.24	0.02
	Residuals	36	34,902.75	969.52			
CL	Pre-test	1	0.08	0.08	0.00	.99	<.01
	Group	2	246.03	123.02	0.43	.65	<.01
	Residuals	36	10,239.54	284.43			
CM	Pre-test	1	409.27	409.27	0.09	.76	<.01
	Group	2	15,395.87	7,697.94	1.75	.19	0.04
	Residuals	36	158,782.63	4,410.63			
PL	Pre-test	1	137.86	137.86	0.14	.71	<.01
	Group	2	1,760.29	880.15	0.92	.41	<.01
	Residuals	36	34,425.23	956.26			
PM	Pre-test	1	913.96	913.96	0.18	.67	<.01
	Group	2	14,456.93	7,228.47	1.43	.25	0.02
	Residuals	36	182,076.90	5,057.69			
OL	Pre-test	1	1,178.75	1,178.75	0.86	.36	<.01
	Group	2	1,510.13	755.07	0.55	.58	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	36	49,177.56	1,366.04			
OM	Pre-test	1	13,308.37	13,308.37	2.94	.10	0.05
	Group	2	2,312.81	1,156.41	0.26	.78	<.01
	Residuals	36	163,063.85	4,529.55			
LTL	Pre-test	1	66.72	66.72	0.20	.66	<.01
	Group	2	325.11	162.55	0.48	.62	<.01
	Residuals	36	12,175.28	338.20			
RTL	Pre-test	1	254.92	254.92	1.08	.30	<.01
	Group	2	158.72	79.36	0.34	.72	<.01
	Residuals	36	8,469.20	235.26			
LTPJ	Pre-test	1	2,289.64	2,289.64	2.34	.13	0.03
	Group	2	508.53	254.26	0.26	.77	<.01
	Residuals	36	35,242.22	978.95			
RTPJ	Pre-test	1	262.92	262.92	0.52	.47	<.01
	Group	2	2,921.79	1,460.90	2.91	.07	0.09
	Residuals	36	18,095.22	502.65			
N4 – peak latency							
FL	Pre-test	1	1,817.30	1,817.30	1.20	.28	0.01
	Group	2	4,167.26	2,083.63	1.38	.26	0.02
	Residuals	36	54,315.54	1,508.77			
FM	Pre-test	1	13.72	13.72	0.00	.96	<.01
	Group	2	1,671.88	835.94	0.16	.86	<.01
	Residuals	36	193,488.73	5,374.69			
CL	Pre-test	1	445.40	445.40	0.29	.60	<.01
	Group	2	510.49	255.24	0.16	.85	<.01
	Residuals	36	56,131.96	1,559.22			
CM	Pre-test	1	862.49	862.49	0.20	.66	<.01
	Group	2	11,645.27	5,822.64	1.32	.28	0.02
	Residuals	36	158,321.74	4,397.83			
PL	Pre-test	1	292.06	292.06	0.21	.65	<.01
	Group	2	1,914.43	957.21	0.70	.50	<.01
	Residuals	36	48,944.21	1,359.56			
PM	Pre-test	1	38.16	38.16	0.01	.92	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	10,666.47	5,333.24	1.30	.29	0.01
	Residuals	36	147,721.51	4,103.38			
OL	Pre-test	1	1,155.71	1,155.71	0.77	.39	<.01
	Group	2	484.54	242.27	0.16	.85	<.01
	Residuals	36	54,211.56	1,505.88			
OM	Pre-test	1	14,837.42	14,837.42	3.83	.06	0.07
	Group	2	4,336.27	2,168.13	0.56	.58	<.01
	Residuals	36	139,416.15	3,872.67			
LTL	Pre-test	1	393.11	393.11	0.48	.49	<.01
	Group	2	2,013.86	1,006.93	1.22	.31	0.01
	Residuals	36	29,683.00	824.53			
RTL	Pre-test	1	190.48	190.48	0.20	.66	<.01
	Group	2	1,830.39	915.19	0.94	.40	<.01
	Residuals	36	35,027.47	972.99			
LTPJ	Pre-test	1	1,631.48	1,631.48	0.99	.33	<.01
	Group	2	1,976.56	988.28	0.60	.55	<.01
	Residuals	36	59,308.35	1,647.45			
RTPJ	Pre-test	1	6,146.76	6,146.76	2.52	.12	0.04
	Group	2	1,202.35	601.18	0.25	.78	<.01
	Residuals	36	87,802.47	2,438.96			
P6 – mean amplitude							
FL	Pre-test	1	2,141.34	2,141.34	1.40	.25	0.02
	Group	2	3,755.33	1,877.66	1.23	.31	0.02
	Residuals	22	33,626.16	1,528.46			
FM	Pre-test	1	155.92	155.92	0.18	.68	<.01
	Group	2	966.67	483.33	0.56	.58	<.01
	Residuals	22	19,002.79	863.76			
CL	Pre-test	1	5.72	5.72	0.02	.90	<.01
	Group	2	548.60	274.30	0.79	.47	<.01
	Residuals	22	7,677.21	348.96			
CM	Pre-test	1	1,267.44	1,267.44	0.18	.67	<.01
	Group	2	23,627.40	11,813.70	1.68	.21	0.05
	Residuals	22	154,280.83	7,012.77			

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
PL	Pre-test	1	120.79	120.79	0.46	.51	<.01
	Group	2	332.82	166.41	0.63	.54	<.01
	Residuals	22	5,816.93	264.41			
PM	Pre-test	1	29.22	29.22	0.02	.89	<.01
	Group	2	2,311.20	1,155.60	0.77	.47	<.01
	Residuals	22	32,888.19	1,494.92			
OL	Pre-test	1	230.75	230.75	0.19	.67	<.01
	Group	2	493.01	246.51	0.20	.82	<.01
	Residuals	22	26,678.22	1,212.65			
OM	Pre-test	1	8,369.27	8,369.27	1.63	.21	0.02
	Group	2	10,557.79	5,278.89	1.03	.37	<.01
	Residuals	22	112,634.61	5,119.76			
LTL	Pre-test	1	0.40	0.40	0.00	.96	0.00
	Group	2	828.04	414.02	2.41	.11	0.10
	Residuals	22	3,779.34	171.79			
RTL	Pre-test	1	0.61	0.61	0.00	.96	<.01
	Group	2	46.35	23.17	0.12	.89	<.01
	Residuals	22	4,398.94	199.95			
LTPJ	Pre-test	1	295.37	295.37	1.15	.30	0.01
	Group	2	518.40	259.20	1.01	.38	<.01
	Residuals	22	5,659.96	257.27			
RTPJ	Pre-test	1	1,639.70	1,639.70	3.11	.09	0.08
	Group	2	640.34	320.17	0.61	.55	<.01
	Residuals	22	11,585.94	526.63			
P6 – peak amplitude							
FL	Pre-test	1	9,378.86	9,378.86	4.37	.05	0.11
	Group	2	3,577.31	1,788.66	0.83	.45	<.01
	Residuals	22	47,231.10	2,146.87			
FM	Pre-test	1	303.05	303.05	0.32	.58	<.01
	Group	2	1,690.68	845.34	0.89	.43	<.01
	Residuals	22	20,993.42	954.25			
CL	Pre-test	1	33.38	33.38	0.10	.76	<.01
	Group	2	536.94	268.47	0.77	.47	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	22	7,637.34	347.15			
CM	Pre-test	1	339.09	339.09	0.05	.82	<.01
	Group	2	21,260.62	10,630.31	1.58	.23	0.04
	Residuals	22	147,639.27	6,710.88			
PL	Pre-test	1	19.57	19.57	0.08	.78	<.01
	Group	2	161.58	80.79	0.33	.72	<.01
	Residuals	22	5,313.91	241.54			
PM	Pre-test	1	225.22	225.22	0.14	.71	<.01
	Group	2	1,530.03	765.02	0.48	.62	<.01
	Residuals	22	34,840.80	1,583.67			
OL	Pre-test	1	315.47	315.47	0.24	.63	<.01
	Group	2	919.58	459.79	0.34	.71	<.01
	Residuals	22	29,521.83	1,341.90			
OM	Pre-test	1	7,919.49	7,919.49	1.46	.24	0.02
	Group	2	12,842.13	6,421.07	1.18	.33	0.01
	Residuals	22	119,492.60	5,431.48			
LTL	Pre-test	1	36.60	36.60	0.19	.66	<.01
	Group	2	530.33	265.16	1.40	.27	0.03
	Residuals	22	4,153.68	188.80			
RTL	Pre-test	1	17.03	17.03	0.09	.77	<.01
	Group	2	1.09	0.55	0.00	1	<.01
	Residuals	22	4,275.46	194.34			
LTPJ	Pre-test	1	139.50	139.50	0.69	.41	<.01
	Group	2	457.75	228.88	1.13	.34	0.01
	Residuals	22	4,443.33	201.97			
RTPJ	Pre-test	1	1,993.16	1,993.16	4.37	.05	0.11
	Group	2	133.37	66.68	0.15	.86	<.01
	Residuals	22	10,023.10	455.60			
P6 – peak latency							
FL	Pre-test	1	3,186.46	3,186.46	2.78	.11	0.06
	Group	2	1,383.64	691.82	0.60	.56	<.01
	Residuals	22	25,215.27	1,146.15			
FM	Pre-test	1	276.21	276.21	0.07	.8	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	16,249.32	8,124.66	1.98	.16	0.07
	Residuals	22	90,266.11	4,103.01			
CL	Pre-test	1	94.68	94.68	0.09	.77	<.01
	Group	2	7,936.72	3,968.36	3.59	.04	0.17
	Residuals	22	24,291.09	1,104.14			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	22	-53.59	20.54	-2.61	.05	-1.61
	MCST-Control	22	-22.84	14.26	-1.60	.37	-0.69
	CST-Control	22	30.76	19.83	1.55	.41	0.93
CM	Pre-test	1	29.04	29.04	0.01	.93	<.01
	Group	2	23,303.96	11,651.98	3.07	.07	0.14
	Residuals	22	83,502.41	3,795.56			
PL	Pre-test	1	19.43	19.43	0.01	.92	<.01
	Group	2	1,619.45	809.72	0.45	.64	<.01
	Residuals	22	39,216.64	1,782.57			
PM	Pre-test	1	10,256.86	10,256.86	2.22	.15	0.04
	Group	2	1,074.13	537.06	0.12	.89	<.01
	Residuals	22	101,783.66	4,626.53			
OL	Pre-test	1	1,838.84	1,838.84	1.01	.33	<.01
	Group	2	4,446.37	2,223.18	1.22	.31	0.02
	Residuals	22	39,927.95	1,814.91			
OM	Pre-test	1	6,378.06	6,378.06	1.39	.25	0.01
	Group	2	894.55	447.28	0.10	.91	<.01
	Residuals	22	101,051.01	4,593.23			
LTL	Pre-test	1	104.98	104.98	0.08	.78	<.01
	Group	2	1,483.10	741.55	0.58	.57	<.01
	Residuals	22	28,101.68	1,277.35			
RTL	Pre-test	1	1,453.38	1,453.38	1.10	.31	<.01
	Group	2	1,513.29	756.65	0.57	.57	<.01
	Residuals	22	29,045.23	1,320.24			
LTPJ	Pre-test	1	1,087.41	1,087.41	0.39	.54	<.01
	Group	2	7,581.80	3,790.90	1.36	.28	0.03
	Residuals	22	61,444.87	2,792.95			

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
RTPJ	Pre-test	1	11,685.02	11,685.02	4.63	.04	0.12
	Group	2	412.77	206.38	0.08	.92	<.01
	Residuals	22	55,495.45	2,522.52			

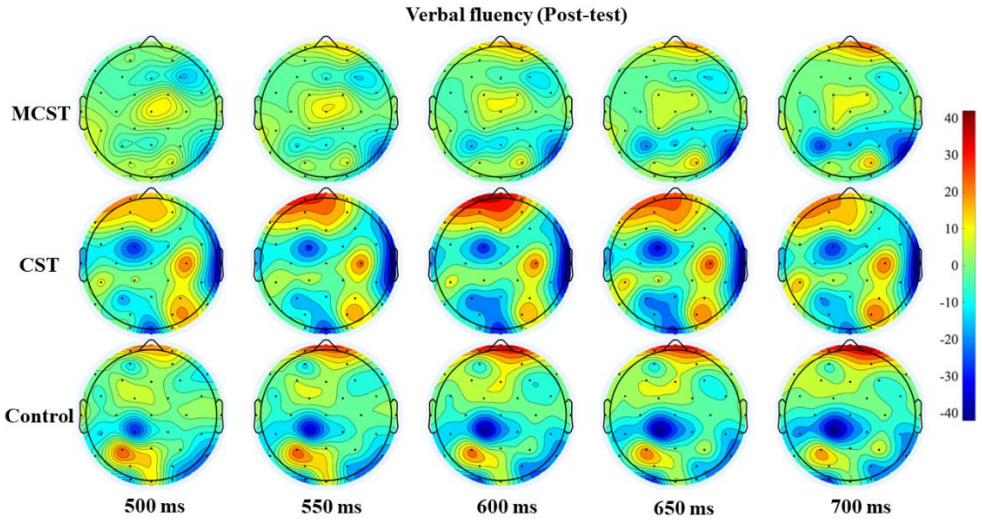

Figure 63 The topographic brain mapping of mean amplitude for each 50 ms latency window during the verbal fluency task at the post-test

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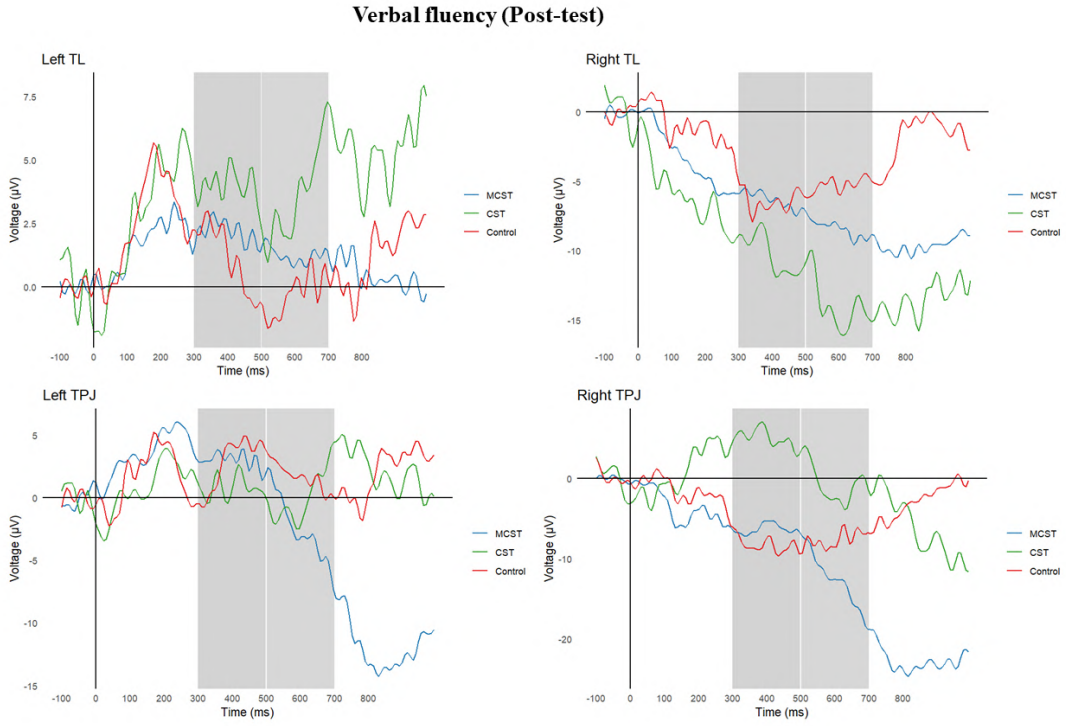

Figure 64 Grand-average N4 and P6 waveforms over the temporal and parietal area across three groups in the verbal fluency task

ERP - Corsi block-tapping task

Analysis of the amplitude and latency characteristics

P300 component - Mean amplitude

In the frontal region, the MCST group showed a substantial increase in mean amplitude post-test. The CST group experienced a decrease, while the control group showed a slight decrease.

In the central region, the MCST group showed an increase in mean amplitude post-test, whereas the CST group showed a slight increase. The control group remained relatively stable.

In the parietal region, the MCST group displayed a decrease in mean amplitude post-test. The CST group showed a slight increase, and the control group experienced a slight increase.

In the temporal region, the MCST group showed mixed changes: for example, the left temporal lobe (LTL) decreased from 3.83 to 0.75, while

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the right temporal lobe (RTL) increased from -2.13 to 0.31. The CST group showed slight increases, while the control group experienced slight increases or remained stable.

P300 component - Peak amplitude

In the frontal region, the MCST group showed a substantial increase in peak amplitude post-test. The CST group experienced a decrease, and the control group remained relatively stable.

In the central region, the MCST group showed a slight decrease in peak amplitude post-test, whereas the CST group showed a slight increase. The control group experienced a slight increase.

In the parietal region, the MCST group showed mixed changes with slight decreases in some areas. For instance, the parietal midline (PM) decreased from 1.99 to -14.31, while the parietal lobe (PL) decreased from 11.37 to 2.08. The CST group experienced a slight increase, and the control group remained relatively stable.

In the temporal region, the MCST group showed mixed changes: the left temporal lobe (LTL) decreased from 14.09 to 7.51, while the right temporal lobe (RTL) remained relatively stable. The CST group experienced slight decreases, while the control group showed slight increases or remained stable.

P300 component - Peak latency

In the frontal region, the MCST group showed a slight decrease in peak latency post-test. The CST group showed a slight decrease, and the control group exhibited a slight increase.

In the central region, the MCST group showed a slight decrease in peak latency post-test. The CST group showed a slight increase, while the control group remained relatively stable.

In the parietal region, the MCST group showed slight decreases in peak latency. The CST group experienced slight decreases, and the control group remained stable.

In the temporal region, the MCST group showed mixed changes: for example, the left temporal lobe (LTL) increased from 391 to 408, while

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the right temporal lobe (RTL) remained relatively stable. The CST group experienced slight decreases, while the control group showed slight increases or remained stable.

P3/LPC component - Mean amplitude

In the frontal region, the MCST group showed a substantial increase in mean amplitude post-test. The CST group experienced a decrease, while the control group showed a slight decrease.

In the central region, the MCST group showed an increase in mean amplitude post-test, whereas the CST group showed a slight increase. The control group remained relatively stable.

In the parietal region, the MCST group displayed a decrease in mean amplitude post-test. The CST group showed a slight increase, and the control group experienced a slight increase.

In the temporal region, the MCST group showed mixed changes: for example, the left temporal lobe (LTL) decreased from 3.37 to 1.65, while the right temporal lobe (RTL) increased from -2.67 to 1.79. The CST group showed slight increases, while the control group experienced slight increases or remained stable.

P3/LPC component - Peak amplitude

In the frontal region, the MCST group showed a substantial increase in peak amplitude post-test. The CST group experienced a decrease, and the control group remained relatively stable.

In the central region, the MCST group showed a slight decrease in peak amplitude post-test, whereas the CST group showed a slight increase. The control group experienced a slight increase.

In the parietal region, the MCST group showed mixed changes with slight decreases in some areas. For instance, the parietal midline (PM) decreased from -1.10 to -14.82, while the parietal lobe (PL) decreased from 20.73 to 0.59. The CST group experienced a slight increase, and the control group remained relatively stable.

In the temporal region, the MCST group showed mixed changes: the left temporal lobe (LTL) decreased from 12.70 to 7.95, while the right

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temporal lobe (RTL) remained relatively stable. The CST group experienced slight decreases, while the control group showed slight increases or remained stable.

P3/LPC component - Peak latency

In the frontal region, the MCST group showed a slight decrease in peak latency post-test. The CST group showed a slight decrease, and the control group exhibited a slight increase.

In the central region, the MCST group showed a slight decrease in peak latency post-test. The CST group showed a slight increase, while the control group remained relatively stable.

In the parietal region, the MCST group showed slight decreases in peak latency. The CST group experienced slight decreases, and the control group remained stable.

In the temporal region, the MCST group showed mixed changes: for example, the left temporal lobe (LTL) increased from 585 to 607, while the right temporal lobe (RTL) remained relatively stable. The CST group experienced slight decreases, while the control group showed slight increases or remained stable.

Table 66 Characteristic of amplitude and latency of ERPs in the Corsi block-tapping task

		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
P300 – mean amplitude										
FL	Pre	21	-12.56	39.29	22	-14.11	21.15	23	-1.85	31.54
	Post	21	-0.24	21.96	22	-17.12	31.52	23	-6.66	29.27
FM	Pre	21	-2.40	35.24	22	-9.76	57.08	23	-3.78	18.83
	Post	21	7.15	25.23	22	-11.27	43.60	23	1.56	20.80
CL	Pre	21	-5.97	17.81	22	1.24	12.89	23	5.12	16.85
	Post	21	0.69	14.54	22	0.67	9.08	23	0.37	11.14
CM	Pre	21	2.11	62.60	22	0.08	53.21	23	8.71	30.76
	Post	21	-15.84	35.42	22	6.44	37.02	23	7.46	30.05
PL	Pre	21	3.04	32.29	22	7.19	32.13	23	-2.47	26.63
	Post	21	-3.70	16.86	22	4.92	16.75	23	2.47	20.75

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
PM	Pre	21	-4.32	83.25	22	3.54	29.06	23	-10.72	78.53
	Post	21	-21.96	46.56	22	9.17	30.65	23	3.44	49.69
OL	Pre	21	13.46	53.41	22	2.96	22.39	23	-9.25	42.89
	Post	21	1.98	36.79	22	8.73	34.63	23	4.89	25.99
OM	Pre	21	28.94	67.67	22	-3.29	93.91	23	-8.75	56.69
	Post	21	0.07	111.2	22	7.52	52.57	23	9.63	83.48
LTL	Pre	21	3.83	13.15	22	2.99	18.07	23	1.17	11.09
	Post	21	0.75	9.86	22	0.48	6.58	23	-3.01	10.20
RTL	Pre	21	-2.13	23.93	22	-0.72	15.95	23	5.88	13.20
	Post	21	0.31	14.47	22	1.85	10.61	23	2.11	8.27
LTPJ	Pre	21	14.53	23.59	22	8.72	18.66	23	-0.28	22.78
	Post	21	2.66	20.53	22	0.98	14.63	23	-3.04	21.42
RTPJ	Pre	21	5.53	20.41	22	8.40	32.66	23	3.65	17.55
	Post	21	2.09	27.48	22	2.71	14.22	23	2.88	22.07
P300 – peak amplitude										
FL	Pre	21	-4.50	40.48	22	-4.22	21.31	23	7.23	36.03
	Post	21	7.66	26.08	22	-10.05	31.16	23	2.32	30.10
FM	Pre	21	2.53	33.50	22	0.39	53.12	23	0.22	18.95
	Post	21	20.25	38.29	22	-5.28	38.77	23	7.10	22.67
CL	Pre	21	3.35	17.54	22	10.41	16.50	23	11.27	17.71
	Post	21	6.86	16.61	22	6.23	10.09	23	6.91	11.09
CM	Pre	21	7.69	61.63	22	10.22	58.30	23	13.64	31.80
	Post	21	-9.52	37.90	22	11.31	38.63	23	14.53	32.34
PL	Pre	21	11.37	38.29	22	15.28	35.14	23	3.51	27.25
	Post	21	2.08	15.21	22	9.49	16.18	23	9.41	21.72
PM	Pre	21	1.99	82.78	22	11.60	24.01	23	-4.92	81.92
	Post	21	-14.31	45.41	22	12.91	34.13	23	9.09	52.50
OL	Pre	21	25.41	59.74	22	14.12	24.69	23	0.99	39.13
	Post	21	13.77	38.94	22	16.70	34.15	23	15.24	27.98
OM	Pre	21	43.32	72.74	22	11.69	94.39	23	5.42	56.80
	Post	21	14.91	104.33	22	15.42	50.72	23	19.38	91.94
LTL	Pre	21	14.09	15.85	22	11.12	22.73	23	7.27	11.17

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	21	7.51	10.57	22	6.30	7.04	23	3.77	9.59
RTL	Pre	21	7.17	21.83	22	8.42	15.77	23	12.71	14.45
	Post	21	6.98	16.65	22	8.57	11.93	23	9.12	7.90
LTPJ	Pre	21	24.80	31.43	22	16.27	20.11	23	5.72	21.49
	Post	21	9.51	20.54	22	5.94	15.27	23	4.54	22.44
RTPJ	Pre	21	15.79	18.26	22	16.52	36.40	23	10.42	18.22
	Post	21	7.65	28.81	22	8.69	15.13	23	10.03	22.78
P300 – peak latency										
FL	Pre	21	403	42.08	22	411	41.85	23	407	40.09
	Post	21	402	37.28	22	401	32.41	23	409	36.07
FM	Pre	21	403	69.03	22	403	56.94	23	404	66.48
	Post	21	422	62.09	22	407	53.80	23	410	60.13
CL	Pre	21	412	22.81	22	401	37.13	23	394	35.30
	Post	21	397	38.83	22	398	26.80	23	398	38.62
CM	Pre	21	409	74.54	22	408	65.89	23	384	76.09
	Post	21	401	76.07	22	410	59.39	23	417	69.03
PL	Pre	21	413	33.32	22	391	32.36	23	394	35.58
	Post	21	398	41.92	22	378	28.25	23	396	35.22
PM	Pre	21	410	66.48	22	390	59.06	23	394	62.28
	Post	21	400	69.14	22	365	53.46	23	398	70.83
OL	Pre	21	413	36.97	22	397	33.51	23	396	31.95
	Post	21	397	37.53	22	405	25.81	23	390	32.45
OM	Pre	21	405	70.07	22	386	75.31	23	382	70.86
	Post	21	400	67.69	22	384	58.78	23	374	60.34
LTL	Pre	21	391	31.36	22	396	30.91	23	391	34.19
	Post	21	408	33.00	22	401	24.17	23	393	38.91
RTL	Pre	21	398	38.23	22	399	30.88	23	400	35.94
	Post	21	396	34.65	22	394	33.87	23	399	35.86
LTPJ	Pre	21	399	46.02	22	393	48.71	23	397	42.62
	Post	21	400	36.30	22	392	30.04	23	383	51.73
RTPJ	Pre	21	408	48.49	22	391	44.07	23	408	36.74
	Post	21	391	38.31	22	394	50.83	23	389	43.08

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P3/LPC – mean amplitude										
FL	Pre	21	-9.68	41.24	22	-10.18	21.98	23	-0.30	29.14
	Post	21	0.51	20.96	22	-14.90	29.81	23	-4.38	29.78
FM	Pre	21	-2.31	40.40	22	-19.41	65.99	23	-3.81	26.03
	Post	21	9.52	35.21	22	-11.27	49.44	23	0.38	20.22
CL	Pre	21	-6.41	25.24	22	-2.60	16.87	23	6.56	21.64
	Post	21	2.90	16.61	22	1.67	11.48	23	-0.40	12.54
CM	Pre	21	1.76	86.20	22	-11.37	63.79	23	10.82	43.36
	Post	21	-7.18	38.79	22	10.46	40.68	23	7.94	34.10
PL	Pre	21	9.56	42.72	22	7.31	33.90	23	-2.48	27.98
	Post	21	-5.13	20.12	22	4.06	19.55	23	-1.04	25.79
PM	Pre	21	-9.65	71.28	22	7.17	18.78	23	-14.60	74.72
	Post	21	-23.53	64.64	22	7.41	27.43	23	-1.43	31.49
OL	Pre	21	5.70	50.64	22	2.08	28.12	23	-13.50	59.00
	Post	21	-2.42	55.06	22	7.68	38.57	23	4.35	36.82
OM	Pre	21	19.91	68.54	22	-17.51	117.4	23	-20.92	79.50
	Post	21	2.36	139.3	22	-2.69	69.50	23	10.47	102.6
LTL	Pre	21	3.37	11.50	22	3.45	15.22	23	0.88	16.54
	Post	21	1.65	14.28	22	0.76	8.45	23	-0.54	10.58
RTL	Pre	21	-2.67	31.77	22	-0.62	19.42	23	7.23	20.04
	Post	21	1.79	20.63	22	0.48	14.06	23	1.76	10.36
LTPJ	Pre	21	13.59	24.82	22	12.16	28.55	23	-1.05	25.72
	Post	21	2.05	23.52	22	-0.40	16.31	23	0.28	27.89
RTPJ	Pre	21	12.66	23.43	22	5.69	20.55	23	7.62	15.43
	Post	21	1.66	29.62	22	1.82	14.38	23	-3.04	26.47
P3/LPC – peak amplitude										
FL	Pre	21	0.34	40.92	22	2.88	25.38	23	9.22	31.99
	Post	21	8.76	22.96	22	-3.86	27.11	23	3.18	30.63
FM	Pre	21	4.08	39.81	22	-7.99	80.27	23	0.62	25.25
	Post	21	15.38	35.75	22	-4.38	46.37	23	5.52	20.92
CL	Pre	21	2.82	24.00	22	9.92	17.51	23	12.20	23.17
	Post	21	8.46	17.97	22	7.63	10.44	23	6.46	12.91
CM	Pre	21	8.42	85.08	22	10.11	60.27	23	17.86	44.55
	Post	21	0.75	40.15	22	16.62	43.02	23	15.01	33.92

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
PL	Pre	21	20.73	45.96	22	18.53	41.83	23	5.05	27.34
	Post	21	0.59	17.95	22	10.64	21.46	23	5.91	24.90
PM	Pre	21	-1.10	85.10	22	21.17	35.82	23	-5.71	73.92
	Post	21	-14.82	55.33	22	14.76	30.21	23	9.32	47.61
OL	Pre	21	22.08	52.93	22	13.55	27.48	23	-1.07	56.06
	Post	21	8.02	50.61	22	16.79	39.67	23	11.46	37.09
OM	Pre	21	37.27	74.65	22	-0.84	107.8	23	-7.82	74.78
	Post	21	11.83	127.5	22	7.42	82.16	23	14.95	100.3
LTL	Pre	21	12.70	14.87	22	12.78	19.76	23	7.73	18.41
	Post	21	7.95	15.49	22	7.97	8.61	23	5.63	12.31
RTL	Pre	21	7.44	29.55	22	8.69	18.86	23	14.51	22.00
	Post	21	8.27	22.39	22	8.53	13.85	23	7.91	13.54
LTPJ	Pre	21	24.28	31.33	22	23.08	35.89	23	6.21	25.73
	Post	21	7.50	22.98	22	5.26	18.09	23	6.53	30.29
RTPJ	Pre	21	23.64	25.04	22	15.33	26.31	23	14.85	14.42
	Post	21	7.51	27.99	22	9.12	15.98	23	2.84	24.43
P3/LPC – peak latency										
FL	Pre	21	619	34.21	22	622	34.17	23	609	47.02
	Post	21	596	47.49	22	599	43.97	23	610	36.59
FM	Pre	21	619	63.65	22	609	63.10	23	616	66.39
	Post	21	584	64.50	22	587	71.78	23	592	65.89
CL	Pre	21	594	38.16	22	599	33.83	23	604	30.50
	Post	21	599	26.46	22	600	34.84	23	586	34.90
CM	Pre	21	585	67.07	22	574	78.38	23	604	66.52
	Post	21	602	68.70	22	628	62.08	23	598	71.75
PL	Pre	21	585	26.32	22	608	31.93	23	595	42.07
	Post	21	614	33.68	22	588	37.15	23	589	31.24
PM	Pre	21	551	52.76	22	579	77.86	23	586	67.40
	Post	21	626	64.31	22	585	66.97	23	579	61.42
OL	Pre	21	577	37.47	22	589	38.28	23	607	40.07
	Post	21	591	38.48	22	599	41.92	23	584	34.59
OM	Pre	21	576	58.18	22	575	71.42	23	597	63.73

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		MCST			CST			Control	
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	21	588	72.79	22	588	71.26	23	600	73.64
LTL	Pre	21	585	36.59	22	608	29.23	23	603	32.54
	Post	21	607	33.35	22	584	33.72	23	603	41.41
RTL	Pre	21	606	36.59	22	599	37.67	23	594	41.02
	Post	21	605	40.44	22	583	43.41	23	583	30.08
LTPJ	Pre	21	577	43.12	22	615	50.76	23	587	35.42
	Post	21	605	45.75	22	577	44.87	23	593	48.18
RTPJ	Pre	21	588	42.77	22	603	35.81	23	597	45.54
	Post	21	608	38.90	22	585	43.89	23	577	38.19

Analysis of assumptions

In the Corsi block-tapping task, the assumption testing was conducted for the amplitude and latency of P300 and P3/LPC components across various regions of interest (ROIs).

P300 component

For the mean amplitude of P300, normality assumptions were violated across ROIs (W range = 0.68 - 0.98, all $p < .05$), except for PL. Homoscedasticity was generally observed (K-squared range = 0.02 - 12.86, all $p > .05$), except for LTL. Parallelism was mostly met (F range = 0.02 - 2.71, all $p > .05$), except for RTL.

Regarding the peak amplitude of P300, normality assumptions were frequently violated (W range = 0.77 - 0.97, all $p < .05$), except for PL. Homoscedasticity was predominantly observed (K-squared range = 0.07 - 10.84, all $p > .05$), except for RTL and OM. Parallelism was generally met (F range = 0.07 - 2.84, all $p > .05$), except for LTL, RTL, and LTPJ.

For the peak latency of P300, normality assumptions were generally met (W range = 0.91 - 0.99, all $p > .05$). Homoscedasticity was observed in most cases (K-squared range = 0.02 - 6.53, all $p > .05$), except for CM. Parallelism was generally met (F range = 0.01 - 3.86, all $p > .05$), except for CM.

P3/LPC component

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Moving to P3/LPC, the mean amplitude analysis showed violations of normality assumptions across ROIs (W range = 0.75 - 0.99, all $p < .05$), except for PL and LTL. Homoscedasticity was observed in most cases (K-squared range = 0.34 - 18.38, all $p > .05$), except for RTL. Parallelism was generally met (F range = 0.05 - 1.70, all $p > .05$), except for RTL.

Regarding the peak amplitude of P3/LPC, normality assumptions were frequently violated (W range = 0.77 - 0.97, all $p < .05$), except for PL. Homoscedasticity was predominantly observed (K-squared range = 0.16 - 12.25, all $p > .05$), except for RTL. Parallelism was generally met (F range = 0.15 - 1.95, all $p > .05$), except for RTL.

For the peak latency of P3/LPC, normality assumptions were generally met (W range = 0.91 - 0.99, all $p > .05$). Homoscedasticity was observed in most cases (K-squared range = 0.02 - 3.86, all $p > .05$), except for OM. Parallelism was generally met (F range = 0.01 - 3.86, all $p > .05$), except for CM.

Overall, while there were some violations of normality assumptions, homoscedasticity and parallelism were generally observed across most ROIs and contrasts in the Corsi block-tapping task, suggesting that the assumptions for subsequent analyses were reasonably met.

Analysis of group comparisons

The study investigated the effects of group condition on various parameters of ERPs components during the Corsi block-tapping task to measure visuospatial skills in older adults with MCI. The parameters analyzed included mean amplitude, peak amplitude, and peak latency of both P300 and P3/LPC components across different brain regions.

P300 component

In the Corsi block-tapping task, the mean amplitude of the P300 ERP component showed a significant group effect at the central midline (CM) and parietal midline (PM) with a small effect size (CM: $F(2, 62) = 3.28$, $p = .04$, partial $\omega^2 = 0.06$; PM: $F(2, 62) = 3.28$, $p = .04$, partial $\omega^2 = 0.06$). Post hoc comparisons indicated that for CM, the MCST group had a non-significantly lower mean amplitude compared to the control group ($t(62) = -2.32$, $p = .07$, Cohen's d = -

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0.70), while for PM, the MCST group also had a lower mean amplitude compared to The control group *(t(62)* = -2.11, *p* = .12, Cohen's *d* = -0.64).

Other regions, including the frontal lobe (FL), frontal midline (FM), central lobe (CL), parietal lobe (PL), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ), did not show significant group effects (all p > .05).

The peak amplitude of the P300 ERP component did not show significant group effects in most regions, including the frontal lobe (FL), frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all p > .05).

The peak latency of the P300 ERP component showed a significant group effect in the parietal lobe (PL) with a small effect size *(F(*2, 62*)* = 3.30, *p* = .04, partial $\omega^2 = 0.07$). Post hoc comparisons indicated that the MCST group had a non-significantly longer peak latency compared to the CST group with a medium effect size *(t(62)* = 2.21, *p* = .09, Cohen's *d* = 0.70) and the control group with a medium effect size *(t(62)* = 2.28, *p* = .08, Cohen's *d* = 0.69).

Other regions, including the frontal lobe (FL), frontal midline (FM), central lobe (CL), central midline (CM), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ), did not show significant group effects (all p > .05).

P3/LPC component

The results of the ANCOVA for the P3/LPC ERP component (Peak Latency) could not be interpreted due to violations of the regression slope homogeneity assumption. Therefore, a separate regression analysis for each group is presented in the following section for the affected ROI: CM. The following are the ANCOVA results for ROIs that met the assumption.

For the mean amplitude of the P3/LPC ERP component, no significant group effects were observed across regions, including the frontal lobe

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(FL), frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all $p > .05$).

The peak amplitude of the P3/LPC ERP component did not show significant group effects across regions. This includes the frontal lobe (FL), frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all $p > .05$).

The peak latency of the P3/LPC ERP component showed a significant group effect in the right temporal-parietal junction (RTPJ) with a moderate effect size ($F(2, 62) = 3.92$, $p = .02$, partial $\omega^2 = 0.08$). Post hoc comparisons indicated that the MCST group had a significantly longer peak latency compared to the control group with a large effect size ($t(62) = 2.70$, $p = .03$, Cohen's $d = 0.82$). Other regions, including the frontal lobe (FL), frontal midline (FM), central lobe (CL), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), and left temporal-parietal junction (LTPJ), did not show significant group effects (all $p > .05$).

In summary, the ANCOVA results for the Corsi block-tapping task revealed significant group effects in the mean amplitude and peak latency of the P300 component and the peak latency of the P3/LPC component in specific regions. The central midline (CM) and parietal midline (PM) regions showed significant group effects for the mean amplitude of the P300 component, while the parietal lobe (PL) and right temporal-parietal junction (RTPJ) regions showed significant group effects for the peak latency of the P300 and P3/LPC components, respectively. The effect sizes ranged from small to moderate, indicating some differences in neural processing across groups in these specific measures.

Table 67 ANCOVA of amplitude and latency of ERPs in the Corsi block-tapping task

	df	*SS*	*MS*	*F*	*p*	ω_p^2

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
P300 – mean amplitude							
FL	Pre-test	1	1,375.74	1,375.74	1.79	.19	0.01
	Group	2	3,389.00	1,694.50	2.20	.12	0.04
	Residuals	62	47,736.10	769.94			
FM	Pre-test	1	975.42	975.42	0.99	.32	<.01
	Group	2	4,210.51	2,105.25	2.15	.13	0.03
	Residuals	62	60,837.59	981.25			
CL	Pre-test	1	4.73	4.73	0.03	.85	<.01
	Group	2	3.12	1.56	0.01	.99	<.01
	Residuals	62	8,681.01	140.02			
CM	Pre-test	1	1,446.14	1,446.14	1.24	.27	<.01
	Group	2	7,633.41	3,816.70	3.28	.04	0.06
	Residuals	62	72,100.41	1,162.91			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	62	-22.07	10.41	-2.12	.11	-0.65
	MCST-Control	62	-23.96	10.31	-2.32	.07	-0.70
	CST-Control	62	-1.89	10.20	-0.19	1	-0.06
PL	Pre-test	1	6.66	6.66	0.02	.89	<.01
	Group	2	850.65	425.32	1.25	.29	0.01
	Residuals	62	21,038.75	339.33			
PM	Pre-test	1	9,933.10	9,933.10	5.71	.02	0.07
	Group	2	11,416.21	5,708.11	3.28	.04	0.06
	Residuals	62	107,818.75	1,739.01			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	62	-29.71	12.74	-2.33	.07	-0.71
	MCST-Control	62	-26.56	12.60	-2.11	.12	-0.64
	CST-Control	62	3.15	12.48	0.25	1	0.08
OL	Pre-test	1	438.36	438.36	0.41	.53	<.01
	Group	2	602.93	301.47	0.28	.76	<.01
	Residuals	62	66,571.36	1,073.73			
OM	Pre-test	1	23,621.51	23,621.51	3.36	.07	0.03
	Group	2	7.86	3.93	0.00	1	<.01
	Residuals	62	436,449.14	7,039.50			

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
LTL	Pre-test	1	106.43	106.43	1.32	.26	<.01
	Group	2	221.47	110.73	1.37	.26	0.01
	Residuals	62	5,011.91	80.84			
RTL	Pre-test	1	41.79	41.79	0.32	.57	<.01
	Group	2	30.99	15.49	0.12	.89	<.01
	Residuals	62	8,025.53	129.44			
LTPJ	Pre-test	1	328.14	328.14	0.89	.35	<.01
	Group	2	229.31	114.65	0.31	.73	<.01
	Residuals	62	22,840.60	368.40			
RTPJ	Pre-test	1	303.24	303.24	0.63	.43	<.01
	Group	2	10.38	5.19	0.01	.99	<.01
	Residuals	62	29,763.64	480.06			
P300 – peak amplitude							
FL	Pre-test	1	2,173.03	2,173.03	2.62	.11	0.02
	Group	2	3,854.78	1,927.39	2.32	.11	0.04
	Residuals	62	51,483.04	830.37			
FM	Pre-test	1	85.47	85.47	0.07	.79	<.01
	Group	2	7,041.35	3,520.68	3.03	.06	0.06
	Residuals	62	72,069.53	1,162.41			
CL	Pre-test	1	0.15	0.15	0.00	.98	<.01
	Group	2	6.17	3.08	0.02	.98	<.01
	Residuals	62	10,361.55	167.12			
CM	Pre-test	1	2,688.81	2,688.81	2.08	.15	0.02
	Group	2	7,746.91	3,873.46	3.00	.06	0.06
	Residuals	62	79,979.80	1,290.00			
PL	Pre-test	1	0.80	0.80	0.00	.96	<.01
	Group	2	775.82	387.91	1.17	.32	0.01
	Residuals	62	20,505.93	330.74			
PM	Pre-test	1	11,718.26	11,718.26	6.32	.01	0.07
	Group	2	8,977.86	4,488.93	2.42	.10	0.04
	Residuals	62	114,966.29	1,854.29			
OL	Pre-test	1	645.22	645.22	0.56	.46	<.01
	Group	2	182.90	91.45	0.08	.92	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	62	71,306.38	1,150.10			
OM	Pre-test	1	9,039.37	9,039.37	1.25	.27	<.01
	Group	2	218.81	109.41	0.02	.98	<.01
	Residuals	62	448,684.37	7,236.84			
LTL	Pre-test	1	93.67	93.67	1.13	.29	<.01
	Group	2	209.86	104.93	1.26	.29	0.01
	Residuals	62	5,157.24	83.18			
RTL	Pre-test	1	23.68	23.68	0.15	.70	<.01
	Group	2	46.59	23.29	0.15	.86	<.01
	Residuals	62	9,891.14	159.53			
LTPJ	Pre-test	1	106.26	106.26	0.27	.61	<.01
	Group	2	210.99	105.50	0.27	.77	<.01
	Residuals	62	24,386.21	393.33			
RTPJ	Pre-test	1	386.92	386.92	0.74	.39	<.01
	Group	2	97.71	48.86	0.09	.91	<.01
	Residuals	62	32,402.92	522.63			
P300 – peak latency							
FL	Pre-test	1	1,001.27	1,001.27	0.80	.37	<.01
	Group	2	780.90	390.45	0.31	.73	<.01
	Residuals	62	77,447.37	1,249.15			
FM	Pre-test	1	1,386.00	1,386.00	0.40	.53	<.01
	Group	2	2,796.40	1,398.20	0.40	.67	<.01
	Residuals	62	216,061.61	3,484.86			
CL	Pre-test	1	250.37	250.37	0.20	.66	<.01
	Group	2	38.62	19.31	0.02	.98	<.01
	Residuals	62	77,772.50	1,254.40			
CM	Pre-test	1	976.06	976.06	0.21	.65	<.01
	Group	2	2,204.90	1,102.45	0.23	.79	<.01
	Residuals	62	294,025.40	4,742.35			
PL	Pre-test	1	5,958.34	5,958.34	4.94	.03	0.06
	Group	2	3,979.11	1,989.55	1.65	.20	0.02
	Residuals	62	74,788.07	1,206.26			
PM	Pre-test	1	16,124.47	16,124.47	3.96	.05	0.04

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	13,879.51	6,939.75	1.70	.19	0.02
	Residuals	62	252,489.69	4,072.41			
OL	Pre-test	1	1,567.92	1,567.92	1.53	.22	0.01
	Group	2	2,350.10	1,175.05	1.14	.33	<.01
	Residuals	62	63,700.37	1,027.43			
OM	Pre-test	1	11,937.58	11,937.58	3.23	.08	0.03
	Group	2	10,446.46	5,223.23	1.41	.25	0.01
	Residuals	62	229,290.61	3,698.24			
LTL	Pre-test	1	41.27	41.27	0.04	.85	<.01
	Group	2	2,332.81	1,166.41	1.07	.35	<.01
	Residuals	62	67,319.74	1,085.80			
RTL	Pre-test	1	1,230.31	1,230.31	1.01	.32	<.01
	Group	2	216.44	108.22	0.09	.91	<.01
	Residuals	62	75,184.80	1,212.66			
LTPJ	Pre-test	1	2.55	2.55	0.00	.97	<.01
	Group	2	3,284.46	1,642.23	0.98	.38	<.01
	Residuals	62	104,174.95	1,680.24			
RTPJ	Pre-test	1	5,887.08	5,887.08	3.10	.08	0.03
	Group	2	1,076.38	538.19	0.28	.75	<.01
	Residuals	62	117,816.16	1,900.26			
P3/LPC – mean amplitude							
FL	Pre-test	1	123.27	123.27	0.16	.69	<.01
	Group	2	2,738.77	1,369.38	1.82	.17	0.02
	Residuals	62	46,777.64	754.48			
FM	Pre-test	1	3.41	3.41	0.00	.96	<.01
	Group	2	4,748.30	2,374.15	1.73	.19	0.02
	Residuals	62	85,053.07	1,371.82			
CL	Pre-test	1	24.54	24.54	0.13	.72	<.01
	Group	2	162.72	81.36	0.43	.65	<.01
	Residuals	62	11,682.62	188.43			
CM	Pre-test	1	643.32	643.32	0.44	.51	<.01
	Group	2	3,813.46	1,906.73	1.32	.28	0.01
	Residuals	62	89,859.44	1,449.35			

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
PL	Pre-test	1	528.22	528.22	1.08	.30	<.01
	Group	2	906.09	453.05	0.93	.40	<.01
	Residuals	62	30,240.57	487.75			
PM	Pre-test	1	5,906.53	5,906.53	3.14	.08	0.03
	Group	2	9,708.46	4,854.23	2.58	.08	0.05
	Residuals	62	116,453.59	1,878.28			
OL	Pre-test	1	2,873.36	2,873.36	1.50	.22	0.01
	Group	2	1,462.25	731.12	0.38	.68	<.01
	Residuals	62	118,503.22	1,911.34			
OM	Pre-test	1	80,069.77	80,069.77	7.77	<.01	0.09
	Group	2	4,223.01	2,111.50	0.20	.82	<.01
	Residuals	62	638,775.93	10,302.84			
LTL	Pre-test	1	27.24	27.24	0.21	.65	<.01
	Group	2	59.90	29.95	0.23	.79	<.01
	Residuals	62	8,005.83	129.13			
RTL	Pre-test	1	103.66	103.66	0.43	.51	<.01
	Group	2	21.94	10.97	0.05	.96	0.00
	Residuals	62	14,922.23	240.68			
LTPJ	Pre-test	1	64.45	64.45	0.12	.73	<.01
	Group	2	62.07	31.04	0.06	.94	<.01
	Residuals	62	33,712.61	543.75			
RTPJ	Pre-test	1	44.44	44.44	0.07	.79	<.01
	Group	2	336.36	168.18	0.28	.76	<.01
	Residuals	62	37,260.34	600.97			
P3/LPC – peak amplitude							
FL	Pre-test	1	601.87	601.87	0.81	.37	<.01
	Group	2	1,684.53	842.26	1.13	.33	<.01
	Residuals	62	46,059.88	742.90			
FM	Pre-test	1	18.65	18.65	0.01	.90	0.00
	Group	2	4,183.38	2,091.69	1.61	.21	0.02
	Residuals	62	80,331.62	1,295.67			
CL	Pre-test	1	3.38	3.38	0.02	.90	<.01
	Group	2	50.60	25.30	0.13	.88	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	62	12,410.39	200.17			
CM	Pre-test	1	609.49	609.49	0.39	.53	<.01
	Group	2	3,382.96	1,691.48	1.10	.34	<.01
	Residuals	62	95,676.36	1,543.17			
PL	Pre-test	1	341.06	341.06	0.72	.40	<.01
	Group	2	1,065.09	532.55	1.12	.33	<.01
	Residuals	62	29,439.07	474.82			
PM	Pre-test	1	8,709.34	8,709.34	4.39	.04	0.05
	Group	2	9,248.15	4,624.07	2.33	.11	0.04
	Residuals	62	122,935.83	1,982.84			
OL	Pre-test	1	1,529.15	1,529.15	0.84	.36	<.01
	Group	2	1,018.61	509.30	0.28	.76	<.01
	Residuals	62	112,824.96	1,819.76			
OM	Pre-test	1	93,894.14	93,894.14	9.87	<.01	0.12
	Group	2	5,395.68	2,697.84	0.28	.75	<.01
	Residuals	62	589,708.08	9,511.42			
LTL	Pre-test	1	57.80	57.80	0.37	.54	<.01
	Group	2	102.99	51.50	0.33	.72	<.01
	Residuals	62	9,612.28	155.04			
RTL	Pre-test	1	292.33	292.33	1.02	.32	<.01
	Group	2	17.72	8.86	0.03	.97	<.01
	Residuals	62	17,786.61	286.88			
LTPJ	Pre-test	1	113.92	113.92	0.19	.67	<.01
	Group	2	60.91	30.46	0.05	.95	<.01
	Residuals	62	37,491.45	604.70			
RTPJ	Pre-test	1	236.91	236.91	0.43	.51	<.01
	Group	2	449.47	224.73	0.41	.67	<.01
	Residuals	62	33,951.13	547.60			
P3/LPC – peak latency							
FL	Pre-test	1	891.71	891.71	0.48	.49	<.01
	Group	2	2,184.33	1,092.16	0.59	.56	<.01
	Residuals	62	114,607.44	1,848.51			
FM	Pre-test	1	12,083.32	12,083.32	2.73	.10	0.03

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	683.97	341.98	0.08	.93	<.01
	Residuals	62	274,824.70	4,432.66			
CL	Pre-test	1	1,145.52	1,145.52	1.10	.30	<.01
	Group	2	2,971.68	1,485.84	1.42	.25	0.01
	Residuals	62	64,797.24	1,045.12			
CM*	Pre-test	1	18,426.55	18,426.55	4.32	.04	0.05
	Group	2	17,014.63	8,507.32	1.99	.14	0.03
	Residuals	62	264,676.09	4,268.97			
PL	Pre-test	1	1,977.26	1,977.26	1.69	.20	0.01
	Group	2	7,734.64	3,867.32	3.30	.04	0.07
	Residuals	62	72,582.61	1,170.69			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST		23.92	10.84	2.21	.09	0.70
	MCST-Control		23.78	10.41	2.28	.08	0.69
	CST-Control		-0.14	10.34	-0.01	1	<.01
PM	Pre-test	1	4,208.92	4,208.92	1.01	.32	<.01
	Group	2	24,449.49	12,224.74	2.93	.06	0.06
	Residuals	62	259,050.19	4,178.23			
OL	Pre-test	1	739.79	739.79	0.50	.48	<.01
	Group	2	2,311.68	1,155.84	0.77	.47	<.01
	Residuals	62	92,499.77	1,491.93			
OM	Pre-test	1	4,722.82	4,722.82	0.89	.35	<.01
	Group	2	1,298.57	649.29	0.12	.88	<.01
	Residuals	62	328,064.35	5,291.36			
LTL	Pre-test	1	1,147.75	1,147.75	0.85	.36	<.01
	Group	2	6,028.34	3,014.17	2.24	.12	0.04
	Residuals	62	83,594.44	1,348.30			
RTL	Pre-test	1	0.78	0.78	0.00	.98	<.01
	Group	2	6,812.26	3,406.13	2.29	.11	0.04
	Residuals	62	92,112.24	1,485.68			
LTPJ	Pre-test	1	12,587.67	12,587.67	6.10	.02	0.07
	Group	2	3,340.70	1,670.35	0.81	.45	<.01
	Residuals	62	127,919.88	2,063.22			

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
RTPJ	Pre-test	1	835.66	835.66	0.51	.48	<.01
	Group	2	12,770.87	6,385.43	3.92	.02	0.08
	Residuals	62	101,039.44	1,629.67			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	62	25.40	12.46	2.04	.14	0.63
	MCST-Control	62	33.05	12.23	2.70	.03	0.82
	CST-Control	62	7.65	12.06	0.63	1	0.19

*A significant interaction effect

Analysis of regression

This analysis evaluates the predictive relationships for ERP peak latency in the P3/LPC component within the CM region across the three groups, including MCST, CST, and control (see Table 68 and Figure 65).

For the P3/LPC component's peak latency in the CM region, the MCST group demonstrates a significant and strong predictive relationship (β_1 = 0.75, p < .001, adjusted R^2 = .51), highlighting its effectiveness in modulating the P3b component during this task. In contrast, the CST group shows no significant predictive relationship (β_1 = 0.16, p = .37, adjusted R^2 = -.01), indicating limited or no intervention effects. Similarly, the control group fails to exhibit a significant relationship (β_1 = -0.01, p = .96, adjusted R^2 = -.05), suggesting no natural predictive capacity for peak latency in this region. These results underscore the effectiveness of the MCST intervention in influencing peak latency compared to the CST and control groups.

In summary, in the P3/LPC component of the CM region, the MCST group shows strong predictive power, with significant associations between pre-test performance and peak latency. In contrast, both the CST and control groups fail to exhibit significant predictive relationships, indicating limited or no intervention or natural effects on this ERP component for the Corsi block-tapping task. This highlights the effectiveness of the MCST intervention in influencing cognitive processes reflected in the P3b component.

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Table 68 Regression analysis of the Corsi block-tapping task

ROI	Model	Variable	*B*	*SE*	*t*	*p*
P3/LPC – Peak latency						
CM	MCST	Constant	161.72	94.07	1.72	.10
		Pre-test	0.75	0.16	4.71	<.01
	CST	Constant	536.11	100.47	5.34	<.01
		Pre-test	0.16	0.17	0.92	.37
	Control	Constant	605.27	142.98	4.23	<.01
		Pre-test	-0.01	0.24	-0.05	.96

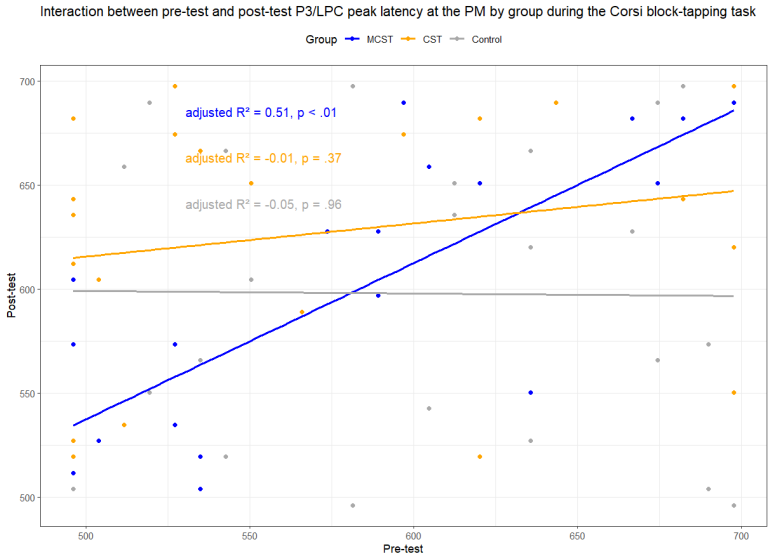

Figure 65 A scatter plot and the regression lines are shows interaction between pre-test and post-test P3/LPC peak latency at the central midline (CM) by group during the Corsi block-tapping task

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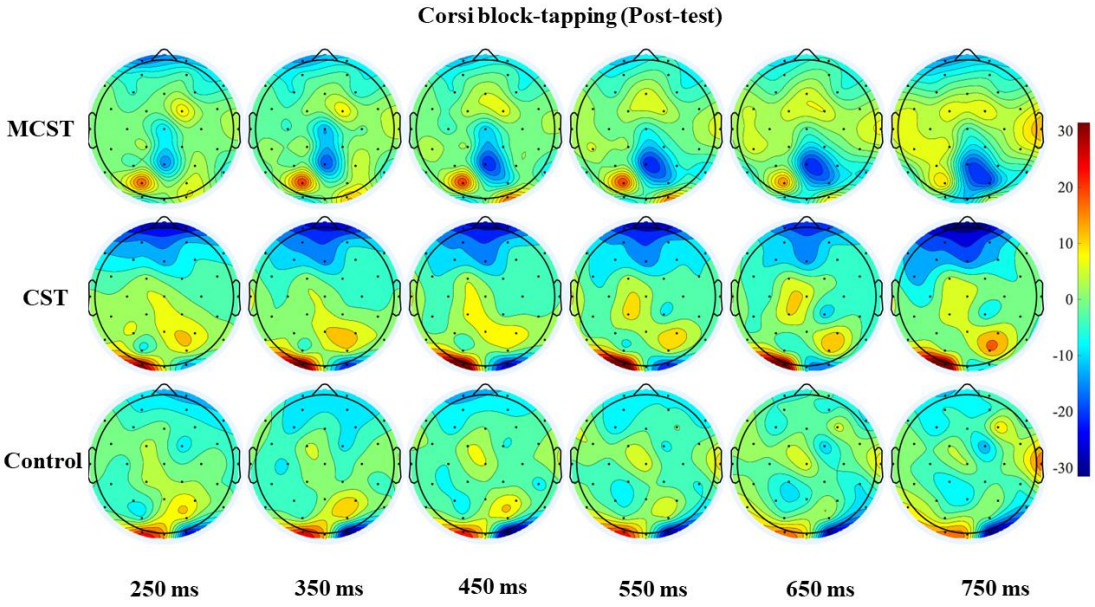

Figure 66 The topographic brain mapping of mean amplitude for each 100 ms latency window during the Corsi block-tapping task at post-test

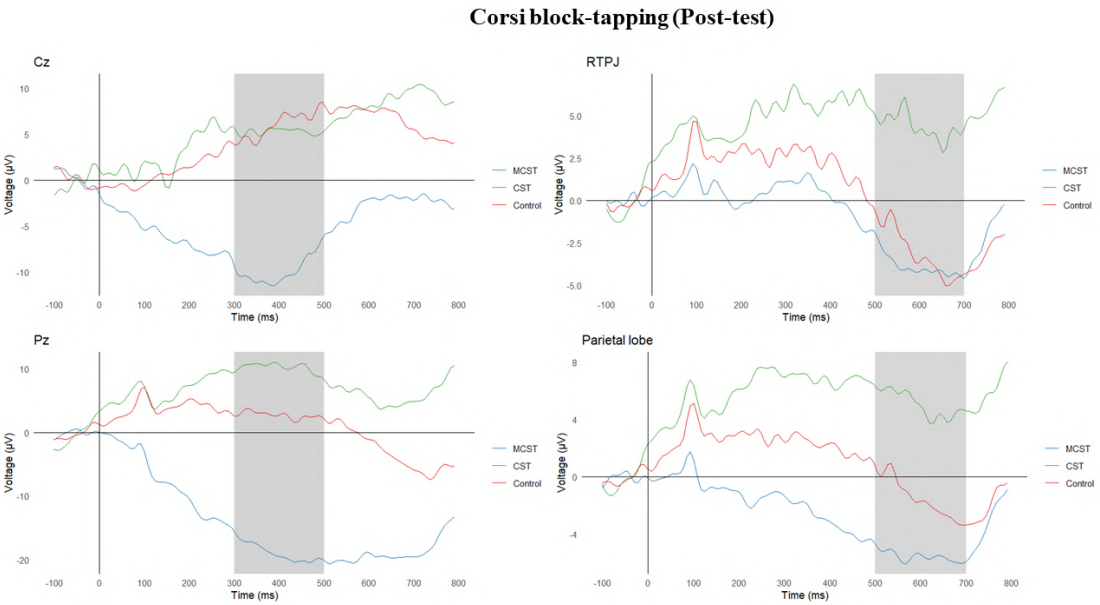

Figure 67 Grand-average ERP waveforms over the central and parietal midlines (Cz and Pz), and the right TPJ (RTPJ) across three groups in the Corsi block-tapping task

ERP - Mental rotation task

Analysis of the amplitude and latency characteristics

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N2 component - Mean amplitude

In the frontal region, the MCST group showed a reduction in mean amplitude post-test, with the CST group also showing a reduction. The control group showed a slight reduction.

In the central region, the MCST group displayed a reduction in mean amplitude post-test, while the CST group showed a slight reduction. The control group showed mixed changes, for example, the central midline (CM) reduced from 6.37 to -1.22 while central electrode locations (CL) slightly reduced from 1.14 to -0.33.

In the parietal region, the MCST group showed an increase in mean amplitude post-test. The CST group showed a slight reduction, and the control group showed a slight increase.

In the temporal region, the MCST group showed mixed changes, for instance, the left temporal lobe (LTL) reduced from 2.84 to -0.64, while the right temporal lobe (RTL) reduced from 1.37 to -1.73. The CST group showed a slight reduction, and the control group showed slight increases or remained stable.

N2 component - Peak amplitude

In the frontal region, the MCST group showed a slight increase in peak amplitude post-test, while the CST group showed an increase. The control group showed a slight reduction.

In the central region, the MCST group showed a slight reduction in peak amplitude post-test, while the CST group showed a reduction. The control group remained relatively stable.

In the parietal region, the MCST group showed a slight increase in peak amplitude post-test. The CST group showed a slight reduction, and the control group experienced a slight increase.

In the temporal region, the MCST group showed mixed changes: the left temporal lobe (LTL) reduced from 5.11 to 1.33, while the right temporal lobe (RTL) reduced from 3.66 to 0.52. The CST group showed a slight reduction, and the control group showed slight increases or remained stable.

N2 component - Peak latency

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In the frontal region, the MCST group showed a slight reduction in peak latency post-test. The CST group showed a slight increase, and the control group remained relatively stable.

In the central region, the MCST group showed a slight reduction in peak latency post-test, while the CST group showed a reduction. The control group showed mixed changes.

In the parietal region, the MCST group showed a slight reduction in peak latency post-test. The CST group showed a slight reduction, and the control group showed a slight increase.

In the temporal region, the MCST group showed mixed changes: the left temporal lobe (LTL) slightly reduced from 255 to 253, while the right temporal lobe (RTL) slightly reduced from 256 to 255. The CST group showed a slight reduction, and the control group showed slight increases or remained stable.

P6 component - Mean amplitude

In the frontal region, the MCST group showed a slight reduction in mean amplitude post-test, while the CST group showed a slight increase. The control group showed a slight reduction.

In the central region, the MCST group showed a slight reduction in mean amplitude post-test, while the CST group showed a reduction. The control group showed mixed changes, for example, the central midline (CM) slightly increased from 1.29 to 3.76, while central electrode locations (CL) reduced from 2.07 to 1.01.

In the parietal region, the MCST group showed a slight increase in mean amplitude post-test. The CST group showed a slight reduction, and the control group showed a slight increase.

In the temporal region, the MCST group showed mixed changes: the left temporal lobe (LTL) slightly increased from -0.14 to 0.38, while the right temporal lobe (RTL) slightly reduced from 1.16 to 0.58. The CST group showed a slight reduction, and the control group showed slight increases or remained stable.

P6 component - Peak amplitude

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In the frontal region, the MCST group showed a slight increase in peak amplitude post-test, while the CST group showed a slight increase. The control group showed a slight reduction.

In the central region, the MCST group showed a slight increase in peak amplitude post-test, while the CST group showed a slight reduction. The control group showed mixed changes.

In the parietal region, the MCST group showed a slight increase in peak amplitude post-test. The CST group showed a slight reduction, and the control group showed a slight increase.

In the temporal region, the MCST group showed mixed changes: the left temporal lobe (LTL) slightly increased from 2.92 to 3.07, while the right temporal lobe (RTL) slightly reduced from 4.34 to 3.43. The CST group showed a slight reduction, and the control group showed slight increases or remained stable.

P6 component - Peak latency

In the frontal region, the MCST group showed a slight increase in peak latency post-test, while the CST group showed a slight increase. The control group showed a slight increase.

In the central region, the MCST group showed a slight reduction in peak latency post-test, while the CST group showed a reduction. The control group showed mixed changes.

In the parietal region, the MCST group showed a slight reduction in peak latency post-test. The CST group showed a slight increase, and the control group showed a slight reduction.

In the temporal region, the MCST group showed mixed changes: the left temporal lobe (LTL) slightly increased from 645 to 650, while the right temporal lobe (RTL) increased from 651 to 665. The CST group showed a slight reduction, and the control group showed slight increases or remained stable.

Table 69 Characteristic of amplitude and latency of ERPs in the verbal paired associates learning task

	MCST	CST	Control

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	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
N2 – mean amplitude										
FL	Pre	28	-7.76	15.69	27	-5.54	10.60	23	-2.78	10.68
	Post	28	-3.47	12.20	27	-1.60	7.35	23	-3.81	7.53
FM	Pre	28	-0.68	20.82	27	-10.34	13.98	23	-0.79	5.62
	Post	28	-1.75	6.66	27	-0.38	4.76	23	-4.35	6.56
CL	Pre	28	1.14	9.05	27	0.83	11.31	23	-1.17	6.59
	Post	28	-0.33	3.44	27	-1.46	7.64	23	0.03	3.68
CM	Pre	28	6.37	36.04	27	7.39	44.58	23	0.09	13.79
	Post	28	-1.22	16.85	27	4.88	39.53	23	-1.10	13.50
PL	Pre	28	1.70	11.01	27	5.18	9.31	23	3.33	6.50
	Post	28	3.03	5.66	27	1.42	9.03	23	1.74	4.78
PM	Pre	28	4.80	16.59	27	3.93	16.99	23	3.72	14.54
	Post	28	4.16	10.53	27	3.15	23.02	23	0.15	10.08
OL	Pre	28	-0.13	17.89	27	-1.70	13.58	23	-0.50	7.80
	Post	28	3.61	7.46	27	4.89	16.31	23	1.46	9.63
OM	Pre	28	-5.63	55.91	27	3.60	30.53	23	-6.25	27.43
	Post	28	4.21	15.00	27	0.25	39.33	23	1.03	20.73
LTL	Pre	28	2.84	7.31	27	2.34	7.75	23	-0.17	6.13
	Post	28	-0.64	2.81	27	-1.02	9.17	23	-0.71	1.91
RTL	Pre	28	1.37	7.25	27	-1.30	8.17	23	1.11	4.02
	Post	28	-1.73	4.79	27	-1.69	6.13	23	1.20	3.27
LTPJ	Pre	28	4.85	15.02	27	3.94	11.17	23	1.71	5.34
	Post	28	1.64	4.83	27	-0.84	9.88	23	1.79	4.94
RTPJ	Pre	28	3.15	12.59	27	0.67	15.42	23	3.37	6.92
	Post	28	1.45	4.24	27	-0.66	8.48	23	3.28	8.10
N2 – peak amplitude										
FL	Pre	28	-5.18	15.57	27	-0.96	10.71	23	0.07	12.11
	Post	28	-1.09	12.11	27	1.68	6.39	23	-1.60	8.20
FM	Pre	28	1.00	20.82	27	-5.82	12.40	23	0.84	6.90
	Post	28	0.23	7.28	27	1.49	4.68	23	-3.25	6.70
CL	Pre	28	4.18	10.02	27	4.74	13.19	23	1.15	5.18
	Post	28	1.47	3.59	27	0.73	8.40	23	1.64	4.02
CM	Pre	28	10.78	37.68	27	12.52	50.11	23	2.32	14.71

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	28	1.05	15.64	27	7.61	42.34	23	0.88	14.80
PL	Pre	28	4.09	9.86	27	9.10	11.21	23	5.59	6.41
	Post	28	4.70	5.54	27	3.85	8.67	23	3.31	4.94
PM	Pre	28	7.13	17.32	27	7.05	16.55	23	5.60	14.92
	Post	28	5.68	10.13	27	5.89	25.28	23	1.72	9.83
OL	Pre	28	4.01	17.56	27	2.94	13.38	23	2.20	8.91
	Post	28	5.83	8.14	27	7.81	17.26	23	3.64	9.19
OM	Pre	28	-2.46	52.88	27	7.67	33.58	23	-4.42	26.38
	Post	28	6.56	15.86	27	1.91	37.14	23	3.65	19.54
LTL	Pre	28	5.11	8.72	27	6.08	7.85	23	2.22	4.21
	Post	28	1.33	2.73	27	1.43	8.61	23	1.18	2.45
RTL	Pre	28	3.66	7.75	27	2.46	7.58	23	3.52	5.62
	Post	28	0.52	4.18	27	0.63	5.73	23	2.93	4.13
LTPJ	Pre	28	6.49	14.94	27	7.94	12.40	23	3.91	4.99
	Post	28	3.50	4.77	27	1.39	8.56	23	3.46	5.38
RTPJ	Pre	28	5.98	12.26	27	4.42	15.45	23	5.24	7.48
	Post	28	3.03	4.30	27	1.33	8.24	23	4.69	8.69
N2 – peak latency										
FL	Pre	28	259	21.38	27	255	21.51	23	254	21.76
	Post	28	259	20.37	27	259	19.08	23	261	14.36
FM	Pre	28	254	35.23	27	248	34.77	23	253	36.17
	Post	28	248	35.49	27	254	29.39	23	260	31.69
CL	Pre	28	249	14.40	27	251	14.62	23	248	15.81
	Post	28	246	16.66	27	245	16.90	23	250	20.97
CM	Pre	28	245	41.36	27	250	34.02	23	244	33.04
	Post	28	242	32.55	27	235	30.49	23	243	38.52
PL	Pre	28	244	18.72	27	252	17.89	23	250	17.63
	Post	28	245	17.79	27	248	21.85	23	253	19.89
PM	Pre	28	250	35.45	27	254	33.97	23	248	32.34
	Post	28	251	27.99	27	249	33.36	23	241	35.59
OL	Pre	28	252	15.66	27	244	18.13	23	248	16.76
	Post	28	256	21.91	27	251	21.29	23	248	19.13

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
OM	Pre	28	257	37.35	27	258	35.80	23	250	34.11
	Post	28	260	34.57	27	244	36.26	23	241	34.78
LTL	Pre	28	255	19.74	27	259	13.35	23	255	19.80
	Post	28	253	20.97	27	258	17.88	23	254	14.83
RTL	Pre	28	256	15.59	27	250	17.14	23	255	16.15
	Post	28	255	21.73	27	250	15.31	23	254	20.42
LTPJ	Pre	28	251	20.77	27	258	22.54	23	257	21.74
	Post	28	252	26.79	27	255	24.36	23	257	18.32
RTPJ	Pre	28	249	22.32	27	244	24.43	23	249	19.00
	Post	28	256	19.52	27	244	24.06	23	251	25.03
P6 – mean amplitude										
FL	Pre	30	-7.59	20.74	27	-3.91	19.82	23	0.72	12.53
	Post	30	-6.80	22.34	27	0.92	15.51	23	-3.35	7.25
FM	Pre	30	4.12	20.49	27	-13.97	49.26	23	-1.29	7.41
	Post	30	1.14	8.24	27	2.05	11.01	23	-4.69	7.64
CL	Pre	30	2.07	13.09	27	6.19	19.99	23	0.37	7.48
	Post	30	1.01	6.39	27	-2.02	8.69	23	0.30	5.10
CM	Pre	30	1.29	47.35	27	12.44	86.57	23	7.10	34.17
	Post	30	3.76	17.20	27	3.52	43.65	23	-2.27	18.77
PL	Pre	30	1.00	12.53	27	6.41	17.96	23	1.53	7.48
	Post	30	3.65	7.81	27	0.93	15.81	23	1.38	8.07
PM	Pre	30	8.64	25.57	27	3.38	26.28	23	-1.58	19.83
	Post	30	6.14	13.65	27	-4.27	39.88	23	1.64	13.45
OL	Pre	30	3.30	21.14	27	-7.94	19.40	23	-2.40	11.62
	Post	30	0.98	10.23	27	6.66	16.87	23	1.98	9.25
OM	Pre	30	6.75	42.90	27	0.62	67.93	23	-8.89	55.18
	Post	30	1.08	18.74	27	10.70	51.69	23	7.29	22.14
LTL	Pre	30	-0.14	8.08	27	-0.11	15.27	23	-2.05	5.78
	Post	30	0.38	6.28	27	-7.31	13.56	23	-1.63	5.57
RTL	Pre	30	1.16	6.88	27	-0.52	10.72	23	1.88	7.18
	Post	30	0.58	6.13	27	1.91	10.85	23	1.38	6.78
LTPJ	Pre	30	4.46	13.78	27	5.20	20.26	23	-0.62	6.15

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	30	2.78	7.53	27	-1.89	13.23	23	1.55	7.10
RTPJ	Pre	30	2.36	12.88	27	-1.46	22.80	23	3.80	9.13
	Post	30	0.62	14.74	27	-0.97	13.90	23	3.28	8.93
P6 – peak amplitude										
FL	Pre	30	-4.36	20.76	27	2.56	18.22	23	5.27	15.56
	Post	30	-3.44	23.25	27	6.02	16.20	23	0.30	7.96
FM	Pre	30	7.01	22.50	27	-10.17	46.55	23	1.29	8.03
	Post	30	3.67	9.59	27	5.33	11.46	23	-2.69	7.19
CL	Pre	30	5.83	13.57	27	12.28	24.70	23	4.04	8.18
	Post	30	3.90	6.36	27	1.80	9.81	23	2.65	5.47
CM	Pre	30	6.97	46.46	27	21.95	95.23	23	10.30	36.35
	Post	30	7.70	19.84	27	8.98	47.82	23	0.28	20.10
PL	Pre	30	5.51	12.77	27	13.75	23.12	23	5.23	7.17
	Post	30	6.26	8.46	27	4.28	16.10	23	4.01	7.45
PM	Pre	30	12.76	27.90	27	8.17	27.00	23	3.02	17.29
	Post	30	8.71	15.85	27	-1.80	36.63	23	3.44	12.48
OL	Pre	30	9.26	21.59	27	-0.43	18.99	23	2.65	14.46
	Post	30	3.87	10.85	27	12.92	26.24	23	5.04	10.36
OM	Pre	30	11.80	51.33	27	11.08	75.80	23	-5.38	59.65
	Post	30	5.10	20.12	27	18.05	63.30	23	10.91	26.53
LTL	Pre	30	2.92	7.31	27	5.59	14.22	23	1.82	5.29
	Post	30	3.07	9.08	27	-3.02	10.58	23	1.12	6.00
RTL	Pre	30	4.34	7.89	27	5.14	10.71	23	5.51	6.89
	Post	30	3.43	4.58	27	6.12	9.39	23	4.31	6.31
LTPJ	Pre	30	7.96	14.94	27	10.38	22.48	23	2.88	5.96
	Post	30	5.49	9.18	27	1.79	12.16	23	3.61	6.89
RTPJ	Pre	30	6.26	13.56	27	5.15	22.16	23	7.19	9.38
	Post	30	3.24	13.33	27	2.99	13.35	23	6.59	9.23
P6 – peak latency										
FL	Pre	30	647	34.34	27	647	37.66	23	643	39.51
	Post	30	654	41.97	27	667	39.61	23	666	43.65
FM	Pre	30	644	68.76	27	650	66.89	23	641	63.93

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		MCST			CST			Control	
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	30	637	71.85	27	660	63.96	23	624	61.52
CL	Pre	30	640	37.62	27	654	30.59	23	644	33.54
	Post	30	644	36.04	27	651	35.80	23	644	39.24
CM	Pre	30	636	72.96	27	638	69.10	23	648	59.20
	Post	30	641	68.23	27	629	66.23	23	630	71.89
PL	Pre	30	639	27.03	27	655	26.93	23	640	36.00
	Post	30	633	32.40	27	646	38.15	23	647	37.67
PM	Pre	30	624	61.44	27	666	62.61	23	636	71.08
	Post	30	642	72.89	27	646	59.38	23	668	60.96
OL	Pre	30	651	31.57	27	650	28.41	23	649	37.41
	Post	30	649	30.83	27	654	38.51	23	653	41.19
OM	Pre	30	659	66.06	27	668	68.10	23	640	66.06
	Post	30	639	67.08	27	640	61.62	23	666	60.47
LTL	Pre	30	645	44.22	27	658	39.04	23	644	43.92
	Post	30	650	37.76	27	656	41.57	23	654	41.63
RTL	Pre	30	651	41.63	27	648	29.98	23	651	32.55
	Post	30	665	38.04	27	645	41.63	23	631	40.52
LTPJ	Pre	30	648	51.93	27	651	39.68	23	646	51.32
	Post	30	635	44.76	27	649	51.43	23	649	46.16
RTPJ	Pre	30	641	45.73	27	637	40.69	23	639	38.72
	Post	30	649	46.58	27	633	45.08	23	641	47.82

Analysis of assumptions

In the assumption testing conducted for the amplitude and latency of ERPs in the mental rotation task, distinct patterns emerged across the parameters of interest, namely N2 and P6 components.

N2 component

For the mean amplitude of N2, violations of normality were observed across most regions (W range = 0.70 - 0.94, all $p < .05$), except for PM. Homoscedasticity was generally met (K-squared range = 3.33 - 61.72, all $p >$

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.05), except for FM, CL, CM, and OL. Parallelism was mostly observed (F range = 0.08 - 5.71, all p > .05), except for CM and OM.

In terms of the peak amplitude of N2, normality assumptions were frequently violated (W range = 0.76 - 0.96, all p < .05), except for PL and RTL. Homoscedasticity was generally observed (K-squared range = 3.64 - 48.90, all p > .05), except for RTL. Parallelism was generally met (F range = 0.01 - 8.22, all p > .05), except for CM.

Regarding the peak latency of N2, normality assumptions were generally met (W range = 0.91 - 0.99, all p > .05). Homoscedasticity was observed across most regions (K-squared range = 0.07 - 3.20, all p > .05), except for PM. Parallelism was generally met (F range = 0.01 - 4.64, all p > .05), except for CM and PL.

P6 component

Moving to the P6 component, for the mean amplitude, normality assumptions were violated across ROIs (W range = 0.71 - 0.91, all p < .05), except for PL. Homoscedasticity was observed in most cases (K-squared range = 3.82 - 41.43, all p > .05), except for RTL. Parallelism was generally met (F range = 0.03 - 12.45, all p > .05), except for RTPJ.

For the peak amplitude of P6, normality assumptions were frequently violated (W range = 0.75 - 0.93, all p < .05), except for PL. Homoscedasticity was predominantly observed (K-squared range = 4.80 - 38.34, all p > .05), except for RTL. Parallelism was generally met (F range = 0.01 - 8.18, all p > .05), except for CM and RTPJ.

Regarding the peak latency of P6, normality assumptions were generally met (W range = 0.91 - 0.99, all p > .05). Homoscedasticity was observed in most cases (K-squared range = 0.07 - 5.55, all p > .05), except for CM and PL. Parallelism was generally met (F range = 0.01 - 5.55, all p > .05), except for CM and PL.

Overall, while there were some violations of normality assumptions, homoscedasticity and parallelism were generally observed across most ROIs and contrasts in the mental rotation task, suggesting that the assumptions for subsequent analyses were reasonably met.

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Analysis of group comparisons

The study investigated the effects of group condition on various parameters of ERPs components during the mental rotation task to measure visuospatial skills in older adults with MCI. The parameters analyzed included mean amplitude, peak amplitude, and peak latency of both N2 and P6 components across different brain regions.

N2 component

The results of the ANCOVA for the N2 ERP component could not be interpreted due to violations of the regression slope homogeneity assumption. Therefore, separate regression analyses for each group are presented in the following section for the affected ROIs: mean amplitude (CM, OL), peak amplitude (CM, OL), and peak latency (PM). The following are the ANCOVA results for ROIs that met the assumption.

The analysis did not show significant group effects on the mean amplitude of the N2 component across different brain regions. For instance, the frontal lobe (FL) *(F(*2, 74*)* = 0.72, *p* = .49, partial $\omega^2 < .01$), central lobe (CL) *(F(*2, 74*)* = 0.73, *p* = .49, partial $\omega^2 < .01$), all demonstrated small effect sizes.

The peak amplitude of the N2 component showed a significant group effect at the frontal midline (FM) *(F(*2, 74*)* = 3.74, *p* = .03, partial $\omega^2 = 0.07$), indicating a moderate effect size. Post-hoc comparisons revealed that the CST group significantly differed from the control group with a medium effect size *(t(74)* = 2.67, *p* = .03, Cohen's *d* = 0.77). No significant group effects were found in other regions, such as the frontal lobe (FL) *(F(*2, 74*)* = 1.04, *p* = .36, partial $\omega^2 < .01$) and central lobe (CL) *(F(*2, 74*)* = 0.59, *p* = .56, partial $\omega^2 < .01$).

The analysis did not show significant group effects on the peak latency of the N2 component across different brain regions. For instance, the frontal lobe (FL) *(F(*2, 74*)* = 0.22, *p* = .81, partial $\omega^2 < .01$), central lobe (CL) *(F(*2, 74*)* = 0.44, *p* = .64, partial $\omega^2 < .01$), and parietal lobe (PL) *(F(*2, 74*)* = 0.78, *p* = .46, partial $\omega^2 < .01$) all had minimal effect sizes.

P6 component

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The results of the ANCOVA for the P6 ERP component could not be interpreted due to violations of the regression slope homogeneity assumption. Therefore, separate regression analyses for each group are presented in the following section for the affected ROIs: mean amplitude (CM, FL, RTPJ), peak amplitude (CM, FL, RTPJ), and peak latency (CM, PL). The following are the ANCOVA results for ROIs that met the assumption.

The analysis of the mean amplitude of the P6 component revealed a significant group effect at the frontal midline (FM) *(F(*2, 76*)* = 3.77, *p* = .03, partial $\omega^2 = 0.06$), indicating a moderate effect size. Post-hoc comparisons showed that the CST group significantly differed from the control group with a moderate effect size *(t(76)* = 2.48, *p* = .05, Cohen's *d* = 0.71). A significant group effect was also observed at the left temporal lobe (LTL) *(F(*2, 76*)* = 5.16, *p* < .01, partial $\omega^2 = 0.09$), indicating a moderate effect size. Post-hoc comparisons indicated that the MCST group significantly differed from the CST group with a large effect size *(t(76)* = 3.12, *p* < .01, Cohen's *d* = 0.83).

The peak amplitude of the P6 component showed a significant group effect at the frontal midline (FM) *(F(*2, 76*)* = 4.47, *p* = .01, partial $\omega^2 = 0.08$), indicating a moderate effect size. Post-hoc analysis revealed that the CST group significantly differed from the control group with a large effect size *(t(76)* = 2.79, *p* = .02, Cohen's *d* = 0.80). Additionally, the MCST group significantly differed from the CST group with a moderate effect size *(t(76)* = 2.57, *p* = .04, Cohen's *d* = 0.69). At the left temporal lobe (LTL), a significant group effect was also observed *(F(*2, 76*)* = 3.37, *p* = .04, partial $\omega^2 = 0.06$). Post-hoc comparisons indicated that the MCST group significantly differed from the CST group with a moderate effect size *(t(76)* = 2.57, *p* = .04, Cohen's *d* = 0.69).

The peak latency of the P6 component showed a significant group effect at the right temporal lobe (RTL) *(F(*2, 76*)* = 4.80, *p* = .01, partial $\omega^2 = 0.09$), indicating a moderate effect size. Post-hoc analysis indicated that the MCST group significantly differed from the control group with a large effect size *(t(76)* = 3.06, *p* < .01, Cohen's *d* = 0.85). The comparison between MCST and CST was not significant *(t(76)* = 1.85, *p* = .20, Cohen's *d* = 0.49).

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The analysis of ERP components during the mental rotation task indicated minimal significant group effects overall. Notable findings include significant group effects for the P6 mean amplitude at the frontal midline and left temporal lobe, as well as the P6 peak amplitude at the frontal midline and left temporal lobe. These regions showed moderate to large effect sizes, with significant differences observed in the post-hoc comparisons. The N2 component showed significant group effects only at the frontal midline in peak amplitude, with other regions showing non-significant differences. These results suggest that group differences in ERP responses are primarily observed in specific brain regions during the mental rotation task.

Table 70 ANCOVA of amplitude and latency of ERPs in the mental rotation task

		df	*SS*	*MS*	*F*	*p*	ω_p^2
N2 – mean amplitude							
FL	Pre-test	1	939.73	939.73	12.22	<.01	0.13
	Group	2	111.02	55.51	0.72	.49	<.01
	Residuals	74	5,692.32	76.92			
FM	Pre-test	1	0.02	0.02	0.00	.98	<.01
	Group	2	209.03	104.51	2.84	.06	0.05
	Residuals	74	2,723.48	36.80			
CL	Pre-test	1	110.12	110.12	4.04	.05	0.04
	Group	2	39.68	19.84	0.73	.49	<.01
	Residuals	74	2,016.05	27.24			
CM*	Pre-test	1	14,237.39	14,237.39	27.54	<.01	0.25
	Group	2	446.71	223.36	0.43	.65	<.01
	Residuals	74	38,252.76	516.93			
PL	Pre-test	1	12.36	12.36	0.26	.61	<.01
	Group	2	47.77	23.89	0.51	.60	<.01
	Residuals	74	3,469.11	46.88			
PM	Pre-test	1	123.21	123.21	0.48	.49	<.01
	Group	2	207.13	103.57	0.41	.67	<.01
	Residuals	74	18,886.18	255.22			
OL*	Pre-test	1	3.08	3.08	0.02	.88	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	149.12	74.56	0.53	.59	<.01
	Residuals	74	10,456.71	141.31			
OM	Pre-test	1	660.56	660.56	0.89	.35	<.01
	Group	2	308.26	154.13	0.21	.81	<.01
	Residuals	74	55,008.75	743.36			
LTL	Pre-test	1	12.95	12.95	0.39	.53	<.01
	Group	2	2.89	1.45	0.04	.96	<.01
	Residuals	74	2,465.23	33.31			
RTL	Pre-test	1	46.57	46.57	1.92	.17	0.01
	Group	2	128.13	64.06	2.64	.08	0.04
	Residuals	74	1,795.13	24.26			
LTPJ	Pre-test	1	85.33	85.33	1.75	.19	0.01
	Group	2	121.60	60.80	1.25	.29	0.01
	Residuals	74	3,611.58	48.81			
RTPJ	Pre-test	1	0.34	0.34	0.01	.94	<.01
	Group	2	194.24	97.12	1.89	.16	0.02
	Residuals	74	3,796.69	51.31			
N2 – peak amplitude							
FL	Pre-test	1	932.97	932.97	12.39	<.01	0.13
	Group	2	156.93	78.46	1.04	.36	<.01
	Residuals	74	5,574.43	75.33			
FM	Pre-test	1	0.02	0.02	0.00	.98	<.01
	Group	2	301.65	150.83	3.74	.03	0.07
	Residuals	74	2,980.41	40.28			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	74	-1.40	1.74	-0.80	1	-0.22
	MCST-Control	74	3.48	1.79	1.95	.16	0.55
	CST-Control	74	4.88	1.83	2.67	.03	0.77
CL	Pre-test	1	340.40	340.40	11.58	<.01	0.12
	Group	2	34.87	17.44	0.59	.56	<.01
	Residuals	74	2,174.92	29.39			
CM*	Pre-test	1	21,391.24	21,391.24	42.83	<.01	0.35
	Group	2	468.62	234.31	0.47	.63	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	74	36,960.17	499.46			
PL	Pre-test	1	54.12	54.12	1.23	.27	<.01
	Group	2	36.48	18.24	0.41	.66	<.01
	Residuals	74	3,257.25	44.02			
PM	Pre-test	1	253.48	253.48	0.88	.35	<.01
	Group	2	248.26	124.13	0.43	.65	<.01
	Residuals	74	21,284.16	287.62			
OL*	Pre-test	1	3.31	3.31	0.02	.88	<.01
	Group	2	214.34	107.17	0.70	.50	<.01
	Residuals	74	11,391.83	153.94			
OM	Pre-test	1	667.54	667.54	0.98	.32	<.01
	Group	2	404.34	202.17	0.30	.74	<.01
	Residuals	74	50,296.90	679.69			
LTL	Pre-test	1	16.52	16.52	0.54	.46	<.01
	Group	2	0.02	0.01	0.00	1	<.01
	Residuals	74	2,244.78	30.33			
RTL	Pre-test	1	0.29	0.29	0.01	.91	<.01
	Group	2	89.79	44.90	1.95	.15	0.02
	Residuals	74	1,700.11	22.97			
LTPJ	Pre-test	1	38.93	38.93	0.93	.34	<.01
	Group	2	90.87	45.43	1.08	.34	<.01
	Residuals	74	3,102.63	41.93			
RTPJ	Pre-test	1	23.77	23.77	0.45	.50	<.01
	Group	2	144.20	72.10	1.37	.26	0.01
	Residuals	74	3,900.06	52.70			
N2 – peak latency							
FL	Pre-test	1	1,928.20	1,928.20	6.15	.02	0.06
	Group	2	136.37	68.18	0.22	.81	0.00
	Residuals	74	23,208.24	313.62			
FM	Pre-test	1	68.08	68.08	0.06	.80	<.01
	Group	2	1,657.51	828.75	0.78	.46	<.01
	Residuals	74	78,498.47	1,060.79			
CL	Pre-test	1	159.40	159.40	0.48	.49	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	292.65	146.33	0.44	.64	<.01
	Residuals	74	24,407.30	329.83			
CM	Pre-test	1	357.11	357.11	0.31	.58	<.01
	Group	2	782.61	391.31	0.34	.71	<.01
	Residuals	74	85,142.22	1,150.57			
PL	Pre-test	1	2,353.38	2,353.38	6.32	.01	0.06
	Group	2	578.44	289.22	0.78	.46	<.01
	Residuals	74	27,543.18	372.21			
PM*	Pre-test	1	1,836.46	1,836.46	1.78	.19	0.01
	Group	2	1,204.75	602.38	0.58	.56	<.01
	Residuals	74	76,232.91	1,030.17			
OL	Pre-test	1	783.91	783.91	1.80	.18	0.01
	Group	2	716.51	358.25	0.82	.44	<.01
	Residuals	74	32,153.42	434.51			
OM	Pre-test	1	5,204.80	5,204.80	4.36	.04	0.04
	Group	2	4,900.54	2,450.27	2.05	.14	0.03
	Residuals	74	88,350.16	1,193.92			
LTL	Pre-test	1	3,577.48	3,577.48	12.24	<.01	0.13
	Group	2	115.07	57.53	0.20	.82	<.01
	Residuals	74	21,621.82	292.19			
RTL	Pre-test	1	1,465.03	1,465.03	4.05	.05	0.04
	Group	2	235.17	117.59	0.33	.72	<.01
	Residuals	74	26,769.59	361.75			
LTPJ	Pre-test	1	2,732.24	2,732.24	5.10	.03	0.05
	Group	2	182.47	91.23	0.17	.84	<.01
	Residuals	74	39,640.15	535.68			
RTPJ	Pre-test	1	3,452.13	3,452.13	7.06	<.01	0.07
	Group	2	1,489.99	744.99	1.52	.22	0.01
	Residuals	74	36,188.29	489.03			
P6 – mean amplitude							
FL*	Pre-test	1	6,844.72	6,844.72	34.21	<.01	0.29
	Group	2	689.70	344.85	1.72	.19	0.02
	Residuals	76	15,205.64	200.07			

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
FM	Pre-test	1	41.90	41.90	0.50	.48	<.01
	Group	2	633.59	316.80	3.77	.03	0.06
	Residuals	76	6,385.33	84.02			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	76	-0.61	2.50	-0.24	1	-0.07
	MCST-Control	76	5.92	2.55	2.32	.07	0.65
	CST-Control	76	6.53	2.63	2.48	.05	0.71
CL	Pre-test	1	38.20	38.20	0.79	.38	<.01
	Group	2	165.16	82.58	1.72	.19	0.02
	Residuals	76	3,656.81	48.12			
CM*	Pre-test	1	20,800.23	20,800.23	35.22	<.01	0.30
	Group	2	750.00	375.00	0.63	.53	<.01
	Residuals	76	44,889.58	590.65			
PL	Pre-test	1	34.41	34.41	0.27	.60	<.01
	Group	2	142.77	71.39	0.56	.57	<.01
	Residuals	76	9,648.53	126.95			
PM	Pre-test	1	122.61	122.61	0.18	.67	<.01
	Group	2	1,481.77	740.89	1.11	.33	<.01
	Residuals	76	50,681.99	666.87			
OL	Pre-test	1	12.47	12.47	0.08	.78	<.01
	Group	2	496.41	248.20	1.53	.22	0.01
	Residuals	76	12,312.79	162.01			
OM	Pre-test	1	1,772.22	1,772.22	1.52	.22	0.01
	Group	2	1,594.01	797.00	0.68	.51	<.01
	Residuals	76	88,438.69	1,163.67			
LTL	Pre-test	1	30.40	30.40	0.35	.55	<.01
	Group	2	891.03	445.51	5.16	<.01	0.09
	Residuals	76	6,567.87	86.42			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	76	7.69	2.47	3.12	<.01	0.83
	MCST-Control	76	1.89	2.58	0.73	1	0.20
	CST-Control	76	-5.80	2.64	-2.19	.09	-0.62
RTL	Pre-test	1	194.77	194.77	2.99	.09	0.02

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	39.02	19.51	0.30	.74	<.01
	Residuals	76	4,950.24	65.13			
LTPJ	Pre-test	1	196.97	196.97	2.12	.15	0.01
	Group	2	362.61	181.30	1.95	.15	0.02
	Residuals	76	7,066.93	92.99			
RTPJ	Pre-test	1	548.03	548.03	3.30	.07	0.03
*	Group	2	151.85	75.92	0.46	.63	<.01
	Residuals	76	12,608.96	165.91			
P6 – peak amplitude							
FL*	Pre-test	1	6,258.41	6,258.41	26.23	<.01	0.24
	Group	2	775.94	387.97	1.63	.20	0.02
	Residuals	76	18,134.68	238.61			
FM	Pre-test	1	68.76	68.76	0.73	.40	<.01
	Group	2	844.50	422.25	4.47	.01	0.08
	Residuals	76	7,179.45	94.47			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	76	-1.28	2.65	-0.48	1	-0.13
	MCST-Control	76	6.49	2.70	2.40	.06	0.67
	CST-Control	76	7.77	2.79	2.79	.02	0.80
CL	Pre-test	1	68.72	68.72	1.23	.27	<.01
	Group	2	87.15	43.58	0.78	.46	<.01
	Residuals	76	4,242.68	55.82			
CM*	Pre-test	1	21,365.10	21,365.10	27.73	<.01	0.25
	Group	2	909.77	454.88	0.59	.56	<.01
	Residuals	76	58,557.87	770.50			
PL	Pre-test	1	74.59	74.59	0.57	.45	<.01
	Group	2	107.76	53.88	0.41	.66	<.01
	Residuals	76	9,936.96	130.75			
PM	Pre-test	1	103.26	103.26	0.17	.68	<.01
	Group	2	1,653.07	826.53	1.38	.26	0.01
	Residuals	76	45,409.34	597.49			
OL	Pre-test	1	26.78	26.78	0.09	.77	<.01
	Group	2	1,297.68	648.84	2.08	.13	0.03

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	76	23,672.98	311.49			
OM	Pre-test	1	1,711.86	1,711.86	1.00	.32	<.01
	Group	2	2,417.72	1,208.86	0.71	.50	<.01
	Residuals	76	129,668.91	1,706.17			
LTL	Pre-test	1	2.84	2.84	0.04	.85	<.01
	Group	2	540.77	270.38	3.37	.04	0.06
	Residuals	76	6,090.18	80.13			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	76	6.13	2.39	2.57	.04	0.69
	MCST-Control	76	1.93	2.48	0.78	1	0.22
	CST-Control	76	-4.21	2.57	-1.64	.32	-0.47
RTL	Pre-test	1	176.54	176.54	3.72	.06	0.03
	Group	2	96.74	48.37	1.02	.37	<.01
	Residuals	76	3,607.68	47.47			
LTPJ	Pre-test	1	133.30	133.30	1.41	.24	0.01
	Group	2	219.32	109.66	1.16	.32	<.01
	Residuals	76	7,175.83	94.42			
RTPJ	Pre-test	1	223.63	223.63	1.48	.23	0.01
*	Group	2	180.51	90.26	0.60	.55	<.01
	Residuals	76	11,454.12	150.71			
P6 – peak latency							
FL	Pre-test	1	22.23	22.23	0.01	.91	<.01
	Group	2	2,964.08	1,482.04	0.84	.43	<.01
	Residuals	76	133,787.75	1,760.37			
FM	Pre-test	1	5,154.44	5,154.44	1.18	.28	<.01
	Group	2	18,181.60	9,090.80	2.07	.13	0.03
	Residuals	76	333,180.16	4,383.95			
CL	Pre-test	1	247.66	247.66	0.18	.67	<.01
	Group	2	674.34	337.17	0.24	.78	<.01
	Residuals	76	104,729.18	1,378.02			
CM*	Pre-test	1	23,739.38	23,739.38	5.31	.02	0.05
	Group	2	1,932.80	966.40	0.22	.81	<.01
	Residuals	76	339,599.27	4,468.41			

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
PL*	Pre-test	1	3,858.75	3,858.75	3.04	.09	0.02
	Group	2	2,433.43	1,216.71	0.96	.39	<.01
	Residuals	76	96,324.58	1,267.43			
PM	Pre-test	1	331.66	331.66	0.08	.78	<.01
	Group	2	9,596.27	4,798.14	1.11	.33	<.01
	Residuals	76	327,112.02	4,304.11			
OL	Pre-test	1	2,052.26	2,052.26	1.54	.22	0.01
	Group	2	323.30	161.65	0.12	.89	<.01
	Residuals	76	101,433.96	1,334.66			
OM	Pre-test	1	776.74	776.74	0.19	.66	<.01
	Group	2	10,581.94	5,290.97	1.30	.28	0.01
	Residuals	76	309,528.52	4,072.74			
LTL	Pre-test	1	88.89	88.89	0.05	.82	<.01
	Group	2	493.31	246.65	0.15	.86	<.01
	Residuals	76	124,374.97	1,636.51			
RTL	Pre-test	1	2,033.12	2,033.12	1.28	.26	<.01
	Group	2	15,322.01	7,661.01	4.80	.01	0.09
	Residuals	76	121,173.81	1,594.39			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	76	19.62	10.60	1.85	.20	0.49
	MCST-Control	76	33.81	11.07	3.06	<.01	0.85
	CST-Control	76	14.19	11.33	1.25	.64	0.36
LTPJ	Pre-test	1	1,807.53	1,807.53	0.80	.37	<.01
	Group	2	3,887.86	1,943.93	0.86	.43	<.01
	Residuals	76	172,028.32	2,263.53			
RTPJ	Pre-test	1	4,774.21	4,774.21	2.25	.14	0.02
	Group	2	3,169.35	1,584.68	0.75	.48	<.01
	Residuals	76	161,613.59	2,126.49			

*A significant interaction effect

Analysis of regression

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This analysis evaluates ERP peak amplitude, mean amplitude, and peak latency across multiple ROIs (Regions of Interest), components, and intervention groups (MCST, CST, and control) during the mental rotation task.

The analysis of ERP components highlights distinct intervention effects. Regarding mean amplitude, the MCST group demonstrates moderate effects for the N200 component in the OL region (β_1 = 0.18, p = .02, adjusted R^2 = .16), with no significant results for CST and control groups in these regions (see Figure 68). For the N200 component's peak amplitude at the PM, only the CST group exhibits a significant relationship (β_1 = 0.49, p = .01, adjusted R^2 = .22), highlighting its efficacy, whereas the MCST and control groups show no significant effects.

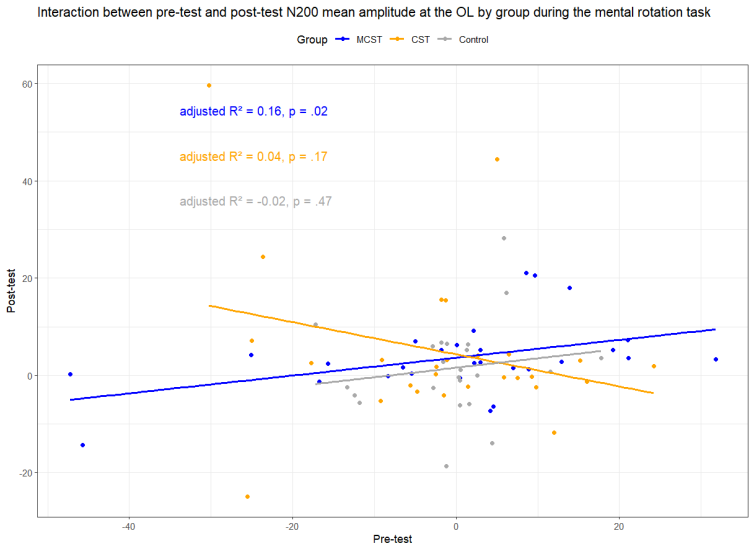

Figure 68 A scatter plot and the regression lines are shows interaction between pre-test and post-test N200 mean amplitude in the occipital lobe (OL) area by group during the Corsi block-tapping task

Regarding mean amplitude, the MCST group demonstrates strong effects for the P600 component in the FL region (β_1 = 0.88, p < .001, adjusted R^2 = .65), with no significant results for CST and control groups in these regions (see Figure 69). For the P600 component's peak amplitude in the CM region, the MCST group shows a significant relationship (β_1 = -0.62, p < .001, adjusted R^2 = .41), indicating substantial modulation by the intervention, while the CST (β_1 = 0.11, p =

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.59, adjusted R^2 = -.03) and control groups (β_1 = -0.11, p = .67, adjusted R^2 = -.04) fail to show significance. For peak latency, the P600 component in the PL region shows a significant relationship for the MCST group (β_1 = 0.69, p < .001, adjusted R^2 = .30), while the CST (β_1 = 0.43, p = .12, adjusted R^2 = .06) and control groups (β_1 = -0.28, p = .22, adjusted R^2 = .03) fail to reach significance.

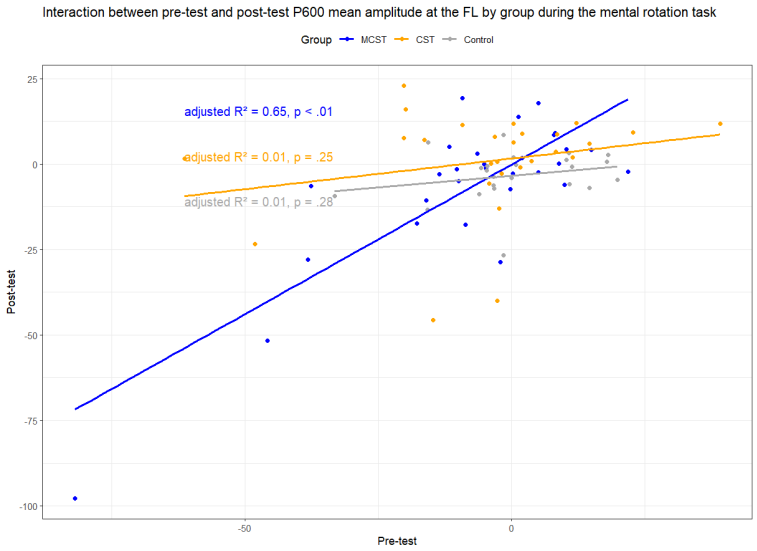

Figure 69 A scatter plot and the regression lines are shows interaction between pre-test and post-test P600 mean amplitude in the frontal lobe (OL) area by group during the Corsi block-tapping task

In summary, In the mental rotation task , The MCST group consistently demonstrates significant relationships in multiple regions and components, particularly in the P600 component (FL and PL regions) and N200 component (OL region). This indicates the MCST intervention effectively modulates ERP responses in cognitive processing regions. The CST group shows moderate success in influencing specific components like the P600 (Pz) and N200 (Pz) but generally demonstrates limited overall impact. The control group consistently fails to show significant predictive relationships, indicating little natural modulation of ERP components during the mental rotation task.

Table 71 Regression analysis of ERP components during the mental rotation task

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ROI	Model	Variable	*β*	*SE*	*t*	*p*
N200 – Mean applitude						
CM	MCST	Constant	-1.96	3.19	-0.61	.54
		Pre-test	0.12	0.09	1.31	.20
	CST	Constant	0.43	5.77	0.07	.94
		Pre-test	0.60	0.13	4.63	<.01
	Control	Constant	-1.12	2.86	-0.39	.70
		Pre-test	0.13	0.21	0.62	.55
OL	MCST	Constant	3.63	1.29	2.81	.01
		Pre-test	0.18	0.07	2.49	.02
	CST	Constant	4.33	3.10	1.39	.18
		Pre-test	-0.33	0.23	-1.43	.17
	Control	Constant	1.56	2.03	0.77	.45
		Pre-test	0.19	0.27	0.73	.47
N200 – Peak amplitude						
CM	MCST	Constant	-0.39	2.97	-0.13	.90
		Pre-test	0.13	0.08	1.74	.09
	CST	Constant	-0.48	5.53	-0.09	.93
		Pre-test	0.65	0.11	5.92	<.01
	Control	Constant	0.62	3.18	0.2	.85
		Pre-test	0.11	0.22	0.51	.62
OL	MCST	Constant	4.93	1.41	3.5	<.01
		Pre-test	0.22	0.08	2.8	.01
	CST	Constant	9.11	3.26	2.79	.01
		Pre-test	-0.44	0.24	-1.82	.08
	Control	Constant	3.17	1.98	1.6	.12
		Pre-test	0.22	0.22	0.99	.34
P600 – Mean amplitude						
FL	MCST	Constant	-0.15	2.58	-0.06	.95
		Pre-test	0.88	0.12	7.37	<.01
	CST	Constant	1.62	3.02	0.53	.60
		Pre-test	0.18	0.15	1.18	.25
	Control	Constant	-3.45	1.51	-2.29	.03
		Pre-test	0.14	0.12	1.11	.28
CM	MCST	Constant	3.81	3.17	1.2	.24
		Pre-test	-0.04	0.07	-0.64	.53
	CST	Constant	-1.53	5.14	-0.3	.77
		Pre-test	0.41	0.06	6.79	<.01
	Control	Constant	-2.58	4.08	-0.63	.54
		Pre-test	0.04	0.12	0.37	.72
RTPJ	MCST	Constant	-0.71	2.42	-0.29	.77
		Pre-test	0.57	0.19	3.01	.01
	CST	Constant	-1.00	2.73	-0.37	.72

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ROI	Model	Variable	*β*	*SE*	*t*	*p*
		Pre-test	-0.02	0.12	-0.17	.87
	Control	Constant	1.96	1.93	1.02	.32
		Pre-test	0.35	0.2	1.74	.10
P600 – Peak amplitude						
FL	MCST	Constant	0.33	2.81	0.12	.91
		Pre-test	0.86	0.13	6.42	<.01
	CST	Constant	5.58	3.15	1.77	.09
		Pre-test	0.17	0.17	1	.33
	Control	Constant	0.27	1.8	0.15	.88
		Pre-test	0.01	0.11	0.06	.95
OM	MCST	Constant	8.15	3.69	2.21	.04
		Pre-test	-0.06	0.08	-0.81	.43
	CST	Constant	0.96	6.61	0.15	.89
		Pre-test	0.37	0.07	5.31	<.01
	Control	Constant	-0.14	4.45	-0.03	.98
		Pre-test	0.04	0.12	0.34	.74
RTPJ	MCST	Constant	0.35	2.42	0.14	.89
		Pre-test	0.46	0.16	2.81	.01
	CST	Constant	3.43	2.67	1.28	.21
		Pre-test	-0.08	0.12	-0.70	.49
	Control	Constant	4.2	2.36	1.78	.09
		Pre-test	0.33	0.2	1.65	.11
P600 – Peak latency						
CM	MCST	Constant	1032.86	85.07	12.14	<.01
		Pre-test	-0.62	0.13	-4.63	<.01
	CST	Constant	562.16	122.25	4.60	<.01
		Pre-test	0.11	0.19	0.55	.59
	Control	Constant	702.49	171.76	4.09	<.01
		Pre-test	-0.11	0.26	-0.43	.67
PL	MCST	Constant	194.61	118.77	1.64	.11
		Pre-test	0.69	0.19	3.70	<.01
	CST	Constant	362.37	176.73	2.05	.05
		Pre-test	0.43	0.27	1.60	.12
	Control	Constant	825.44	141.13	5.85	<.01
		Pre-test	-0.28	0.22	-1.27	.22

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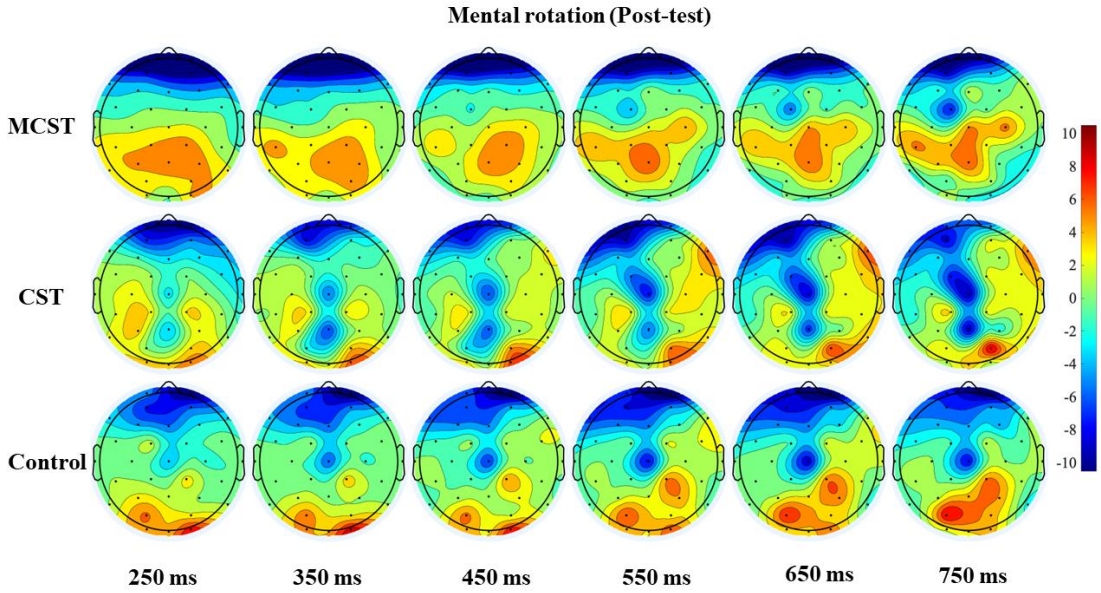

Figure 70 The topographic brain mapping of mean amplitude for each 100 ms latency window during the mental rotation task at post-test

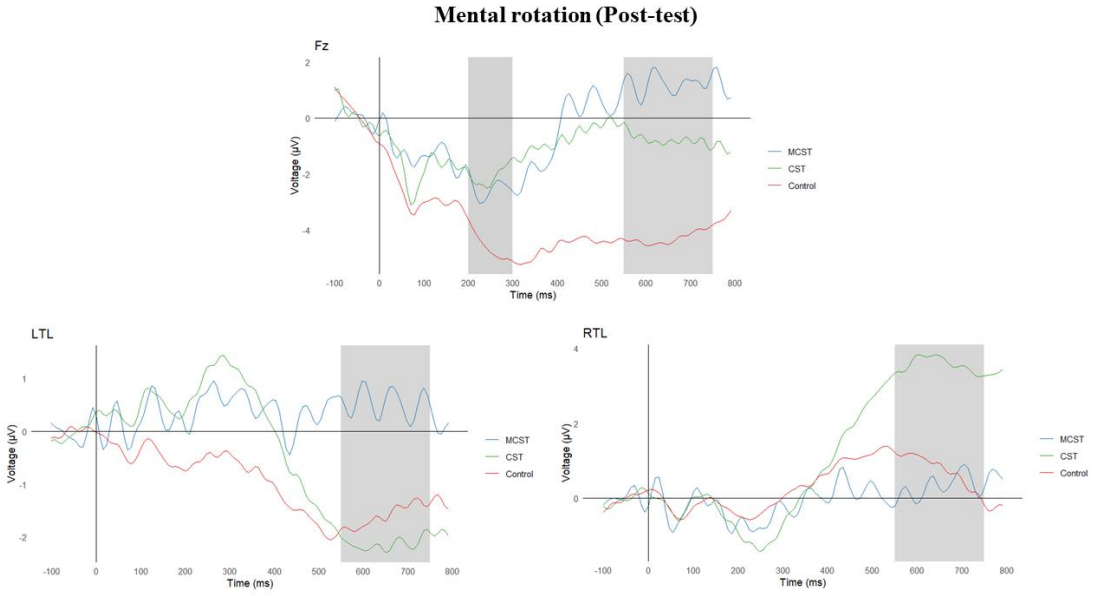

Figure 71 Grand-average ERP waveforms over the frontal midline (Fz), left and right temporal lobes (LTL and RTL) across three groups in the mental rotation task at post-test

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ERP - Wisconsin card sorting test

Analysis of the amplitude and latency characteristics

P300 component - Mean amplitude

In the frontal region (FL, FM), the MCST group showed mixed changes, with a slight increase in mean amplitude in the frontal lobe (FL) but a decrease in the frontal midline (FM) post-test. The CST group experienced a decrease overall, while the control group showed a slight improvement.

In the central region (CL, CM), the MCST group displayed an increase in central electrode locations (CL) but a decrease in the central midline (CM) post-test, indicating mixed changes. The CST group showed a slight reduction overall, whereas The control group experienced a slight increase.

In the parietal region (PL, PM), the MCST group showed a significant decrease in mean amplitude post-test, particularly in the parietal midline (PM), while the CST group experienced a slight increase. The control group showed a mixed response with minor changes.

In the temporal region (LTL, RTL, LTPJ, RTPJ), the MCST group exhibited mixed changes with reductions in the left temporal lobe (LTL) and left temporal-parietal junction (LTPJ) but increases in the right temporal lobe (RTL) and right temporal-parietal junction (RTPJ). The CST group experienced slight decreases overall, and the control group showed minor increases.

P300 component - Peak amplitude

In the frontal region, the MCST group showed a decrease in peak amplitude post-test, particularly in the frontal midline (FM), while the CST group showed slight increases. The control group exhibited a slight increase overall.

In the central region, the MCST group displayed a mixed response with a decrease in the central midline (CM) but a slight increase in central electrode locations (CL). The CST group showed an increase, while the control group had mixed changes with slight increases.

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In the parietal region, the MCST group showed a decrease in peak amplitude post-test, while the CST group experienced a slight increase. The control group showed mixed changes with minor fluctuations.

In the temporal region, the MCST group exhibited mixed changes with decreases in the left temporal lobe (LTL) and right temporal-parietal junction (RTPJ), but an increase in the left temporal-parietal junction (LTPJ). The CST group showed minor changes, and the control group had mixed responses with slight increases.

P300 component - Peak latency

In the frontal region, the MCST group showed an increase in peak latency post-test, indicating a slower response time. The CST group also showed an increase, while the control group remained relatively stable.

In the central region, the MCST group exhibited a slight decrease in peak latency, suggesting a quicker response. The CST group showed a slight increase, while the control group had mixed responses with minor decreases.

In the parietal region, the MCST group displayed a decrease in peak latency post-test, indicating an improved response time. The CST group experienced a slight decrease, while the control group remained stable.

In the temporal region, the MCST group showed mixed changes with decreases in the left temporal lobe (LTL) and right temporal-parietal junction (RTPJ) but increases in the right temporal lobe (RTL) and left temporal-parietal junction (LTPJ). The CST group experienced slight increases, and the control group had mixed responses.

P3/LPC component - Mean amplitude

In the frontal region, the MCST group showed a slight increase in mean amplitude post-test, particularly in the frontal lobe (FL). The CST group experienced a slight decrease, while the control group showed a slight improvement.

In the central region, the MCST group displayed a decrease in mean amplitude post-test, with significant reductions in the central midline (CM). The CST group showed slight increases, and the control group had mixed responses with minor changes.

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In the parietal region, the MCST group showed a significant decrease in mean amplitude post-test, especially in the parietal midline (PM). The CST group experienced a slight increase, while the control group showed mixed changes.

In the temporal region, the MCST group exhibited mixed changes with decreases in the left temporal lobe (LTL) and left temporal-parietal junction (LTPJ) but increases in the right temporal lobe (RTL) and right temporal-parietal junction (RTPJ). The CST group experienced slight decreases overall, and the control group showed minor increases.

P3/LPC component - Peak amplitude

In the frontal region, the MCST group showed a decrease in peak amplitude post-test, particularly in the frontal midline (FM). The CST group showed slight increases, and the control group exhibited slight increases.

In the central region, the MCST group displayed a mixed response with decreases in the central midline (CM) but slight increases in central electrode locations (CL). The CST group showed increases, while the control group had mixed changes with slight increases.

In the parietal region, the MCST group showed a decrease in peak amplitude post-test, while the CST group experienced slight increases. The control group showed mixed changes with minor fluctuations.

In the temporal region, the MCST group exhibited mixed changes with decreases in the left temporal lobe (LTL) and right temporal-parietal junction (RTPJ) but increases in the left temporal-parietal junction (LTPJ). The CST group showed minor changes, and the control group had mixed responses with slight increases.

P3/LPC component - Peak latency

In the frontal region, the MCST group showed an increase in peak latency post-test, indicating a slower response time. The CST group also showed an increase, while the control group remained relatively stable.

In the central region, the MCST group exhibited a slight decrease in peak latency, suggesting a quicker response. The CST group showed a slight increase, while the control group had mixed responses with minor decreases.

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In the parietal region, the MCST group displayed a decrease in peak latency post-test, indicating an improved response time. The CST group experienced a slight decrease, while the control group remained stable.

In the temporal region, the MCST group showed mixed changes with decreases in the left temporal lobe (LTL) and right temporal-parietal junction (RTPJ) but increases in the right temporal lobe (RTL) and left temporal-parietal junction (LTPJ). The CST group experienced slight increases, and the control group had mixed responses.

Overall, across the P300 and P3/LPC components, the MCST group demonstrated various changes in ERP characteristics, with some regions showing improvements in mean and peak amplitudes and latencies, while others exhibited reductions or mixed changes. The CST and control groups generally exhibited minor changes, with some increases or decreases in specific regions.

Table 72 Characteristic of amplitude and latency of ERPs in the verbal paired associates learning task

		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
P300 – mean amplitude										
FL	Pre	17	5.43	10.99	21	10.82	18.17	24	7.21	11.67
	Post	17	5.51	12.99	21	7.65	11.71	24	8.50	10.09
FM	Pre	17	1.84	8.51	21	-2.27	15.09	24	-2.93	15.40
	Post	17	-5.23	18.12	21	-1.60	6.72	24	4.72	14.91
CL	Pre	17	-3.63	15.20	21	-0.94	14.05	24	-1.83	8.38
	Post	17	-0.59	4.74	21	-2.91	7.24	24	0.70	8.02
CM	Pre	17	3.92	49.26	21	-3.36	40.47	24	-8.40	18.29
	Post	17	0.06	15.87	21	3.63	26.37	24	-8.65	24.15
PL	Pre	17	1.84	12.65	21	-3.72	14.22	24	0.45	6.86
	Post	17	-1.00	5.36	21	1.07	8.78	24	-0.66	10.16
PM	Pre	17	17.98	79.18	21	-1.08	31.30	24	2.98	13.69
	Post	17	-0.68	13.36	21	1.46	15.17	24	-0.59	14.79
OL	Pre	17	-0.03	15.96	21	6.10	26.06	24	0.56	21.54
	Post	17	-1.65	13.52	21	1.04	9.31	24	-2.45	19.46

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
OM	Pre	17	-6.21	45.10	21	5.66	45.46	24	20.27	60.16
	Post	17	-6.27	36.44	21	-2.75	48.85	24	-4.82	31.99
LTL	Pre	17	-2.35	9.02	21	-4.85	6.79	24	-3.79	8.49
	Post	17	-3.71	4.97	21	-3.52	6.00	24	-3.13	9.98
RTL	Pre	17	-0.65	6.47	21	-5.37	8.92	24	-1.54	6.80
	Post	17	1.81	4.68	21	-2.18	6.42	24	-1.95	10.59
LTPJ	Pre	17	0.35	14.72	21	-1.30	9.19	24	-1.76	9.90
	Post	17	-1.53	5.73	21	-2.11	6.31	24	-0.77	7.20
RTPJ	Pre	17	-6.64	15.96	21	-5.60	17.56	24	-3.32	13.01
	Post	17	-0.78	6.64	21	-1.24	9.21	24	-1.42	9.12
P300 – peak amplitude										
FL	Pre	17	13.65	14.02	21	17.52	19.62	24	13.18	13.26
	Post	17	10.34	13.90	21	15.43	26.40	24	13.58	11.12
FM	Pre	17	7.95	14.18	21	2.62	14.63	24	1.08	14.82
	Post	17	-1.60	18.07	21	1.55	10.65	24	8.68	17.68
CL	Pre	17	3.77	11.57	21	5.07	14.80	24	2.00	9.33
	Post	17	3.00	6.97	21	0.78	8.30	24	4.54	9.15
CM	Pre	17	12.36	51.86	21	5.52	32.97	24	-5.02	18.03
	Post	17	2.59	16.19	21	7.07	33.35	24	-5.61	22.96
PL	Pre	17	7.96	16.98	21	3.09	13.63	24	4.34	8.54
	Post	17	1.72	5.24	21	6.24	11.79	24	1.88	9.89
PM	Pre	17	29.69	82.50	21	4.87	37.25	24	6.91	14.66
	Post	17	2.57	14.27	21	6.14	19.27	24	3.12	12.83
OL	Pre	17	9.25	16.91	21	13.36	24.83	24	5.81	22.19
	Post	17	3.20	14.81	21	6.66	11.48	24	1.98	18.25
OM	Pre	17	2.87	43.50	21	14.85	49.81	24	27.31	66.33
	Post	17	-1.43	29.29	21	5.22	49.52	24	0.27	35.78
LTL	Pre	17	4.37	13.18	21	0.75	7.06	24	0.55	9.65
	Post	17	-0.55	4.03	21	0.69	6.08	24	0.28	9.53
RTL	Pre	17	6.57	8.29	21	-0.38	8.58	24	2.79	6.13
	Post	17	5.17	4.82	21	2.22	7.79	24	1.32	9.57
LTPJ	Pre	17	6.89	21.42	21	4.56	8.51	24	2.13	10.95

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	17	1.38	5.57	21	1.62	4.94	24	1.49	7.02
RTPJ	Pre	17	0.88	19.69	21	0.55	13.85	24	0.70	12.36
	Post	17	2.28	6.34	21	4.41	9.31	24	1.08	8.89
P300 – peak latency										
FL	Pre	17	412	42.34	21	394	33.77	24	417	31.61
	Post	17	422	37.56	21	422	33.30	24	421	32.52
FM	Pre	17	415	60.61	21	376	54.96	24	377	52.76
	Post	17	431	62.02	21	397	62.40	24	408	50.38
CL	Pre	17	394	27.52	21	382	33.32	24	395	28.15
	Post	17	397	22.24	21	390	34.13	24	389	26.39
CM	Pre	17	407	64.52	21	377	66.17	24	387	63.53
	Post	17	401	58.77	21	392	64.88	24	398	60.04
PL	Pre	17	397	29.80	21	406	32.58	24	399	41.03
	Post	17	392	36.76	21	377	35.26	24	388	36.23
PM	Pre	17	412	68.84	21	395	60.22	24	412	62.14
	Post	17	394	60.58	21	371	62.49	24	398	70.74
OL	Pre	17	382	29.82	21	406	32.54	24	391	22.85
	Post	17	385	29.16	21	396	38.83	24	391	38.29
OM	Pre	17	356	59.89	21	402	72.77	24	388	73.19
	Post	17	390	58.84	21	425	60.84	24	385	64.59
LTL	Pre	17	402	33.70	21	387	31.92	24	386	33.44
	Post	17	386	35.64	21	405	31.09	24	393	29.92
RTL	Pre	17	398	30.17	21	400	25.76	24	400	32.37
	Post	17	397	39.45	21	391	36.57	24	393	32.91
LTPJ	Pre	17	409	41.65	21	404	46.39	24	392	43.85
	Post	17	385	39.76	21	393	39.85	24	393	42.14
RTPJ	Pre	17	393	38.13	21	395	44.47	24	402	38.19
	Post	17	389	49.63	21	385	44.51	24	396	36.05
P3/LPC – mean amplitude										
FL	Pre	17	9.40	14.81	21	11.79	24.98	24	10.18	12.76
	Post	17	10.18	14.55	21	8.51	11.36	24	11.79	11.99
FM	Pre	17	4.41	18.20	21	-7.76	21.72	24	-5.20	16.21

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	17	-2.90	18.43	21	-1.50	5.44	24	4.35	22.79
CL	Pre	17	-2.64	18.09	21	-3.05	18.74	24	0.41	10.98
	Post	17	-1.41	6.18	21	-2.60	3.91	24	0.38	13.16
CM	Pre	17	7.14	57.26	21	-13.33	52.90	24	-8.75	20.25
	Post	17	-4.43	33.39	21	7.58	32.04	24	-9.01	25.92
PL	Pre	17	-1.35	11.81	21	-0.89	17.74	24	-0.93	8.31
	Post	17	-1.66	7.02	21	-1.04	11.13	24	-0.87	12.78
PM	Pre	17	21.74	90.95	21	-3.86	48.45	24	3.94	18.11
	Post	17	-1.87	18.48	21	1.23	17.19	24	-0.44	16.00
OL	Pre	17	-1.49	16.67	21	6.95	35.48	24	-2.66	27.33
	Post	17	-4.59	18.72	21	1.09	11.57	24	-3.53	26.99
OM	Pre	17	-9.05	62.22	21	-2.05	72.95	24	18.79	72.00
	Post	17	-12.24	51.97	21	-0.35	60.50	24	-7.12	42.53
LTL	Pre	17	-2.35	11.45	21	-7.70	14.66	24	-3.74	9.66
	Post	17	-3.44	5.87	21	-3.22	5.11	24	-3.12	12.15
RTL	Pre	17	-0.92	4.48	21	-4.63	10.60	24	-2.09	9.25
	Post	17	1.34	5.55	21	-1.75	5.24	24	-3.37	15.48
LTPJ	Pre	17	0.04	21.03	21	-1.57	11.67	24	-1.74	12.15
	Post	17	-2.39	6.72	21	-1.62	7.21	24	-0.26	10.63
RTPJ	Pre	17	-9.12	15.49	21	-6.33	20.93	24	-4.61	15.84
	Post	17	-1.68	8.39	21	-3.65	18.51	24	-2.91	13.33
P3/LPC – peak amplitude										
FL	Pre	17	17.61	15.32	21	18.00	24.55	24	16.80	14.89
	Post	17	16.14	15.56	21	17.17	26.29	24	17.30	12.81
FM	Pre	17	8.36	13.95	21	-2.33	19.33	24	-1.32	16.27
	Post	17	0.39	17.23	21	2.66	7.53	24	7.39	26.06
CL	Pre	17	3.23	14.37	21	1.46	19.15	24	4.48	11.81
	Post	17	2.37	5.38	21	1.32	4.93	24	4.36	13.75
CM	Pre	17	13.32	57.19	21	-7.81	52.31	24	-4.97	19.51
	Post	17	0.27	21.33	21	11.99	33.35	24	-6.04	25.30
PL	Pre	17	5.95	16.57	21	6.76	19.05	24	3.48	9.74
	Post	17	1.11	7.28	21	4.04	12.40	24	2.31	12.46

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
PM	Pre	17	30.87	100.6	21	2.90	47.23	24	9.48	23.90
	Post	17	0.89	18.55	21	5.67	21.94	24	2.65	15.79
OL	Pre	17	6.12	17.03	21	14.99	42.17	24	3.85	25.49
	Post	17	-0.69	21.71	21	6.92	12.89	24	0.99	27.00
OM	Pre	17	1.38	68.60	21	6.17	79.18	24	24.72	75.44
	Post	17	-8.34	45.02	21	4.32	59.91	24	-1.46	41.42
LTL	Pre	17	4.09	13.17	21	-2.44	14.42	24	0.92	10.35
	Post	17	0.22	5.06	21	1.50	6.39	24	0.47	12.42
RTL	Pre	17	5.62	7.06	21	0.46	11.39	24	2.85	8.23
	Post	17	4.73	6.25	21	3.00	6.41	24	0.22	15.42
LTPJ	Pre	17	5.78	25.71	21	4.69	12.23	24	2.70	12.33
	Post	17	1.06	6.52	21	2.88	8.35	24	2.57	11.48
RTPJ	Pre	17	-2.08	17.82	21	-0.55	21.24	24	-0.81	16.26
	Post	17	0.97	8.21	21	1.75	15.94	24	-0.08	14.21
P3/LPC – peak latency										
FL	Pre	17	600	41.99	21	603	35.87	24	608	37.11
	Post	17	609	41.89	21	597	50.88	24	606	40.01
FM	Pre	17	580	68.49	21	577	62.67	24	579	58.16
	Post	17	622	61.11	21	578	77.23	24	589	74.97
CL	Pre	17	598	32.24	21	585	30.30	24	604	38.88
	Post	17	575	31.22	21	589	45.77	24	579	33.59
CM	Pre	17	607	75.40	21	586	60.52	24	592	60.55
	Post	17	581	64.36	21	585	67.87	24	579	69.42
PL	Pre	17	586	30.68	21	586	30.57	24	589	32.12
	Post	17	583	26.27	21	576	45.23	24	582	43.61
PM	Pre	17	612	60.51	21	596	72.55	24	590	50.48
	Post	17	587	69.80	21	564	61.46	24	559	61.83
OL	Pre	17	597	37.99	21	591	39.22	24	585	29.09
	Post	17	577	36.22	21	594	33.17	24	583	36.26
OM	Pre	17	596	68.04	21	594	77.76	24	581	64.96
	Post	17	575	66.88	21	577	61.01	24	575	65.22
LTL	Pre	17	593	35.44	21	596	35.57	24	605	34.84

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		MCST			CST			Control	
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	17	585	31.63	21	602	30.88	24	602	27.07
RTL	Pre	17	585	27.99	21	586	24.59	24	603	41.11
	Post	17	602	36.20	21	594	32.08	24	594	31.15
LTPJ	Pre	17	586	36.23	21	576	36.44	24	585	36.97
	Post	17	572	51.27	21	591	47.43	24	593	51.92
RTPJ	Pre	17	569	33.87	21	579	33.63	24	599	44.03
	Post	17	599	48.12	21	574	52.09	24	578	37.23

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Analysis of assumptions

In the Wisconsin Card Sorting Test (WCST), assumption testing was conducted for the amplitude and latency of the P300 and P3/LPC components across various regions of interest (ROIs).

P300 component

For the mean amplitude of P300, normality assumptions were frequently violated (W range = 0.81 - 0.97, all $p < .05$), except for LTPJ. Homoscedasticity was generally observed (K-squared range = 0.09 - 11.32, all $p > .05$), except for CM. Parallelism was generally met (F range = 0.02 - 11.32, all $p > .05$), except for CM.

Similarly, for the peak amplitude of P300, normality assumptions were violated across ROIs (W range = 0.67 - 0.98, all $p < .05$), except for OL. Homoscedasticity was predominantly observed (K-squared range = 1.31 - 12.69, all $p > .05$), except for CM. Parallelism was generally met (F range = 0.03 - 9.34, all $p > .05$), except for CM.

Regarding the peak latency of P300, normality assumptions were generally met (W range = 0.80 - 0.99, all $p > .05$). Homoscedasticity was observed in most cases (K-squared range = 0.11 - 5.25, all $p > .05$), except for PL. Parallelism was generally met (F range = 0.02 - 3.10, all $p > .05$), except for PL.

P3/LPC component

Moving to the P3/LPC component, for the mean amplitude, normality assumptions were frequently violated (W range = 0.70 - 0.98, all $p < .05$), except for OL. Homoscedasticity was generally observed (K-squared range = 0.07 - 31.88, all $p > .05$), except for LTL and RTL. Parallelism was generally met (F range = 0.12 - 6.59, all $p > .05$), except for CM, LTL, and RTL.

Concerning the peak amplitude of P3/LPC, normality assumptions were violated across ROIs (W range = 0.67 - 0.93, all $p < .05$), except for OL and OM. Homoscedasticity was predominantly observed (K-squared range = 0.01 - 30.08, all $p > .05$), except for CM and RTL. Parallelism was generally met (F range = 0.01 - 9.34, all $p > .05$), except for CM and RTL.

For the peak latency of P3/LPC, normality assumptions were generally met (W range = 0.80 - 0.98, all $p > .05$). Homoscedasticity was observed in most cases (K-squared range = 0.03 - 5.25, all $p > .05$), except for PL and RTL. Parallelism was generally met (F range = 0.01 - 3.10, all $p > .05$), except for PL and RTL.

Overall, while there were some violations of normality assumptions, homoscedasticity and parallelism were generally observed across most ROIs and contrasts in the WCST, indicating that the assumptions for subsequent analyses were reasonably met.

Analysis of group comparisons

This section presents the results of ANCOVA for various parameters during the Wisconsin card sorting test to measure executive functions in older adults with MCI. Overall, all of amplitude and latency of P300 and P3/LPC no significant group effects were observed across any brain regions in the test.

P300 component

The results of the ANCOVA for the P300 ERP component could not be interpreted due to violations of the regression slope homogeneity assumption. Therefore, separate regression analyses for each group are presented in the following section for the affected ROI: mean amplitude (CM) and peak amplitude (CM). The following are the ANCOVA results for ROIs that met the assumption.

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The analysis of the mean amplitude for the P300 component across various brain regions did not show any significant group effects. Specifically, the frontal lobe (FL), frontal midline (FM), central lobe (CL), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) all exhibited non-significant F values for the group variable. The effect sizes were all very small (partial ω^2 ranging from 0.00 to 0.05).

For the peak amplitude of the P300 component, no significant group effects were found across the brain regions. Similar to the mean amplitude, regions such as the frontal lobe (FL), frontal midline (FM), central lobe (CL), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) all showed non-significant F values for the group variable. The effect sizes remained small (partial ω^2 ranging from 0.00 to 0.04).

The analysis of peak latency for the P300 component also indicated no significant group effects across all brain regions examined. The frontal lobe (FL), frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) all had non-significant F values for the group variable with very small effect sizes (partial ω^2 ranging from 0.00 to 0.03).

P3/LPC component

The results of the ANCOVA for the P3/LPC ERP component could not be interpreted due to violations of the regression slope homogeneity assumption. Therefore, separate regression analyses for each group are presented in the following section for the affected ROIs: mean amplitude (CM, LTL) and peak amplitude (CM). The following are the ANCOVA results for ROIs that met the assumption.

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For the mean amplitude of the P3/LPC component, no significant group effects were found across the brain regions analyzed. The regions, including the frontal lobe (FL), frontal midline (FM), central lobe (CL), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ), showed non-significant F values for the group variable, and the effect sizes were negligible (partial ω^2 ranging from 0.00 to 0.02).

The peak amplitude analysis of the P3/LPC component indicated no significant group effects across all brain regions. The frontal lobe (FL), frontal midline (FM), central lobe (CL), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) all had non-significant F values for the group variable with very small effect sizes (partial ω^2 ranging from 0.00 to 0.05).

The peak latency analysis for the P3/LPC component revealed no significant group effects in the examined brain regions. Regions such as the frontal lobe (FL), frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) demonstrated non-significant F values for the group variable with small effect sizes (partial ω^2 ranging from 0.00 to 0.03).

Overall, the analysis of ERP components during the Wisconsin card sorting test did not reveal significant group effects for mean amplitude, peak amplitude, or peak latency across the brain regions examined. The effect sizes for the group variable were generally small, indicating minimal impact of the group condition on these ERP parameters. These findings suggest that the group differences in ERP responses were not substantial in the context of the Wisconsin card sorting test. For more information, please see Table 73 ANCOVA of amplitude and latency of ERPs in the Wisconsin card sorting test.

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Table 73 ANCOVA of amplitude and latency of ERPs in the Wisconsin card sorting test

		df	*SS*	*MS*	*F*	*p*	ω_p^2
P300 – mean amplitude							
FL	Pre-test	1	1,107.27	1,107.27	9.59	<.01	0.12
	Group	2	72.07	36.03	0.31	.73	<.01
	Residuals	58	6,695.95	115.45			
FM	Pre-test	1	22.08	22.08	0.11	.74	<.01
	Group	2	1,029.69	514.85	2.65	.08	0.05
	Residuals	58	11,273.51	194.37			
CL	Pre-test	1	7.75	7.75	0.16	.69	<.01
	Group	2	151.59	75.79	1.53	.23	0.02
	Residuals	58	2,875.94	49.59			
CM*	Pre-test	1	1,777.37	1,777.37	3.53	.07	0.04
	Group	2	2,169.21	1,084.61	2.15	.13	0.04
	Residuals	58	29,215.87	503.72			
PL	Pre-test	1	235.51	235.51	3.27	.08	0.04
	Group	2	16.38	8.19	0.11	.89	<.01
	Residuals	58	4,175.50	71.99			
PM	Pre-test	1	77.58	77.58	0.36	.55	<.01
	Group	2	47.65	23.82	0.11	.89	<.01
	Residuals	58	12,424.70	214.22			
OL	Pre-test	1	685.43	685.43	3.12	.08	0.03
	Group	2	80.21	40.10	0.18	.83	<.01
	Residuals	58	12,748.37	219.80			
OM	Pre-test	1	161.07	161.07	0.10	.75	<.01
	Group	2	143.97	71.99	0.05	.96	<.01
	Residuals	58	92,324.31	1,591.80			
LTL	Pre-test	1	267.40	267.40	4.95	.03	0.06
	Group	2	10.13	5.07	0.09	.91	<.01
	Residuals	58	3,130.54	53.97			
RTL	Pre-test	1	300.71	300.71	4.97	.03	0.06
	Group	2	128.34	64.17	1.06	.35	<.01
	Residuals	58	3,510.04	60.52			

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
LTPJ	Pre-test	1	54.12	54.12	1.28	.26	<.01
	Group	2	22.49	11.24	0.27	.77	<.01
	Residuals	58	2,456.01	42.34			
RTPJ	Pre-test	1	556.11	556.11	8.57	<.01	0.11
	Group	2	0.94	0.47	0.01	.99	<.01
	Residuals	58	3,761.54	64.85			
P300 – peak amplitude							
FL	Pre-test	1	1,134.29	1,134.29	3.50	.07	0.04
	Group	2	172.20	86.10	0.27	.77	<.01
	Residuals	58	18,809.99	324.31			
FM	Pre-test	1	23.79	23.79	0.09	.76	<.01
	Group	2	1,142.84	571.42	2.26	.11	0.04
	Residuals	58	14,681.60	253.13			
CL	Pre-test	1	25.64	25.64	0.37	.55	<.01
	Group	2	147.28	73.64	1.05	.36	<.01
	Residuals	58	4,068.87	70.15			
CM*	Pre-test	1	506.25	506.25	0.78	.38	<.01
	Group	2	2,250.22	1,125.11	1.73	.19	0.02
	Residuals	58	37,672.21	649.52			
PL	Pre-test	1	2.61	2.61	0.03	.87	<.01
	Group	2	269.29	134.64	1.43	.25	0.01
	Residuals	58	5,470.20	94.31			
PM	Pre-test	1	25.99	25.99	0.10	.75	<.01
	Group	2	135.56	67.78	0.27	.76	<.01
	Residuals	58	14,456.48	249.25			
OL	Pre-test	1	1,044.34	1,044.34	4.70	.03	0.06
	Group	2	132.40	66.20	0.30	.74	<.01
	Residuals	58	12,883.54	222.13			
OM	Pre-test	1	8.86	8.86	0.01	.94	<.01
	Group	2	476.96	238.48	0.15	.86	<.01
	Residuals	58	92,185.73	1,589.41			
LTL	Pre-test	1	245.87	245.87	5.07	.03	0.06
	Group	2	41.53	20.76	0.43	.65	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	58	2,813.60	48.51			
RTL	Pre-test	1	316.15	316.15	5.32	.02	0.07
	Group	2	83.94	41.97	0.71	.50	<.01
	Residuals	58	3,446.45	59.42			
LTPJ	Pre-test	1	42.51	42.51	1.19	.28	<.01
	Group	2	1.89	0.94	0.03	.97	<.01
	Residuals	58	2,074.19	35.76			
RTPJ	Pre-test	1	133.75	133.75	1.91	.17	0.01
	Group	2	124.84	62.42	0.89	.42	<.01
	Residuals	58	4,062.70	70.05			
P300 – peak latency							
FL	Pre-test	1	8,765.77	8,765.77	8.57	<.01	0.11
	Group	2	1,038.90	519.45	0.51	.60	<.01
	Residuals	58	59,301.54	1,022.44			
FM	Pre-test	1	126.54	126.54	0.04	.85	<.01
	Group	2	12,709.41	6,354.71	1.88	.16	0.03
	Residuals	58	195,921.09	3,377.95			
CL	Pre-test	1	135.25	135.25	0.17	.68	<.01
	Group	2	652.05	326.02	0.40	.67	<.01
	Residuals	58	47,055.63	811.30			
CM	Pre-test	1	826.23	826.23	0.22	.64	<.01
	Group	2	573.64	286.82	0.08	.93	<.01
	Residuals	58	221,764.29	3,823.52			
PL	Pre-test	1	102.17	102.17	0.08	.78	<.01
	Group	2	2,380.43	1,190.22	0.90	.41	<.01
	Residuals	58	76,657.88	1,321.69			
PM	Pre-test	1	3,886.40	3,886.40	0.90	.35	<.01
	Group	2	7,382.31	3,691.16	0.86	.43	<.01
	Residuals	58	249,351.04	4,299.16			
OL	Pre-test	1	1,082.55	1,082.55	0.82	.37	<.01
	Group	2	682.13	341.06	0.26	.77	<.01
	Residuals	58	76,948.20	1,326.69			
OM	Pre-test	1	2,813.37	2,813.37	0.73	.40	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	17,538.15	8,769.07	2.27	.11	0.04
	Residuals	58	224,399.84	3,868.96			
LTL	Pre-test	1	61.95	61.95	0.06	.81	<.01
	Group	2	3,729.90	1,864.95	1.80	.17	0.03
	Residuals	58	59,955.62	1,033.72			
RTL	Pre-test	1	3,819.78	3,819.78	3.05	.09	0.03
	Group	2	486.49	243.25	0.19	.82	<.01
	Residuals	58	72,664.52	1,252.84			
LTPJ	Pre-test	1	5,850.99	5,850.99	3.71	.06	0.04
	Group	2	1,416.60	708.30	0.45	.64	<.01
	Residuals	58	91,386.69	1,575.63			
RTPJ	Pre-test	1	3,300.25	3,300.25	1.81	.18	0.01
	Group	2	1,033.13	516.57	0.28	.75	<.01
	Residuals	58	105,962.10	1,826.93			
P3/LPC – mean amplitude							
FL	Pre-test	1	2,005.94	2,005.94	16.10	<.01	0.20
	Group	2	163.77	81.89	0.66	.52	<.01
	Residuals	58	7,224.41	124.56			
FM	Pre-test	1	4.17	4.17	0.01	.91	<.01
	Group	2	630.49	315.24	1.02	.37	<.01
	Residuals	58	17,971.07	309.85			
CL	Pre-test	1	0.44	0.44	0.01	.94	<.01
	Group	2	101.39	50.70	0.60	.55	<.01
	Residuals	58	4,901.34	84.51			
CM*	Pre-test	1	9,298.08	9,298.08	11.97	<.01	0.15
	Group	2	2,671.86	1,335.93	1.72	.19	0.02
	Residuals	58	45,047.76	776.69			
PL	Pre-test	1	134.70	134.70	1.13	.29	<.01
	Group	2	5.77	2.88	0.02	.98	<.01
	Residuals	58	6,884.67	118.70			
PM	Pre-test	1	23.78	23.78	0.08	.78	<.01
	Group	2	78.30	39.15	0.13	.88	<.01
	Residuals	58	17,249.43	297.40			

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
OL	Pre-test	1	803.27	803.27	1.91	.17	0.01
	Group	2	228.65	114.32	0.27	.76	<.01
	Residuals	58	24,372.13	420.21			
OM	Pre-test	1	2.35	2.35	0.00	.98	<.01
	Group	2	1,357.96	678.98	0.25	.78	<.01
	Residuals	58	158,019.81	2,724.48			
LTL*	Pre-test	1	357.05	357.05	5.05	.03	0.06
	Group	2	16.37	8.19	0.12	.89	<.01
	Residuals	58	4,097.23	70.64			
RTL	Pre-test	1	471.72	471.72	4.48	.04	0.05
	Group	2	192.20	96.10	0.91	.41	<.01
	Residuals	58	6,108.43	105.32			
LTPJ	Pre-test	1	43.32	43.32	0.58	.45	<.01
	Group	2	52.07	26.04	0.35	.71	<.01
	Residuals	58	4,312.53	74.35			
RTPJ	Pre-test	1	698.71	698.71	3.56	.06	0.04
	Group	2	21.84	10.92	0.06	.95	<.01
	Residuals	58	11,380.72	196.22			
P3/LPC – peak amplitude							
FL	Pre-test	1	2,106.42	2,106.42	6.31	.01	0.08
	Group	2	19.99	9.99	0.03	.97	<.01
	Residuals	58	19,355.15	333.71			
FM	Pre-test	1	0.07	0.07	0.00	.99	<.01
	Group	2	554.05	277.02	0.75	.48	<.01
	Residuals	58	21,481.29	370.37			
CL	Pre-test	1	2.97	2.97	0.03	.86	<.01
	Group	2	104.92	52.46	0.57	.57	<.01
	Residuals	58	5,296.47	91.32			
CM*	Pre-test	1	7,156.39	7,156.39	11.12	<.01	0.14
	Group	2	3,457.35	1,728.68	2.69	.08	0.05
	Residuals	58	37,328.35	643.59			
PL	Pre-test	1	291.57	291.57	2.34	.13	0.02
	Group	2	73.92	36.96	0.30	.74	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	58	7,213.93	124.38			
PM	Pre-test	1	34.77	34.77	0.10	.76	<.01
	Group	2	203.65	101.82	0.28	.75	<.01
	Residuals	58	20,857.50	359.61			
OL	Pre-test	1	718.10	718.10	1.54	.22	0.01
	Group	2	463.19	231.59	0.50	.61	<.01
	Residuals	58	27,094.57	467.15			
OM	Pre-test	1	0.00	0.00	0.00	1	<.01
	Group	2	1,506.53	753.27	0.30	.74	<.01
	Residuals	58	143,667.36	2,477.02			
LTL	Pre-test	1	235.20	235.20	3.03	.09	0.03
	Group	2	55.42	27.71	0.36	.70	<.01
	Residuals	58	4,503.49	77.65			
RTL	Pre-test	1	483.14	483.14	4.34	.04	0.05
	Group	2	188.66	94.33	0.85	.43	<.01
	Residuals	58	6,458.47	111.35			
LTPJ	Pre-test	1	36.77	36.77	0.42	.52	<.01
	Group	2	38.58	19.29	0.22	.80	<.01
	Residuals	58	5,063.65	87.30			
RTPJ	Pre-test	1	164.31	164.31	0.90	.35	<.01
	Group	2	38.60	19.30	0.11	.90	<.01
	Residuals	58	10,639.05	183.43			
P3/LPC – peak latency							
FL	Pre-test	1	1,373.89	1,373.89	0.69	.41	<.01
	Group	2	1,613.12	806.56	0.41	.67	<.01
	Residuals	58	115,285.46	1,987.68			
FM	Pre-test	1	8,331.28	8,331.28	1.61	.21	0.01
	Group	2	18,988.54	9,494.27	1.84	.17	0.03
	Residuals	58	299,676.42	5,166.83			
CL	Pre-test	1	107.42	107.42	0.08	.79	<.01
	Group	2	2,423.54	1,211.77	0.85	.43	<.01
	Residuals	58	83,028.54	1,431.53			
CM	Pre-test	1	3,706.31	3,706.31	0.81	.37	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	327.82	163.91	0.04	.96	<.01
	Residuals	58	265,645.11	4,580.09			
PL	Pre-test	1	2,084.27	2,084.27	1.29	.26	<.01
	Group	2	482.69	241.35	0.15	.86	<.01
	Residuals	58	93,657.11	1,614.78			
PM	Pre-test	1	5,219.47	5,219.47	1.29	.26	<.01
	Group	2	10,569.33	5,284.66	1.31	.28	0.01
	Residuals	58	233,983.31	4,034.19			
OL	Pre-test	1	275.04	275.04	0.22	.64	<.01
	Group	2	2,751.05	1,375.52	1.09	.34	<.01
	Residuals	58	72,879.59	1,256.54			
OM	Pre-test	1	20,480.19	20,480.19	5.32	.02	0.07
	Group	2	136.27	68.14	0.02	.98	<.01
	Residuals	58	223,259.54	3,849.30			
LTL	Pre-test	1	4,197.15	4,197.15	5.03	.03	0.06
	Group	2	2,956.70	1,478.35	1.77	.18	0.02
	Residuals	58	48,350.76	833.63			
RTL	Pre-test	1	25.23	25.23	0.02	.88	<.01
	Group	2	818.70	409.35	0.37	.69	<.01
	Residuals	58	63,781.04	1,099.67			
LTPJ	Pre-test	1	1,012.37	1,012.37	0.40	.53	<.01
	Group	2	5,439.57	2,719.79	1.07	.35	<.01
	Residuals	58	147,778.53	2,547.91			
RTPJ	Pre-test	1	460.22	460.22	0.22	.64	<.01
	Group	2	7,936.86	3,968.43	1.89	.16	0.03
	Residuals	58	121,626.59	2,097.01			

*A significant interaction effect

Analysis of regression

This section presents an analysis of ERP parameters (mean amplitude and peak amplitude) for the P300 and P3/LPC components in the CM and LTL regions across intervention groups (MCST, CST, and control) during the Wisconsin Card Sorting Test (WCST).

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The analysis of mean and peak amplitudes for P300 and P3/LPC components in the CM and LTL regions reveals contrasting relationships among groups. For the P300 component's mean amplitude in the CM region, the MCST group showed no significant relationship (β_1 = -0.08, p = .34, adjusted R^2 = .00), while the CST group exhibited a significant negative relationship (β_1 = -0.46, p < .001, adjusted R^2 = .47), and the control group demonstrated a significant positive relationship (β_1 = 0.66, p = .01, adjusted R^2 = .22). Similarly, for the P300 component's peak amplitude, the CST group showed a significant negative relationship (β_1 = -0.53, p = .01, adjusted R^2 = .24), and the control group displayed a significant positive relationship (β_1 = 0.60, p = .02, adjusted R^2 = .19), with no significant results for the MCST group.

For the P3/LPC component, in the CM region, the MCST group showed no significant relationship for both mean amplitude (β_1 = -0.20, p = .18, adjusted R^2 = .06) and peak amplitude (β_1 = -0.11, p = .24, adjusted R^2 = .03). The CST group exhibited strong significant negative relationships for both mean amplitude (β_1 = -0.48, p < .001, adjusted R^2 = .60) and peak amplitude (β_1 = -0.49, p < .001, adjusted R^2 = .58), while the control group showed significant positive relationships for both mean amplitude (β_1 = 0.52, p = .05, adjusted R^2 = .13) and peak amplitude (β_1 = 0.52, p = .05, adjusted R^2 = .12).

In the LTL region, for the P3/LPC component's mean amplitude, the control group was the only one with a significant positive relationship (β_1 = 0.62, p = .01, adjusted R^2 = .21), while the MCST (β_1 = 0.19, p = .15, adjusted R^2 = .07) and CST groups (β_1 = 0.02, p = .84, adjusted R^2 = -.05) showed no significant effects.

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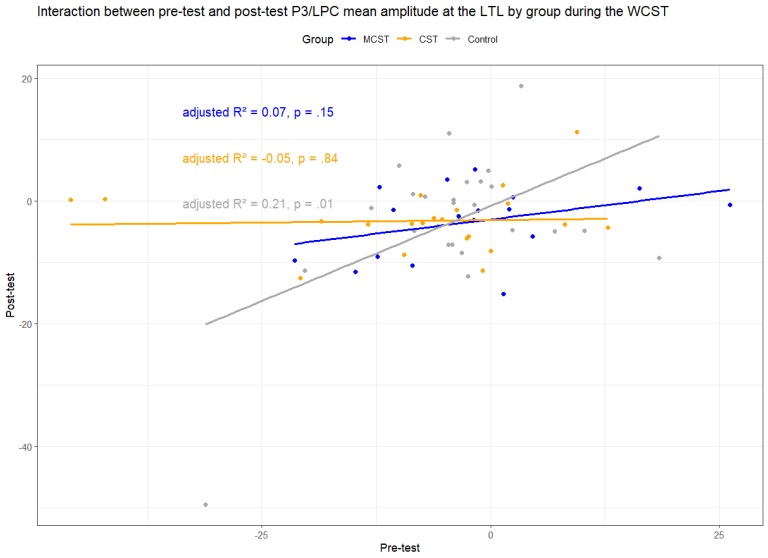

Figure 72 A scatter plot and the regression lines are shows interaction between pre-test and post-test P3/LPC mean amplitude in the left temporal lobe (LTL) area by group during the Wisconsin card sorting test (WCST)

In summary, the CST group shows consistent significant negative relationships between pre-test performance and both mean and peak amplitudes in the P300 and P3/LPC components across the CM region, suggesting a decrease in ERP amplitudes related to task performance. The control group exhibits significant positive relationships, indicating that baseline performance predicts ERP amplitudes for both P300 and P3/LPC components in the CM and LTL regions. The MCST Group generally does not show significant predictive relationships, suggesting less intervention impact on ERP measures during the WCST.

Table 74 Regression analysis of ERP components during the WCST

ROI	Model	Variable	*β*	*SE*	*t*	*P*
P300 – Mean applitude						
CM	MCST	Constant	0.37	3.87	0.09	.93
		Pre-test	-0.08	0.08	-0.98	.34
	CST	Constant	2.09	4.19	0.50	.62
		Pre-test	-0.46	0.11	-4.35	<.01
	Control	Constant	-3.09	4.82	-0.64	.53
		Pre-test	0.66	0.24	2.72	.01

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ROI	Model	Variable	*β*	*SE*	*t*	*P*
P3/LPC– Mean amplitude						
CM	MCST	Constant	-3.01	7.93	-0.38	.71
		Pre-test	-0.20	0.14	-1.40	.18
	CST	Constant	1.22	4.57	0.27	.79
		Pre-test	-0.48	0.09	-5.56	<.01
	Control	Constant	-4.44	5.40	-0.82	.42
		Pre-test	0.52	0.25	2.10	.05
LTL	MCST	Constant	-3.00	1.40	-2.14	.05
		Pre-test	0.19	0.12	1.50	.15
	CST	Constant	-3.10	1.30	-2.39	.03
		Pre-test	0.02	0.08	0.20	.84
	Control	Constant	-0.80	2.38	-0.34	.74
		Pre-test	0.62	0.23	2.65	.01
P3/LPC – Peak amplitude						
CM	MCST	Constant	1.76	5.24	0.34	.74
		Pre-test	-0.11	0.09	-1.22	.24
	CST	Constant	8.15	4.80	1.70	.11
		Pre-test	-0.49	0.09	-5.30	<.01
	Control	Constant	-3.48	5.01	-0.69	.49
		Pre-test	0.52	0.25	2.03	.05

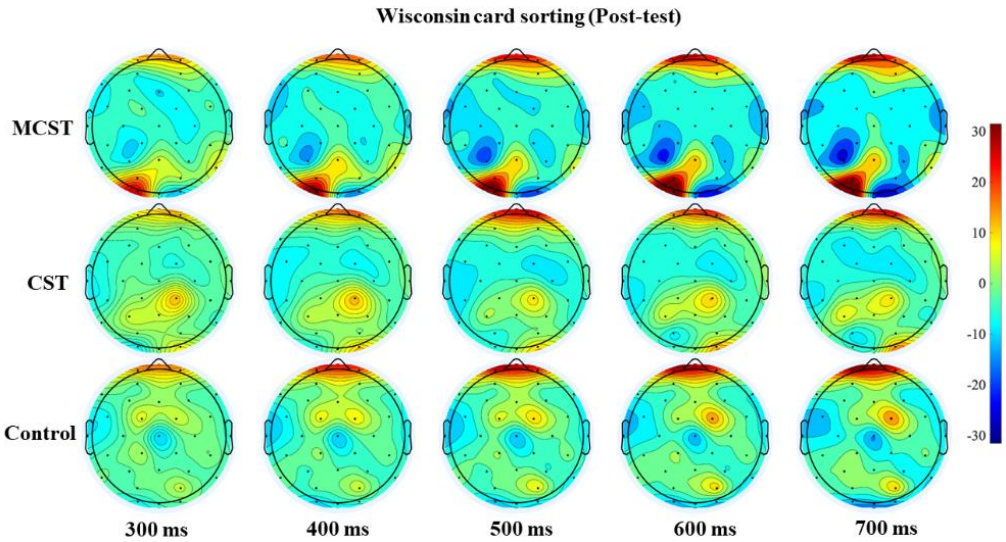

Figure 73 The topographic brain mapping of mean amplitude for each 100 ms latency window during the Wisconsin card sorting test at post-test

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ERP - Simple reaction time task

Analysis of the amplitude and latency characteristics

This section outlines characteristics of ERP component including N1 and P3 especially in mean and peak amplitude and peak latency, in the simple reaction time task.

N1 component - Mean amplitude

In the frontal region (FL, FM), the MCST group showed a decrease in mean amplitude post-test. In contrast, the CST group exhibited a mixed response, with increases in some areas and decreases in others. The control group experienced a minor increase overall.

In the central region (CL, CM), the MCST group demonstrated a significant decrease in mean amplitude post-test, indicating a reduction in neural activity. The CST group also showed a decrease, while the control group had minor decreases.

In the parietal region (PL, PM), the MCST group exhibited an increase in mean amplitude post-test, particularly in the parietal midline (PM). The CST group showed a decrease, while the control group experienced a minor increase.

In the temporal region (LTL, RTL, LTPJ, RTPJ), the MCST group displayed mixed changes, with some areas showing increases (e.g., left temporal-parietal junction) and others showing decreases (e.g., right temporal lobe). The CST group had mixed responses, and the control group showed slight changes with minor increases in some areas.

N1 component - Peak amplitude

In the frontal region, the MCST group showed a decrease in peak amplitude post-test. The CST group exhibited an increase, while the control group had a slight increase overall.

In the central region, the MCST group demonstrated mixed changes, with decreases in some areas and slight increases in others. The CST group showed a slight increase, and the control group had mixed responses.

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In the parietal region, the MCST group showed an increase in peak amplitude post-test, especially in the parietal midline (PM). The CST group experienced a decrease, while the control group showed mixed changes with slight increases.

In the temporal region, the MCST group exhibited mixed changes, with decreases in some areas and increases in others (e.g., right temporal-parietal junction). The CST group had minor increases, and the control group showed mixed responses with slight increases in some areas.

N1 component - Peak latency

In the frontal region, the MCST group showed an increase in peak latency post-test, indicating slower neural responses. The CST group also showed an increase, while the control group had minor changes with a slight increase.

In the central region, the MCST group displayed mixed changes, with slight increases in some areas and decreases in others. The CST group showed a slight decrease, and the control group had mixed responses with minor changes.

In the parietal region, the MCST group exhibited a decrease in peak latency post-test, indicating faster neural responses. The CST group showed a slight decrease, while the control group had mixed changes with minor decreases in some areas.

In the temporal region, the MCST group showed mixed changes, with increases in some areas and decreases in others (e.g., left temporal lobe). The CST group had minor decreases, and the control group showed mixed responses with slight increases in some areas.

P3 component - Mean amplitude

In the frontal region (FL, FM), the MCST group showed a slight increase in mean amplitude post-test. The CST group exhibited a larger increase, while the control group experienced a slight improvement.

In the central region (CL, CM), the MCST group displayed a decrease in mean amplitude post-test, with significant reductions in the

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central midline (CM). The CST group showed slight decreases, and the control group had mixed responses with minor changes.

In the parietal region (PL, PM), the MCST group showed a significant increase in mean amplitude post-test, especially in the parietal midline (PM). The CST group experienced a slight increase, while the control group showed mixed changes.

In the temporal region (LTL, RTL, LTPJ, RTPJ), the MCST group exhibited mixed changes, with decreases in some areas and increases in others. The CST group experienced slight increases overall, and the control group showed minor increases in some areas.

P3 component - Peak amplitude

In the frontal region, the MCST group showed a slight increase in peak amplitude post-test. The CST group exhibited a larger increase, while the control group had a slight increase overall.

In the central region, the MCST group demonstrated mixed changes, with decreases in some areas and slight increases in others. The CST group showed a slight increase, and the control group had mixed responses.

In the parietal region, the MCST group showed a significant increase in peak amplitude post-test, especially in the parietal midline (PM). The CST group experienced a slight increase, while the control group showed mixed changes with slight increases.

In the temporal region, the MCST group exhibited mixed changes, with decreases in some areas and increases in others (e.g., right temporal-parietal junction). The CST group had minor increases, and the control group showed mixed responses with slight increases in some areas.

P3 component - Peak latency

In the frontal region, the MCST group showed an increase in peak latency post-test, indicating slower neural responses. The CST group also showed an increase, while the control group had minor changes with a slight increase.

In the central region, the MCST group displayed mixed changes, with slight increases in some areas and decreases in others. The CST group

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showed a slight decrease, and the control group had mixed responses with minor changes.

In the parietal region, the MCST group exhibited a decrease in peak latency post-test, indicating faster neural responses. The CST group showed a slight decrease, while the control group had mixed changes with minor decreases in some areas.

In the temporal region, the MCST group showed mixed changes, with increases in some areas and decreases in others (e.g., left temporal lobe). The CST group had minor decreases, and the control group showed mixed responses with slight increases in some areas.

Overall, across the N1 and P3 components, the MCST group demonstrated various changes in ERP characteristics, with some regions showing improvements in mean and peak amplitudes and latencies, while others exhibited reductions or mixed changes. The CST and control groups generally exhibited minor changes, with some increases or decreases in specific regions (see Table 1).

Table 75 Characteristic of amplitude and latency of ERPs in the simple reaction time task

		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
N1 – mean amplitude										
FL	Pre	16	3.35	12.43	19	1.96	6.44	24	1.82	3.79
	Post	16	2.51	6.45	19	7.76	13.51	24	3.36	9.38
FM	Pre	16	2.66	5.25	19	4.78	16.99	24	1.33	6.66
	Post	16	0.34	15.92	19	5.40	6.98	24	5.13	21.50
CL	Pre	16	-0.09	7.16	19	-2.30	8.40	24	1.50	4.31
	Post	16	-1.29	3.42	19	-2.50	11.08	24	-1.29	8.02
CM	Pre	16	-0.76	7.72	19	-10.78	28.70	24	0.46	7.51
	Post	16	-6.20	12.63	19	-7.92	31.73	24	-0.71	8.33
PL	Pre	16	-3.13	8.36	19	1.37	7.02	24	0.24	5.07
	Post	16	0.41	5.96	19	-2.89	6.68	24	1.07	7.47
PM	Pre	16	-8.70	18.86	19	0.76	7.81	24	1.05	8.41
	Post	16	3.74	9.64	19	-0.08	9.31	24	1.72	22.94

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
OL	Pre	16	3.56	15.05	19	1.99	12.61	24	-1.98	10.53
	Post	16	-1.60	10.08	19	-2.56	13.50	24	-1.11	6.58
OM	Pre	16	0.60	31.84	19	4.63	30.66	24	-0.15	15.45
	Post	16	-1.04	22.45	19	-0.46	17.16	24	4.54	22.79
LTL	Pre	16	0.03	3.05	19	-0.73	3.64	24	-0.31	3.55
	Post	16	-0.02	2.00	19	0.54	4.84	24	-0.46	2.89
RTL	Pre	16	-3.11	6.67	19	-1.79	6.97	24	-1.00	3.18
	Post	16	-0.01	3.86	19	-0.38	8.74	24	-1.23	5.29
LTPJ	Pre	16	-0.78	7.88	19	-2.01	3.49	24	-1.16	2.69
	Post	16	0.08	6.44	19	-1.41	7.30	24	0.26	8.82
RTPJ	Pre	16	-3.12	4.92	19	-0.94	10.07	24	-1.00	5.44
	Post	16	-1.25	5.15	19	-2.02	9.20	24	0.23	7.84
N1 – peak amplitude										
FL	Pre	16	13.16	24.90	19	9.68	7.12	24	6.83	3.43
	Post	16	7.09	7.37	19	18.08	28.06	24	11.65	12.17
FM	Pre	16	8.78	8.79	19	10.29	15.58	24	5.12	5.53
	Post	16	-0.20	25.30	19	11.19	11.51	24	10.29	25.23
CL	Pre	16	7.23	9.53	19	4.33	7.30	24	5.84	3.57
	Post	16	4.80	7.71	19	5.96	11.15	24	4.15	7.49
CM	Pre	16	4.92	9.67	19	1.35	12.79	24	4.84	5.79
	Post	16	2.82	24.31	19	4.14	13.44	24	3.97	8.63
PL	Pre	16	3.25	6.56	19	6.90	9.62	24	4.80	5.66
	Post	16	6.25	9.79	19	4.05	5.01	24	7.64	13.28
PM	Pre	16	0.93	13.81	19	4.87	9.10	24	6.15	10.59
	Post	16	9.41	13.43	19	5.59	7.98	24	9.43	37.91
OL	Pre	16	14.06	15.71	19	11.64	20.52	24	4.52	15.70
	Post	16	4.99	12.72	19	4.04	15.26	24	7.42	10.08
OM	Pre	16	5.37	24.46	19	16.88	42.99	24	7.80	22.24
	Post	16	3.80	25.78	19	8.80	23.56	24	13.00	27.74
LTL	Pre	16	6.65	7.17	19	4.45	3.13	24	4.04	3.40
	Post	16	5.21	3.04	19	7.04	9.33	24	5.50	6.10
RTL	Pre	16	3.39	3.49	19	5.25	6.12	24	3.00	3.00

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	16	6.09	7.42	19	7.13	13.27	24	3.93	7.60
LTPJ	Pre	16	6.46	14.37	19	3.11	4.52	24	2.79	3.06
	Post	16	5.37	9.40	19	4.77	11.03	24	5.91	13.70
RTPJ	Pre	16	2.53	5.40	19	6.54	12.39	24	2.52	6.87
	Post	16	4.18	7.19	19	5.60	11.83	24	4.26	9.55
N1 – peak latency										
FL	Pre	16	115	46.00	19	111	39.99	24	93	33.59
	Post	16	114	30.78	19	131	30.57	24	112	45.81
FM	Pre	16	100	61.49	19	105	59.79	24	98	58.26
	Post	16	138	55.19	19	115	57.43	24	102	63.50
CL	Pre	16	89	30.66	19	97	30.01	24	90	33.26
	Post	16	89	29.26	19	88	35.81	24	110	33.14
CM	Pre	16	64	47.74	19	79	68.98	24	88	55.03
	Post	16	82	56.82	19	74	55.74	24	109	64.43
PL	Pre	16	74	31.78	19	87	30.53	24	105	34.06
	Post	16	99	37.18	19	72	31.24	24	90	36.13
PM	Pre	16	52	52.92	19	84	66.68	24	100	64.91
	Post	16	115	56.18	19	66	51.12	24	108	60.75
OL	Pre	16	99	29.68	19	100	31.13	24	117	32.15
	Post	16	113	25.25	19	103	29.00	24	97	38.33
OM	Pre	16	76	62.42	19	93	69.00	24	125	54.76
	Post	16	107	64.69	19	100	56.17	24	106	73.29
LTL	Pre	16	91	28.80	19	114	33.13	24	110	37.28
	Post	16	88	31.14	19	99	36.06	24	113	33.66
RTL	Pre	16	84	28.93	19	100	36.82	24	84	32.69
	Post	16	88	33.79	19	98	30.72	24	108	43.76
LTPJ	Pre	16	65	42.26	19	95	39.15	24	111	36.83
	Post	16	78	45.27	19	63	33.73	24	95	39.17
RTPJ	Pre	16	84	41.90	19	100	50.92	24	94	38.97
	Post	16	95	48.33	19	73	45.88	24	89	36.74
P3 – mean amplitude										
FL	Pre	16	5.87	19.12	19	5.45	12.21	24	10.24	11.90

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	16	10.71	13.82	19	15.30	20.24	24	11.61	15.58
FM	Pre	16	2.32	10.03	19	2.96	36.89	24	2.86	12.30
	Post	16	5.22	23.97	19	8.72	12.44	24	6.37	24.38
CL	Pre	16	2.63	15.16	19	-4.19	16.07	24	0.29	6.90
	Post	16	-6.07	8.63	19	-4.61	21.52	24	-1.67	11.18
CM	Pre	16	3.90	44.54	19	-19.15	59.78	24	-1.90	12.15
	Post	16	-16.62	27.11	19	-16.90	40.17	24	-3.68	11.96
PL	Pre	16	-5.64	15.04	19	0.18	9.78	24	-1.15	8.06
	Post	16	0.11	10.83	19	-5.63	12.19	24	-2.31	14.26
PM	Pre	16	-14.77	32.95	19	5.60	21.48	24	-2.78	19.55
	Post	16	-0.38	12.76	19	-4.22	23.67	24	2.90	54.27
OL	Pre	16	6.24	29.07	19	0.14	12.21	24	-7.17	16.03
	Post	16	-4.33	17.87	19	-6.86	24.15	24	-6.06	8.60
OM	Pre	16	4.67	63.45	19	0.65	43.41	24	-2.16	24.03
	Post	16	1.87	35.15	19	-9.77	30.99	24	-3.46	31.17
LTL	Pre	16	-0.76	8.31	19	-0.47	5.81	24	-0.31	3.74
	Post	16	0.17	3.77	19	1.17	11.68	24	-0.43	4.76
RTL	Pre	16	-6.83	13.44	19	-0.84	11.48	24	-1.53	6.60
	Post	16	-0.52	5.82	19	0.33	17.87	24	-0.88	12.56
LTPJ	Pre	16	-3.41	15.87	19	-5.10	9.42	24	-2.93	7.34
	Post	16	2.41	16.43	19	-1.96	15.51	24	-0.56	15.35
RTPJ	Pre	16	-6.63	7.78	19	-0.08	11.63	24	-4.06	12.80
	Post	16	-1.73	11.00	19	-2.68	18.49	24	-2.25	19.17
P3 – peak amplitude										
FL	Pre	16	16.24	20.28	19	13.50	15.41	24	21.22	18.98
	Post	16	20.02	21.11	19	27.22	30.32	24	22.96	18.28
FM	Pre	16	6.88	9.45	19	7.01	41.21	24	6.58	11.54
	Post	16	7.82	30.79	19	14.25	16.63	24	11.43	25.74
CL	Pre	16	8.17	17.72	19	1.25	16.73	24	3.56	6.57
	Post	16	1.54	9.20	19	1.87	18.93	24	3.16	9.45
CM	Pre	16	11.73	49.26	19	-11.86	62.81	24	1.23	12.16
	Post	16	-2.90	26.13	19	-5.68	24.66	24	2.00	10.90

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
PL	Pre	16	-1.71	16.42	19	7.12	10.50	24	4.34	9.06
	Post	16	5.76	12.90	19	1.12	11.43	24	3.03	17.40
PM	Pre	16	-12.18	32.35	19	9.69	22.64	24	3.74	19.61
	Post	16	6.30	15.32	19	2.60	21.36	24	8.87	63.31
OL	Pre	16	15.38	33.02	19	7.12	13.99	24	-2.32	17.60
	Post	16	2.89	15.91	19	2.04	24.48	24	1.10	12.07
OM	Pre	16	14.01	65.24	19	7.10	38.93	24	2.85	24.25
	Post	16	4.03	36.40	19	1.24	27.36	24	4.01	32.79
LTL	Pre	16	5.45	7.65	19	5.45	5.41	24	4.62	3.39
	Post	16	5.62	5.05	19	7.56	15.38	24	4.95	5.50
RTL	Pre	16	-1.17	9.96	19	4.87	11.49	24	3.05	7.05
	Post	16	4.97	7.19	19	6.22	18.49	24	5.14	13.34
LTPJ	Pre	16	3.10	15.80	19	0.71	8.09	24	2.26	8.71
	Post	16	7.75	19.11	19	4.06	17.65	24	4.41	16.61
RTPJ	Pre	16	-1.35	8.18	19	6.86	12.76	24	-0.01	13.63
	Post	16	2.70	11.63	19	3.46	17.30	24	3.19	22.55
P3 – peak latency										
FL	Pre	16	301	42.00	19	314	34.93	24	325	48.10
	Post	16	300	42.02	19	319	50.18	24	319	39.43
FM	Pre	16	299	54.07	19	308	56.79	24	314	56.36
	Post	16	290	59.57	19	322	59.11	24	302	65.10
CL	Pre	16	316	29.77	19	299	31.43	24	301	33.17
	Post	16	313	30.92	19	308	31.94	24	300	38.49
CM	Pre	16	300	76.36	19	311	71.14	24	297	69.16
	Post	16	301	82.24	19	323	62.35	24	297	71.44
PL	Pre	16	310	39.01	19	295	38.84	24	294	48.51
	Post	16	311	38.01	19	302	42.69	24	284	42.97
PM	Pre	16	326	64.92	19	304	75.71	24	264	55.94
	Post	16	288	70.81	19	304	73.39	24	296	64.60
OL	Pre	16	301	39.25	19	287	29.48	24	299	40.05
	Post	16	294	46.98	19	291	38.34	24	298	45.09
OM	Pre	16	272	64.73	19	295	59.46	24	298	77.08

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		MCST			CST			Control	
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	16	289	72.04	19	297	57.07	24	283	71.67
LTL	Pre	16	300	40.52	19	313	32.35	24	298	28.76
	Post	16	317	33.99	19	302	32.71	24	307	21.30
RTL	Pre	16	299	32.77	19	291	27.96	24	312	27.65
	Post	16	305	28.75	19	309	29.16	24	313	35.84
LTPJ	Pre	16	301	55.28	19	295	46.92	24	292	53.55
	Post	16	318	52.84	19	298	40.48	24	288	43.54
RTPJ	Pre	16	296	45.16	19	291	55.20	24	292	45.60
	Post	16	304	53.46	19	311	58.27	24	301	43.80

Analysis of assumptions

In the simple reaction time task, assumption testing was conducted for the amplitude and latency of the N1 and P3 components across various regions of interest (ROIs).

N1 component

For the mean amplitude of N1, normality assumptions were frequently violated (W range = 0.62 - 0.95, all $p < .05$), except for OM. Homoscedasticity was generally observed (K-squared range = 0.34 - 35.87, all $p > .05$), except for CL and OL. Parallelism was mostly met (F range = 0.07 - 5.83, all $p > .05$), except for CL.

Similarly, for the peak amplitude of N1, normality assumptions were violated across ROIs (W range = 0.52 - 0.87, all $p < .05$), except for OL and OM. Homoscedasticity was predominantly observed (K-squared range = 0.52 - 42.52, all $p > .05$), except for CL and RTL. Parallelism was generally met (F range = 0.19 - 5.53, all $p > .05$), except for CL and RTL.

Regarding the peak latency of N1, normality assumptions were generally met (W range = 0.94 - 0.99, all $p > .05$). Homoscedasticity was observed in most cases (K-squared range = 0.34 - 4.36, all $p > .05$), except for OL. Parallelism was generally met (F range = 0.07 - 3.05, all $p > .05$), except for OL and LTL.

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P3 component

Moving to the P3 component, for the mean amplitude, normality assumptions were violated across ROIs (W range = 0.58 - 0.96, all $p < .05$), except for OM. Homoscedasticity was generally observed (K-squared range = 0.09 - 32.18, all $p > .05$), except for CL and OL. Parallelism was mostly met (F range = 0.21 - 5.78, all $p > .05$), except for CL, OL, and LTL.

Concerning the peak amplitude of P3, normality assumptions were violated across ROIs (W range = 0.51 - 0.93, all $p < .05$), except for OM. Homoscedasticity was predominantly observed (K-squared range = 0.19 - 37.63, all $p > .05$), except for CL and OL. Parallelism was generally met (F range = 0.14 - 5.78, all $p > .05$), except for CL, OL, and LTL.

For the peak latency of P3, normality assumptions were generally met (W range = 0.76 - 0.99, all $p > .05$). Homoscedasticity was observed in most cases (K-squared range = 0.23 - 4.89, all $p > .05$), except for OL. Parallelism was generally met (F range = 0.07 - 3.05, all $p > .05$), except for OL and LTL.

Overall, while there were some violations of normality assumptions, homoscedasticity and parallelism were generally observed across most ROIs and contrasts in the simple reaction time task, indicating that the assumptions for subsequent analyses were reasonably met.

Analysis of group comparisons

The analysis investigated the effects of group condition on various parameters of N1 and P3 components, including mean amplitude, peak amplitude, and peak latency across different brain regions during the simple reaction time task to measure psychomotor performance in older adults with MCI.

N1 component

The results of the ANCOVA for the N1 ERP component could not be interpreted due to violations of the regression slope homogeneity assumption. Therefore, separate regression analyses for each group are presented in the following section for the affected ROIs: mean amplitude (CL, OL) and peak amplitude (OL). The following are the ANCOVA results for ROIs that met the assumption.

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For the N1 component, there were no significant group effects found for mean amplitude across any brain regions, including the frontal lobe (FL), frontal midline (FM), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ). Similarly, no significant group effects were observed for the peak amplitude of the N1 component in these regions.

However, for N1 peak latency, significant group effects were found in central electrode locations (CL), parietal midline (PM), and left temporal-parietal junction (LTPJ). Specifically, the central area showed a significant group effect with a moderate effect size *(F(*2, 55*)* = 3.61, *p* = .03, partial $\omega^2 = 0.08$). Post-hoc comparisons revealed that the CST group had a significantly shorter peak latency than the control group *(t(55)* = -2.49, *p* = .05, Cohen's *d* = -0.77). In the parietal midline, there was a significant group effect with a moderate effect size *(F(*2, 55*)* = 4.88, *p* = .01, partial $\omega^2 = 0.12$), where the MCST group had a significantly longer peak latency than the CST group *(t(55)* = 2.97, *p* = .01, Cohen's *d* = 1.03). For the left temporal-parietal junction, a significant group effect with a moderate effect size *(F(*2, 55*)* = 3.44, *p* = .04, partial $\omega^2 = 0.08$) indicated that the CST group had a significantly shorter peak latency than the control group *(t(55)* = -2.62, *p* = .03, Cohen's *d* = -0.82).

P3 component

The results of the ANCOVA for the P3 ERP component could not be interpreted due to violations of the regression slope homogeneity assumption. Therefore, separate regression analyses for each group are presented in the following section for the affected ROIs: mean amplitude (CL, LTL, OL, PM) and peak amplitude (LTL, OL). The following are the ANCOVA results for ROIs that met the assumption.

For the P3 component, no significant group effects were found for mean or peak amplitude across all brain regions, including the frontal lobe (FL), frontal midline (FM), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital midline (OM), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ). Additionally, no

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significant group effects were observed for the peak latency of the P3 component in these regions.

In summary, significant group effects were observed for the N1 peak latency in the central area, parietal midline, and left temporal-parietal junction, indicating that ERP responses differed notably among the MCST, CST, and control groups in these specific brain regions during the simple reaction time task. No significant group effects were found for the N1 mean amplitude, N1 peak amplitude, P3 mean amplitude, P3 peak amplitude, or P3 peak latency across all brain regions.

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Table 76 ANCOVA of amplitude and latency of ERPs in the simple reaction time task

		Df	*SS*	*MS*	*F*	*p*	ω_p^2
N1 – mean amplitude							
FL	Pre-test	1	16.37	16.37	0.15	.70	<.01
	Group	2	291.07	145.54	1.35	.27	0.01
	Residuals	55	5,924.18	107.71			
FM	Pre-test	1	9.79	9.79	0.04	.85	<.01
	Group	2	280.63	140.31	0.50	.61	<.01
	Residuals	55	15,305.51	278.28			
CL*	Pre-test	1	1,123.76	1,123.76	22.58	<.01	0.27
	Group	2	21.02	10.51	0.21	.81	<.01
	Residuals	55	2,737.65	49.78			
CM	Pre-test	1	5,468.03	5,468.03	17.66	<.01	0.22
	Group	2	232.40	116.20	0.38	.69	<.01
	Residuals	55	17,025.45	309.55			
PL	Pre-test	1	28.13	28.13	0.60	.44	<.01
	Group	2	207.52	103.76	2.23	.12	0.04
	Residuals	55	2,564.11	46.62			
PM	Pre-test	1	91.75	91.75	0.34	.56	<.01
	Group	2	221.84	110.92	0.41	.67	<.01
	Residuals	55	14,865.84	270.29			
OL*	Pre-test	1	173.53	173.53	1.69	.2	0.01
	Group	2	13.81	6.91	0.07	.93	<.01
	Residuals	55	5,637.69	102.50			

		Df	*SS*	*MS*	*F*	*p*	ω_p^2
OM	Pre-test	1	62.33	62.33	0.14	.71	<.01
	Group	2	416.41	208.20	0.46	.63	<.01
	Residuals	55	24,727.31	449.59			
LTL	Pre-test	1	12.21	12.21	1.01	.32	<.01
	Group	2	9.54	4.77	0.40	.68	<.01
	Residuals	55	663.80	12.07			
RTL	Pre-test	1	84.72	84.72	2.17	.15	0.02
	Group	2	29.49	14.74	0.38	.69	<.01
	Residuals	55	2,142.99	38.96			
LTPJ	Pre-test	1	195.10	195.10	3.37	.07	0.04
	Group	2	20.06	10.03	0.17	.84	<.01
	Residuals	55	3,186.17	57.93			
RTPJ	Pre-test	1	130.62	130.62	2.24	.14	0.02
	Group	2	54.48	27.24	0.47	.63	<.01
	Residuals	55	3,204.56	58.26			
N1 – peak amplitude							
FL	Pre-test	1	81.85	81.85	0.25	.62	<.01
	Group	2	1,041.55	520.77	1.56	.22	0.02
	Residuals	55	18,345.95	333.56			
FM	Pre-test	1	648.30	648.30	1.37	.25	0.01
	Group	2	1,341.03	670.52	1.42	.25	0.01
	Residuals	55	26,022.95	473.14			
CL	Pre-test	1	37.63	37.63	0.47	.49	<.01
	Group	2	44.57	22.28	0.28	.76	<.01
	Residuals	55	4,375.25	79.55			
CM	Pre-test	1	241.39	241.39	0.98	.33	<.01
	Group	2	38.29	19.15	0.08	.93	<.01
	Residuals	55	13,573.31	246.79			
PL	Pre-test	1	230.38	230.38	2.24	.14	0.02
	Group	2	195.89	97.94	0.95	.39	<.01
	Residuals	55	5,657.43	102.86			
PM	Pre-test	1	1,744.32	1,744.32	2.74	.10	0.03
	Group	2	297.99	149.00	0.23	.79	<.01

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		Df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	55	35,058.04	637.42			
OL*	Pre-test	1	31.46	31.46	0.19	.66	<.01
	Group	2	110.40	55.20	0.34	.71	<.01
	Residuals	55	8,948.16	162.69			
OM	Pre-test	1	12.96	12.96	0.02	.89	<.01
	Group	2	813.03	406.52	0.59	.56	<.01
	Residuals	55	37,646.63	684.48			
LTL	Pre-test	1	24.44	24.44	0.53	.47	<.01
	Group	2	31.92	15.96	0.35	.71	<.01
	Residuals	55	2,539.38	46.17			
RTL	Pre-test	1	89.02	89.02	0.93	.34	<.01
	Group	2	82.31	41.15	0.43	.65	<.01
	Residuals	55	5,265.94	95.74			
LTPJ	Pre-test	1	264.24	264.24	1.92	.17	0.02
	Group	2	27.19	13.60	0.10	.91	<.01
	Residuals	55	7,555.61	137.37			
RTPJ	Pre-test	1	336.74	336.74	3.65	.06	0.04
	Group	2	1.06	0.53	0.01	.99	<.01
	Residuals	55	5,079.66	92.36			
N1 – peak latency							
FL	Pre-test	1	822.20	822.20	0.57	.45	<.01
	Group	2	3,918.29	1,959.14	1.37	.26	0.01
	Residuals	55	78,865.44	1,433.92			
FM	Pre-test	1	13.16	13.16	0.00	.95	<.01
	Group	2	12,473.47	6,236.73	1.73	.19	0.02
	Residuals	55	197,775.82	3,595.92			
CL	Pre-test	1	5,446.01	5,446.01	5.46	.02	0.07
	Group	2	7,197.55	3,598.78	3.61	.03	0.08
	Residuals	55	54,856.75	997.40			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	55	4.32	10.77	0.40	1	0.14
	MCST-Control	55	-19.95	10.19	-1.96	.17	-0.63

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		Df	*SS*	*MS*	*F*	*p*	ω_p^2
	CST-Control	55	-24.27	9.75	-2.49	.05	-0.77
CM	Pre-test	1	715.63	715.63	0.20	.66	<.01
	Group	2	14,012.23	7,006.11	1.93	.15	0.03
	Residuals	55	199,653.30	3,630.06			
PL	Pre-test	1	1,732.01	1,732.01	1.45	.23	0.01
	Group	2	7,640.72	3,820.36	3.19	.05	0.07
	Residuals	55	65,859.87	1,197.45			
PM	Pre-test	1	7,974.93	7,974.93	2.61	.11	0.03
	Group	2	29,827.02	14,913.51	4.88	.01	0.12
	Residuals	55	168,088.86	3,056.16			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	55	56.88	19.14	2.97	.01	1.03
	MCST-Control	55	18.48	18.70	0.99	.98	0.33
	CST-Control	55	-38.40	17.07	-2.25	.09	-0.69
OL	Pre-test	1	6.00	6.00	0.01	.94	<.01
	Group	2	2,609.93	1,304.97	1.23	.30	0.01
	Residuals	55	58,285.81	1,059.74			
OM	Pre-test	1	3,454.02	3,454.02	0.79	.38	<.01
	Group	2	922.16	461.08	0.11	.90	<.01
	Residuals	55	239,157.12	4,348.31			
LTL	Pre-test	1	457.41	457.41	0.39	.53	<.01
	Group	2	6,126.90	3,063.45	2.63	.08	0.05
	Residuals	55	63,969.78	1,163.09			
RTL	Pre-test	1	10,914.39	10,914.39	9.04	<.01	0.12
	Group	2	4,767.76	2,383.88	1.97	.15	0.03
	Residuals	55	66,420.30	1,207.64			
LTPJ	Pre-test	1	537.93	537.93	0.34	.56	<.01
	Group	2	10,824.46	5,412.23	3.44	.04	0.08
	Residuals	55	86,488.09	1,572.51			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	55	15.86	14.09	1.13	.80	0.40
	MCST-	55	-16.54	14.24	-1.16	.75	-0.42

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		Df	*SS*	*MS*	*F*	*p*	ω_p^2
	Control						
	CST-Control	55	-32.40	12.35	-2.62	.03	-0.82
RTPJ	Pre-test	1	236.96	236.96	0.13	.72	<.01
	Group	2	4,378.86	2,189.43	1.16	.32	0.01
	Residuals	55	103,923.94	1,889.53			
P3 – mean amplitude							
FL	Pre-test	1	2,219.31	2,219.31	9.09	<.01	0.12
	Group	2	386.88	193.44	0.79	.46	<.01
	Residuals	55	13,432.22	244.22			
FM	Pre-test	1	310.23	310.23	0.69	.41	0.00
	Group	2	111.26	55.63	0.12	.88	<.01
	Residuals	55	24,769.68	450.36			
CL*	Pre-test	1	2,450.40	2,450.40	13.83	<.01	0.18
	Group	2	335.98	167.99	0.95	.39	<.01
	Residuals	55	9,744.29	177.17			
CM	Pre-test	1	2,954.60	2,954.60	3.99	.05	0.05
	Group	2	2,151.51	1,075.76	1.45	.24	0.02
	Residuals	55	40,685.89	739.74			
PL	Pre-test	1	680.21	680.21	4.56	.04	0.06
	Group	2	519.01	259.50	1.74	.19	0.02
	Residuals	55	8,206.19	149.20			
PM*	Pre-test	1	3,898.23	3,898.23	2.84	.10	0.03
	Group	2	1,409.97	704.98	0.51	.60	<.01
	Residuals	55	75,493.07	1,372.60			
OL*	Pre-test	1	204.85	204.85	0.67	.42	<.01
	Group	2	113.75	56.88	0.19	.83	<.01
	Residuals	55	16,724.34	304.08			
OM	Pre-test	1	1,722.27	1,722.27	1.68	.20	0.01
	Group	2	1,112.74	556.37	0.54	.59	<.01
	Residuals	55	56,525.19	1,027.73			
LTL*	Pre-test	1	100.69	100.69	1.79	.19	0.01
	Group	2	26.10	13.05	0.23	.79	<.01
	Residuals	55	3,088.99	56.16			

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		Df	*SS*	*MS*	*F*	*p*	ω_p^2
RTL	Pre-test	1	740.82	740.82	4.47	.04	0.06
	Group	2	46.55	23.28	0.14	.87	<.01
	Residuals	55	9,109.27	165.62			
LTPJ	Pre-test	1	261.79	261.79	1.06	.31	<.01
	Group	2	152.17	76.08	0.31	.74	<.01
	Residuals	55	13,555.06	246.46			
RTPJ	Pre-test	1	472.89	472.89	1.64	.21	0.01
	Group	2	62.55	31.28	0.11	.90	<.01
	Residuals	55	15,893.28	288.97			
P3 – peak amplitude							
FL	Pre-test	1	4,321.59	4,321.59	9.08	<.01	0.12
	Group	2	873.90	436.95	0.92	.41	<.01
	Residuals	55	26,186.02	476.11			
FM	Pre-test	1	115.46	115.46	0.19	.67	<.01
	Group	2	358.56	179.28	0.29	.75	<.01
	Residuals	55	34,319.04	623.98			
CL	Pre-test	1	1,278.75	1,278.75	8.36	<.01	0.11
	Group	2	107.58	53.79	0.35	.71	<.01
	Residuals	55	8,413.83	152.98			
CM	Pre-test	1	140.05	140.05	0.32	.57	<.01
	Group	2	607.60	303.80	0.70	.50	<.01
	Residuals	55	23,821.54	433.12			
PL	Pre-test	1	499.89	499.89	2.49	.12	0.02
	Group	2	436.63	218.32	1.09	.34	<.01
	Residuals	55	11,060.93	201.11			
PM	Pre-test	1	3,302.47	3,302.47	1.82	.18	0.01
	Group	2	1,145.49	572.75	0.32	.73	<.01
	Residuals	55	99,905.81	1,816.47			
OL*	Pre-test	1	82.84	82.84	0.25	.62	<.01
	Group	2	7.93	3.97	0.01	.99	<.01
	Residuals	55	17,877.85	325.05			
OM	Pre-test	1	2,311.92	2,311.92	2.28	.14	0.02
	Group	2	123.28	61.64	0.06	.94	<.01

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		Df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	55	55,734.87	1,013.36			
LTL*	Pre-test	1	193.90	193.90	2.08	.15	0.02
	Group	2	90.04	45.02	0.48	.62	<.01
	Residuals	55	5,127.98	93.24			
RTL	Pre-test	1	575.81	575.81	3.03	.09	0.03
	Group	2	14.60	7.30	0.04	.96	<.01
	Residuals	55	10,444.58	189.90			
LTPJ	Pre-test	1	380.79	380.79	1.23	.27	<.01
	Group	2	114.90	57.45	0.19	.83	<.01
	Residuals	55	17,078.33	310.52			
RTPJ	Pre-test	1	389.93	389.93	1.15	.29	<.01
	Group	2	16.69	8.34	0.02	.98	<.01
	Residuals	55	18,704.18	340.08			
P3 – peak latency							
FL	Pre-test	1	5,444.12	5,444.12	2.89	.09	0.03
	Group	2	2,633.36	1,316.68	0.70	.50	<.01
	Residuals	55	103,659.25	1,884.71			
FM	Pre-test	1	717.56	717.56	0.19	.67	<.01
	Group	2	9,153.11	4,576.56	1.18	.31	0.01
	Residuals	55	213,060.86	3,873.83			
CL	Pre-test	1	3,587.68	3,587.68	3.09	.08	0.03
	Group	2	1,157.36	578.68	0.50	.61	<.01
	Residuals	55	63,797.12	1,159.95			
CM	Pre-test	1	21,407.68	21,407.68	4.37	.04	0.05
	Group	2	5,437.77	2,718.89	0.55	.58	<.01
	Residuals	55	269,450.41	4,899.10			
PL	Pre-test	1	3,011.40	3,011.40	1.74	.19	0.01
	Group	2	6,880.69	3,440.34	1.99	.15	0.03
	Residuals	55	95,036.27	1,727.93			
PM	Pre-test	1	17,525.48	17,525.48	3.91	.05	0.05
	Group	2	6,667.78	3,333.89	0.74	.48	<.01
	Residuals	55	246,232.13	4,476.95			
OL	Pre-test	1	344.91	344.91	0.18	.67	<.01

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		Df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	443.42	221.71	0.11	.89	<.01
	Residuals	55	106,063.57	1,928.43			
OM	Pre-test	1	950.91	950.91	0.21	.65	<.01
	Group	2	1,965.78	982.89	0.21	.81	<.01
	Residuals	55	253,589.62	4,610.72			
LTL	Pre-test	1	81.62	81.62	0.10	.76	<.01
	Group	2	2,073.79	1,036.90	1.21	.31	0.01
	Residuals	55	47,015.06	854.82			
RTL	Pre-test	1	3.62	3.62	0.00	.95	<.01
	Group	2	617.25	308.62	0.30	.74	<.01
	Residuals	55	57,205.83	1,040.11			
LTPJ	Pre-test	1	1,075.56	1,075.56	0.52	.47	<.01
	Group	2	8,437.04	4,218.52	2.03	.14	0.03
	Residuals	55	114,310.75	2,078.38			
RTPJ	Pre-test	1	643.83	643.83	0.24	.63	<.01
	Group	2	1,139.46	569.73	0.21	.81	<.01
	Residuals	55	147,440.13	2,680.73			

*A significant interaction effect

Analysis of regression

This section examines the ERP parameters (mean amplitude and peak amplitude) across regions of interest (ROIs) and components, grouped by intervention conditions (MCST, CST, and Control) for the simple reaction time task.

The analysis of N100 and P300 components across regions reveals significant differences in the relationships between pre-test performance and mean and peak amplitudes among groups. For the N100 component's mean amplitude in the CL region, the CST group demonstrates a strong predictive relationship (β_1 = 1.08, p < .001, adjusted R^2 = .65), while the MCST (β_1 = 0.08, p = .56, adjusted R^2 = -.05) and control groups (β_1 = 0.55, p = .16, adjusted R^2 = .05) fail to show significance. Similarly, for the P300 component's mean amplitude in the same region, both the CST (β_1 = 0.82, p = .01, adjusted R^2 = .34) and control (β_1 = 0.73, p = .03,

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adjusted R^2 = .17) groups exhibit significant relationships, while the MCST group does not (β_1 = 0.08, p = .62, adjusted R^2 = -.05).

In the OL region, the N100 component's mean amplitude shows a significant negative relationship for the CST group (β_1 = -0.56, p = .02, adjusted R^2 = .23), with non-significant results for the MCST (β_1 = 0.17, p = .35, adjusted R^2 = -.01) and control groups (β_1 = -0.07, p = .62, adjusted R^2 = -.03). For the P300 component's mean amplitude, the CST group again demonstrates significance (β_1 = -1.05, p = .02, adjusted R^2 = .24), while the MCST (β_1 = 0.07, p = .69, adjusted R^2 = -.06) and control groups (β_1 = -0.06, p = .59, adjusted R^2 = -.03) do not.

For peak amplitudes, the N100 component in the OL region shows a strong predictive relationship for the MCST group (β_1 = 0.52, p = .01, adjusted R^2 = .37), whereas the CST (β_1 = -0.26, p = .13, adjusted R^2 = .08) and control groups (β_1 = -0.06, p = .66, adjusted R^2 = -.04) do not (see). For the P300 component, the MCST group demonstrates significance in the OL region (β_1 = 0.27, p = .02, adjusted R^2 = .28), with non-significant results for the CST (β_1 = -0.74, p = .07, adjusted R^2 = .13) and control groups (β_1 = -0.08, p = .57, adjusted R^2 = -.03). In the LTL region, the CST group shows a significant negative relationship (β_1 = -1.42, p = .03, adjusted R^2 = .21), while the control group exhibits a non-significant positive trend (β_1 = 0.49, p = .15, adjusted R^2 = .05), and the MCST group fails to reach significance (β_1 = 0.03, p = .86, adjusted R^2 = -.07).

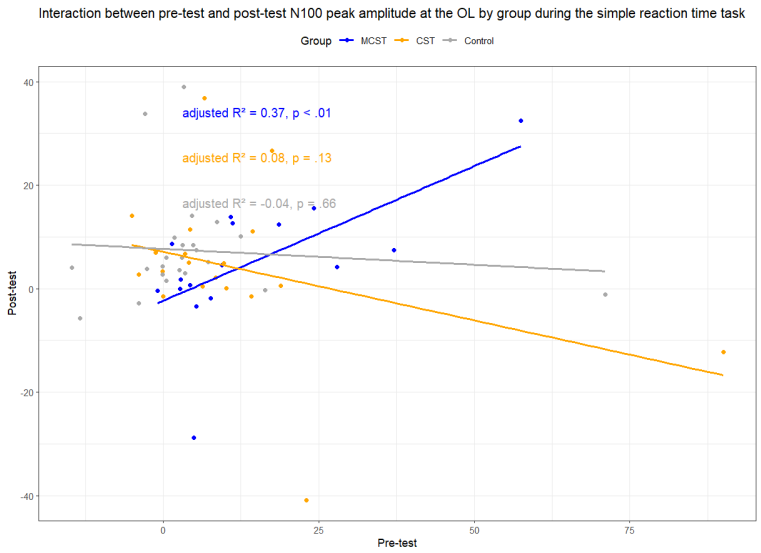

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Figure 74 A scatter plot and the regression lines are shows interaction between pre-test and post-test N100 peak amplitude in the occipital lobe (OL) area by group during the simple reaction time task (SRAT)

In summary, In the simple reaction time task, the CST group demonstrates consistent and significant relationships across several ROIs and components (e.g., N100 and P300 in the CL and OL regions), indicating that the intervention had a meaningful effect on ERP parameters. The MCST group shows some significant effects, particularly for the N100 component (OL region), suggesting partial modulation by this intervention. The control group exhibits fewer significant relationships, though notable effects are seen for the P300 component (CL and LTL regions).

Table 77 Regression analysis of ERP components during the simple reaction time task

ROI	Model	Variable	*β*	*SE*	*t*	*P*
N100 – Mean applitude						
CL	MCST	Constant	-1.28	0.87	-1.46	.17
		Pre-test	0.08	0.13	0.59	.56
	CST	Constant	-0.01	1.55	-0.01	.99
		Pre-test	1.08	0.18	5.91	<.01
	Control	Constant	-2.11	1.70	-1.25	.23
		Pre-test	0.55	0.38	1.45	.16
OL	MCST	Constant	-2.19	2.60	-0.84	.41
		Pre-test	0.17	0.17	0.96	.35
	CST	Constant	-1.44	2.75	-0.52	.61
		Pre-test	-0.56	0.22	-2.53	.02
	Control	Constant	-1.24	1.39	-0.89	.38
		Pre-test	-0.07	0.13	-0.50	.62
N100 – Peak amplitude						
OL	MCST	Constant	-2.33	3.43	-0.68	.51
		Pre-test	0.52	0.17	3.14	.01
	CST	Constant	7.13	3.90	1.83	.09
		Pre-test	-0.26	0.17	-1.57	.13
	Control	Constant	7.70	2.18	3.53	<.01
		Pre-test	-0.06	0.14	-0.45	.66
P300 – Mean amplitude						
CL	MCST	Constant	-6.27	2.25	-2.79	.01

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ROI	Model	Variable	*β*	*SE*	*t*	*P*
		Pre-test	0.08	0.15	0.51	.62
	CST	Constant	-1.18	4.16	-0.28	.78
		Pre-test	0.82	0.26	3.19	.01
	Control	Constant	-1.88	2.09	-0.90	.38
		Pre-test	0.73	0.31	2.37	.03
OL	MCST	Constant	-4.74	4.71	-1.01	.33
		Pre-test	0.07	0.16	0.40	.69
	CST	Constant	-6.72	4.83	-1.39	.18
		Pre-test	-1.05	0.41	-2.59	.02
	Control	Constant	-6.50	1.96	-3.32	<.01
		Pre-test	-0.06	0.11	-0.54	.59
PM	MCST	Constant	0.32	3.61	0.09	.93
		Pre-test	0.05	0.10	0.46	.65
	CST	Constant	-4.48	5.78	-0.77	.45
		Pre-test	0.05	0.27	0.17	.87
	Control	Constant	6.53	10.1	0.65	.52
		Pre-test	1.31	0.52	2.5	.02
LTL	MCST	Constant	0.12	0.97	0.13	.90
		Pre-test	-0.06	0.12	-0.51	.62
	CST	Constant	0.73	2.46	0.30	.77
		Pre-test	-0.92	0.43	-2.13	.05
	Control	Constant	-0.25	0.90	-0.28	.78
		Pre-test	0.56	0.24	2.30	.03

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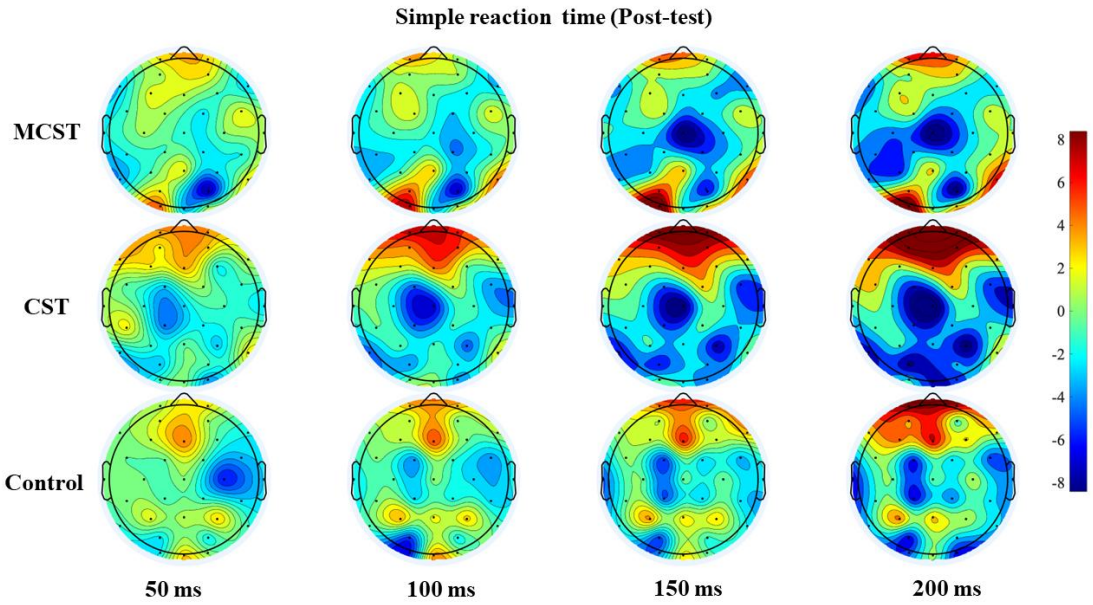

Figure 75 The topographic brain mapping of mean amplitude for each 50 ms latency window during the simple reaction time task at post-test

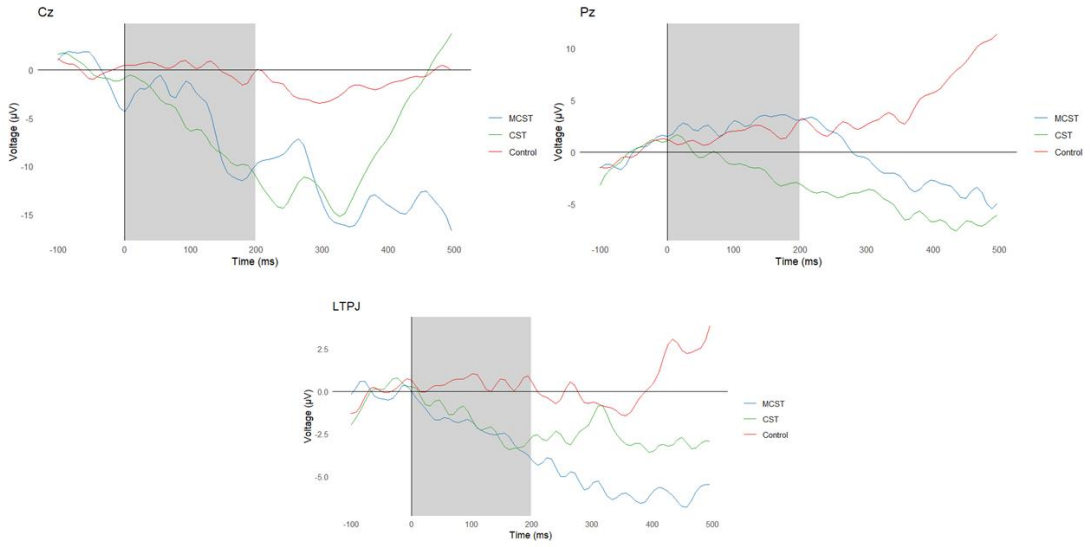

Figure 76 Grand-average ERP waveforms over the central and parietal midlines (Cz and Pz) and the left temporoparietal junction (LTPJ) across three groups in the simple reaction time task

ERP - Choice reaction time task

Analysis of the amplitude and latency characteristics

P3 component - Mean amplitude

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In the frontal region (FL, FM), the MCST group demonstrated a significant increase in mean amplitude post-test, indicating enhanced neural activity. The CST group also exhibited an increase, though less pronounced than the MCST group. The control group showed a moderate improvement in this region.

In the central region (CL, CM), the MCST group displayed mixed changes post-test. Specifically, there was a decrease in mean amplitude at the central midline (CM) but an increase in central electrode locations (CL). The CST group experienced an overall increase, while the control group showed a slight improvement.

In the parietal region (PL, PM), the MCST group showed mixed changes, with a slight increase in the parietal lobe (PL) and a decrease in the parietal midline (PM). The CST group exhibited a decrease in mean amplitude, whereas The control group experienced minor improvements.

In the temporal region (LTL, RTL, LTPJ, RTPJ), the MCST group demonstrated mixed changes with increases in some areas and decreases in others. The CST group exhibited minor increases overall, while the control group had slight changes, with some areas showing improvements and others experiencing decreases.

P3 component - Peak amplitude

In the frontal region (FL, FM), the MCST group exhibited a notable increase in peak amplitude post-test, suggesting stronger neural responses. The CST group also showed an increase, while the control group experienced a slight improvement.

In the central region (CL, CM), the MCST group displayed mixed changes post-test, with a decrease in peak amplitude at the central midline (CM) but increases in central electrode locations (CL). The CST group showed a slight increase, while the control group had minor improvements.

In the parietal region (PL, PM), the MCST group showed an increase in peak amplitude post-test in both the parietal lobe (PL) and parietal midline (PM), indicating stronger neural responses in these areas. The CST

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group exhibited mixed changes, with minor increases, while the control group showed slight improvements.

In the temporal region (LTL, RTL, LTPJ, RTPJ), the MCST group exhibited mixed changes with increases in some areas and decreases in others. The CST group showed minor increases overall, while the control group experienced slight improvements.

P3 component - Peak latency

In the frontal region (FL, FM), the MCST group showed an increase in peak latency post-test, indicating slower neural responses. The CST group also experienced an increase, while the control group showed a slight decrease.

In the central region (CL, CM), the MCST group displayed mixed changes post-test, with increases in some areas and decreases in others. The CST group showed minor increases, while the control group had slight changes.

In the parietal region (PL, PM), the MCST group showed a decrease in peak latency post-test, indicating faster neural responses. The CST group exhibited a slight decrease, while the control group showed mixed changes with minor decreases.

In the temporal region (LTL, RTL, LTPJ, RTPJ), the MCST group showed mixed changes, with increases in some areas and decreases in others. The CST group exhibited minor decreases overall, while the control group showed slight increases in some areas.

Overall, the MCST group demonstrated various changes in ERP characteristics, with some regions showing improvements in mean and peak amplitudes and latencies, while others exhibited reductions or mixed changes. The CST and control groups generally exhibited minor changes, with some increases or decreases in specific regions.

Table 78 Characteristic of amplitude and latency of ERPs in the choice reaction time task

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
P3 – mean amplitude										
FL	Pre	23	5.53	15.82	21	-0.27	15.20	22	5.21	10.67
	Post	23	11.82	19.91	21	3.83	18.77	22	7.07	8.79
FM	Pre	23	3.88	11.02	21	1.24	12.26	22	1.05	14.69
	Post	23	11.26	21.28	21	6.04	8.31	22	12.73	31.42
CL	Pre	23	1.73	10.00	21	-0.44	7.55	22	2.15	10.11
	Post	23	-1.49	6.04	21	3.62	6.98	22	2.88	5.96
CM	Pre	23	7.85	31.80	21	1.97	28.57	22	2.82	14.69
	Post	23	-5.17	18.05	21	7.58	15.06	22	1.66	10.30
PL	Pre	23	-2.04	13.93	21	-0.39	5.02	22	-4.29	7.31
	Post	23	0.86	15.38	21	-3.11	9.52	22	-0.16	11.43
PM	Pre	23	13.64	39.96	21	2.92	13.15	22	-8.58	31.04
	Post	23	8.31	26.56	21	-2.78	26.66	22	-0.23	18.37
OL	Pre	23	1.09	23.98	21	1.44	12.18	22	-1.94	10.23
	Post	23	-10.83	39.68	21	-7.09	15.78	22	-7.42	13.71
OM	Pre	23	-7.14	47.98	21	-5.17	23.50	22	-5.68	17.44
	Post	23	-16.79	52.94	21	6.53	25.57	22	-0.38	18.07
LTL	Pre	23	-5.44	14.97	21	-0.70	4.07	22	-1.00	4.38
	Post	23	1.94	11.27	21	1.63	5.75	22	-1.30	6.25
RTL	Pre	23	0.17	13.77	21	0.41	9.62	22	0.06	6.91
	Post	23	-2.24	6.37	21	0.65	7.94	22	-0.67	4.67
LTPJ	Pre	23	-12.72	22.78	21	-4.22	10.31	22	-2.97	4.86
	Post	23	-4.10	12.33	21	-2.69	6.99	22	-4.28	8.76
RTPJ	Pre	23	0.01	10.65	21	0.09	13.17	22	-1.23	6.17
	Post	23	-5.98	12.20	21	-0.02	8.51	22	1.02	9.91
P3 – peak amplitude										
FL	Pre	23	16.11	23.25	21	5.48	15.19	22	11.54	14.44
	Post	23	20.24	23.90	21	12.85	24.74	22	13.96	14.71
FM	Pre	23	8.98	12.49	21	4.91	12.67	22	4.59	14.57
	Post	23	16.83	24.93	21	10.57	10.73	22	18.13	39.04
CL	Pre	23	8.84	9.04	21	3.08	7.04	22	5.94	11.41
	Post	23	4.37	7.66	21	7.90	8.53	22	6.94	9.73

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
CM	Pre	23	15.91	30.02	21	5.73	24.99	22	6.12	13.08
	Post	23	-1.21	18.56	21	13.04	16.99	22	4.47	10.64
PL	Pre	23	6.61	13.72	21	3.34	4.67	22	0.12	6.55
	Post	23	5.71	16.78	21	1.59	10.72	22	4.66	16.74
PM	Pre	23	22.31	46.30	21	6.44	14.97	22	-1.30	18.96
	Post	23	13.99	33.73	21	2.87	29.35	22	4.36	22.16
OL	Pre	23	12.70	28.33	21	6.11	15.29	22	4.02	11.56
	Post	23	-1.41	28.42	21	-0.34	16.74	22	-1.91	11.43
OM	Pre	23	1.87	45.17	21	-1.01	24.26	22	0.18	19.12
	Post	23	-8.13	39.31	21	12.30	35.62	22	6.17	16.19
LTL	Pre	23	1.77	17.16	21	3.23	3.76	22	3.27	4.28
	Post	23	6.61	13.13	21	6.52	6.31	22	3.26	5.62
RTL	Pre	23	9.93	19.86	21	5.35	9.97	22	4.58	7.84
	Post	23	3.29	6.75	21	5.47	8.23	22	3.57	4.43
LTPJ	Pre	23	-5.36	24.59	21	-0.67	7.44	22	0.23	4.56
	Post	23	-0.13	12.59	21	2.30	6.77	22	0.04	12.57
RTPJ	Pre	23	10.26	16.61	21	5.00	11.31	22	3.00	6.66
	Post	23	-0.62	10.43	21	4.76	8.05	22	5.39	12.56
P3 – peak latency										
FL	Pre	23	317	34.43	21	317	29.42	22	300	35.46
	Post	23	320	43.95	21	312	44.79	22	288	27.37
FM	Pre	23	296	54.85	21	300	62.97	22	303	71.12
	Post	23	328	58.49	21	325	57.83	22	291	64.00
CL	Pre	23	312	37.46	21	301	27.67	22	300	32.69
	Post	23	312	38.70	21	310	32.41	22	304	42.06
CM	Pre	23	313	62.49	21	300	68.69	22	295	70.96
	Post	23	310	64.96	21	318	74.13	22	319	63.52
PL	Pre	23	299	41.43	21	276	25.72	22	301	40.54
	Post	23	300	46.48	21	292	39.41	22	317	39.74
PM	Pre	23	294	58.99	21	272	54.45	22	319	75.53
	Post	23	297	70.24	21	299	67.38	22	323	60.78
OL	Pre	23	299	38.63	21	278	31.92	22	298	39.63

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		MCST			CST			Control	
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	23	279	40.79	21	289	37.62	22	306	38.92
OM	Pre	23	310	75.19	21	284	75.57	22	276	72.54
	Post	23	265	58.87	21	277	59.75	22	309	71.73
LTL	Pre	23	317	30.39	21	303	37.73	22	328	27.44
	Post	23	322	25.12	21	305	36.91	22	307	37.85
RTL	Pre	23	307	37.65	21	291	38.48	22	297	35.23
	Post	23	309	31.74	21	295	33.94	22	304	31.17
LTPJ	Pre	23	304	47.09	21	287	47.42	22	308	43.78
	Post	23	308	58.38	21	280	41.56	22	321	46.52
RTPJ	Pre	23	299	49.57	21	283	37.84	22	291	41.15
	Post	23	289	42.05	21	284	47.14	22	322	44.86

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Analysis of assumptions

In the choice reaction time task, assumption testing was performed for the amplitude and latency of the P3 component across various regions of interest (ROIs).

For the mean amplitude of P3, normality assumptions were violated across ROIs (W range = 0.54 - 0.96, all $p < .05$), except for CL and CM. Homoscedasticity was generally observed (K-squared range = 0.04 - 29.08, all $p > .05$), except for FM and LTPJ. Parallelism was mostly met (F range = 0.06 - 3.17, all $p > .05$), except for CM and LTPJ.

Similarly, normality assumptions were frequently violated for the peak amplitude of P3 (W range = 0.51 - 0.97, all $p < .05$), except for OM. Homoscedasticity was predominantly observed (K-squared range = 0.16 - 28.01, all $p > .05$), except for CM and RTL. Parallelism was generally met (F range = 0.09 - 3.82, all $p > .05$), except for CM, RTL, and LTPJ.

Regarding the peak latency of P3, normality assumptions were generally met (W range = 0.92 - 0.99, all $p > .05$). Homoscedasticity was observed in most cases (K-squared range = 0.14 - 5.60, all $p > .05$), except for RTL. Parallelism was generally met (F range = 0.09 - 2.68, all $p > .05$), except for LTPJ.Overall, while

there were some violations of normality assumptions, homoscedasticity and parallelism were generally observed across most ROIs and contrasts in the choice reaction time task, suggesting that the assumptions for subsequent analyses were reasonably met.

Analysis of group comparisons

The analysis investigated the effects of group condition on various parameters of P3 components, including mean amplitude, peak amplitude, and peak latency across different brain regions during the choice reaction time task to measure psychomotor performance in older adults with MCI. However, The results of the ANCOVA for the P3 ERP component (Peak Amplitude) could not be interpreted due to violations of the regression slope homogeneity assumption. Therefore, a separate regression analysis for each group is presented in the following section for the affected the OM. The following are the ANCOVA results for ROIs that met the assumption.

The analysis of mean amplitude P3 ERP revealed several significant and non-significant group effects across different brain regions. For the frontal lobe (FL), frontal midline (FM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), and left temporal-parietal junction (LTPJ), no significant group effects were observed (all $p > .05$, partial $\omega^2 < .01$). These results indicate that the group condition did not significantly influence the mean amplitude P3 ERP in these regions. However, significant effects were found in central electrode locations (CL) and central midline (CM). For the central area, a significant group effect was observed *(F(*2, 62*)* = 4.11, $p = .02$, partial $\omega^2 = 0.09$), indicating a moderate effect size. Post-hoc comparisons using the t-test with Bonferroni correction revealed that the MCST group had a significantly lower mean amplitude than the CST group *(t(62)* = -2.59, $p = .04$, Cohen's $d = -0.79$). Additionally, the MCST group showed a trend towards being significantly different from the control group *(t(62)* = -2.31, $p = .07$, Cohen's $d = -0.69$), while the CST group did not significantly differ from The control group *(t(62)* = 0.31, $p = 1$, Cohen's $d = 0.10$).

For the central midline, a significant group effect was also found *(F(*2, 62*)* = 3.74, $p = .03$, partial $\omega^2 = 0.08$), indicating a moderate effect size.

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Post-hoc analysis indicated that the MCST group was significantly different from the CST group *(t(62)* = -2.73, *p* = .02, Cohen's *d* = -0.83). However, no significant differences were found between the MCST and control groups *(t(62)* = -1.45, *p* = .46, Cohen's *d* = -0.43) and the CST and control groups *(t(62)* = 1.29, *p* = .60, Cohen's *d* = 0.39).

In the right temporal-parietal junction (RTPJ), a significant group effect was observed *(F(*2, 62*)* = 3.19, *p* = .05, partial $\omega^2 = 0.06$), indicating a moderate effect size. Post-hoc comparisons revealed that the MCST group was significantly different from the control group *(t(62)* = -2.53, *p* = .04, Cohen's *d* = -0.78). No significant differences were found between the MCST and CST groups *(t(62)* = -2.16, *p* = .10, Cohen's *d* = -0.66) and the CST and control groups *(t(62)* = -0.37, *p* = 1, Cohen's *d* = -0.11).

The peak amplitude P3 ERP analysis showed no significant group effects in most regions, including the frontal lobe (FL), frontal midline (FM), central lobe (CL), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), left temporal lobe (LTL), right temporal lobe (RTL), and left temporal-parietal junction (LTPJ) (all $p > .05$, partial $\omega^2 < .01$).

A significant effect was found in the central midline (CM), where the group effect was significant *(F(*2, 62*)* = 3.90, *p* = .03, partial $\omega^2 = 0.08$), indicating a moderate effect size. Post-hoc analysis indicated that the MCST group was significantly different from the CST group *(t(62)* = -2.76, *p* = .02, Cohen's *d* = -0.85). No significant differences were found between the MCST and control groups *(t(62)* = -1.01, *p* = .95, Cohen's *d* = -0.31) and the CST and control groups *(t(62)* = 1.77, *p* = .24, Cohen's *d* = 0.54).

The right temporal-parietal junction (RTPJ) also showed a significant group effect *(F(*2, 62*)* = 3.72, *p* = .03, partial $\omega^2 = 0.08$), indicating a moderate effect size. Post-hoc comparisons revealed that the MCST group was significantly different from the control group *(t(62)* = -2.53, *p* = .04, Cohen's *d* = -0.78). No significant differences were found between the MCST and CST groups *(t(62)* = -2.16, *p* = .10, Cohen's *d* = -0.66) and the CST and control groups *(t(62)* = -0.37, *p* = 1, Cohen's *d* = -0.11).

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The peak latency P3 ERP analysis revealed a significant group effect in the frontal lobe (FL) *(F(*2, 62*)* = 3.68, *p* = .03, partial ω² = 0.08), indicating a moderate effect size. Post-hoc comparisons indicated that the MCST group was significantly different from the control group *(t(62)* = 2.62, *p* = .03, Cohen's *d* = 0.80). However, no significant differences were found between the MCST and CST groups *(t(62)* = 0.62, *p* = 1, Cohen's *d* = 0.19) and the CST and control groups *(t(62)* = 1.97, *p* = .16, Cohen's *d* = 0.61).

The right temporal-parietal junction (RTPJ) also showed a significant group effect *(F(*2, 62*)* = 4.56, *p* = .01, partial ω² = 0.10), indicating a moderate effect size. Post-hoc comparisons revealed that the MCST group was significantly different from the control group *(t(62)* = -2.50, *p* = .05, Cohen's *d* = -0.75) and the CST group *(t(62)* = -2.70, *p* = .03, Cohen's *d* = -0.83). No significant differences were found between the MCST and CST groups *(t(62)* = 0.26, *p* = 1, Cohen's *d* = 0.08).

Overall, the analysis highlighted significant group effects in specific brain regions for the P3 component, particularly in the central area, central midline, and right temporal-parietal junction for mean and peak amplitude, as well as the frontal lobe and right temporal-parietal junction for peak latency. These findings suggest that the MCST group's ERP responses differed notably from the CST and control groups in these regions.

Table 79 ANCOVA of amplitude and latency of ERPs in the choice reaction time task

		df	*SS*	*MS*	*F*	*p*	ω_p^2
P3 – mean amplitude							
FL	Pre-test	1	544.36	544.36	1.98	.16	0.01
	Group	2	549.48	274.74	1.00	.37	<.01
	Residuals	62	17,010.28	274.36			
FM	Pre-test	1	30.20	30.20	0.06	.81	<.01
	Group	2	537.57	268.78	0.52	.60	<.01
	Residuals	62	32,036.87	516.72			
CL	Pre-test	1	21.80	21.80	0.54	.47	0.00
	Group	2	332.48	166.24	4.11	.02	0.09

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	62	2,509.83	40.48			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	62	-5.00	1.93	-2.59	.04	-0.79
	MCST-Control	62	-4.39	1.90	-2.31	.07	-0.69
	CST-Control	62	0.61	1.95	0.31	1	0.10
CM	Pre-test	1	398.11	398.11	1.80	.18	0.01
	Group	2	1,648.21	824.10	3.74	.03	0.08
	Residuals	62	13,676.83	220.59			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	62	-12.29	4.50	-2.73	.02	-0.83
	MCST-Control	62	-6.44	4.44	-1.45	.46	-0.43
	CST-Control	62	5.85	4.53	1.29	.60	0.39
PL	Pre-test	1	890.63	890.63	6.30	.01	0.07
	Group	2	298.27	149.13	1.06	.35	<.01
	Residuals	62	8,758.30	141.26			
PM	Pre-test	1	426.78	426.78	0.72	.4	<.01
	Group	2	1,244.21	622.11	1.05	.36	<.01
	Residuals	62	36,654.19	591.20			
OL	Pre-test	1	852.35	852.35	1.24	.27	<.01
	Group	2	172.68	86.34	0.13	.88	<.01
	Residuals	62	42,734.69	689.27			
OM	Pre-test	1	4,157.16	4,157.16	3.34	.07	0.03
	Group	2	6,652.33	3,326.17	2.67	.08	0.05
	Residuals	62	77,165.53	1,244.61			
LTL	Pre-test	1	36.23	36.23	0.53	.47	<.01
	Group	2	127.03	63.51	0.92	.40	<.01
	Residuals	62	4,257.90	68.68			
RTL	Pre-test	1	114.68	114.68	2.85	.1	0.03
	Group	2	90.46	45.23	1.12	.33	<.01
	Residuals	62	2,498.01	40.29			
LTPJ	Pre-test	1	61.48	61.48	0.65	.42	<.01
	Group	2	30.06	15.03	0.16	.85	<.01
	Residuals	62	5,874.88	94.76			

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
RTPJ	Pre-test	1	229.05	229.05	2.18	.15	0.02
	Group	2	672.52	336.26	3.19	.05	0.06
	Residuals	62	6,525.46	105.25			
P3 – peak amplitude							
FL	Pre-test	1	817.84	817.84	1.76	.19	0.01
	Group	2	450.82	225.41	0.49	.62	<.01
	Residuals	62	28,785.56	464.28			
FM	Pre-test	1	31.32	31.32	0.04	.84	<.01
	Group	2	689.55	344.77	0.45	.64	<.01
	Residuals	62	47,958.28	773.52			
CL	Pre-test	1	267.25	267.25	3.65	.06	0.04
	Group	2	72.88	36.44	0.50	.61	<.01
	Residuals	62	4,540.76	73.24			
CM	Pre-test	1	572.98	572.98	2.30	.13	0.02
	Group	2	1,943.06	971.53	3.90	.03	0.08
	Residuals	62	15,462.77	249.40			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	62	-13.36	4.84	-2.76	.02	-0.85
	MCST-Control	62	-4.83	4.78	-1.01	.95	-0.31
	CST-Control	62	8.53	4.82	1.77	.24	0.54
PL	Pre-test	1	1,754.14	1,754.14	8.66	<.01	0.10
	Group	2	256.34	128.17	0.63	.53	<.01
	Residuals	62	12,564.45	202.65			
PM	Pre-test	1	433.36	433.36	0.51	.48	<.01
	Group	2	1,294.95	647.47	0.76	.47	<.01
	Residuals	62	52,487.37	846.57			
OL	Pre-test	1	177.67	177.67	0.42	.52	<.01
	Group	2	34.83	17.42	0.04	.96	<.01
	Residuals	62	25,929.13	418.21			
OM*	Pre-test	1	9,190.69	9,190.69	10.15	<.01	0.12
	Group	2	4,400.59	2,200.29	2.43	.10	0.04
	Residuals	62	56,162.30	905.84			
LTL	Pre-test	1	11.63	11.63	0.14	.71	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	157.38	78.69	0.93	.40	<.01
	Residuals	62	5,242.05	84.55			
RTL	Pre-test	1	303.65	303.65	7.74	<.01	0.09
	Group	2	95.02	47.51	1.21	.30	0.01
	Residuals	62	2,432.71	39.24			
LTPJ	Pre-test	1	102.39	102.39	0.83	.37	<.01
	Group	2	69.33	34.67	0.28	.76	<.01
	Residuals	62	7,629.97	123.06			
RTPJ	Pre-test	1	354.73	354.73	3.45	.07	0.04
	Group	2	765.87	382.93	3.72	.03	0.08
	Residuals	62	6,373.94	102.81			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	62	-6.73	3.11	-2.16	.1	-0.66
	MCST-Control	62	-7.87	3.12	-2.53	.04	-0.78
	CST-Control	62	-1.14	3.10	-0.37	1	-0.11
P3 – peak latency							
FL	Pre-test	1	842.97	842.97	0.53	.47	<.01
	Group	2	11,687.20	5,843.60	3.68	.03	0.08
	Residuals	62	98,348.23	1,586.26			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	62	7.43	12.02	0.62	1	0.19
	MCST-Control	62	31.89	12.16	2.62	.03	0.80
	CST-Control	62	24.46	12.43	1.97	.16	0.61
FM	Pre-test	1	2,297.64	2,297.64	0.63	.43	<.01
	Group	2	17,616.16	8,808.08	2.41	.10	0.04
	Residuals	62	226,331.33	3,650.51			
CL	Pre-test	1	31.32	31.32	0.02	.88	<.01
	Group	2	799.65	399.83	0.27	.76	<.01
	Residuals	62	91,097.42	1,469.31			
CM	Pre-test	1	269.01	269.01	0.06	.81	<.01
	Group	2	848.59	424.30	0.09	.91	<.01
	Residuals	62	287,299.16	4,633.86			
PL	Pre-test	1	871.06	871.06	0.48	.49	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	6,562.10	3,281.05	1.82	.17	0.02
	Residuals	62	111,678.36	1,801.26			
PM	Pre-test	1	168.20	168.20	0.04	.85	<.01
	Group	2	9,339.53	4,669.77	1.05	.36	<.01
	Residuals	62	276,803.02	4,464.56			
OL	Pre-test	1	2,321.84	2,321.84	1.52	.22	0.01
	Group	2	8,507.40	4,253.70	2.79	.07	0.05
	Residuals	62	94,526.38	1,524.62			
OM	Pre-test	1	725.11	725.11	0.18	.67	<.01
	Group	2	26,094.97	13,047.49	3.20	.05	0.06
	Residuals	62	252,746.85	4,076.56			
LTL	Pre-test	1	1,028.46	1,028.46	0.91	.34	<.01
	Group	2	3,531.40	1,765.70	1.56	.22	0.02
	Residuals	62	70,330.36	1,134.36			
RTL	Pre-test	1	2,808.25	2,808.25	2.74	.1	0.03
	Group	2	1,469.33	734.66	0.72	.49	<.01
	Residuals	62	63,505.36	1,024.28			
LTPJ	Pre-test	1	15,846.15	15,846.15	6.79	.01	0.08
	Group	2	13,627.67	6,813.83	2.92	.06	0.05
	Residuals	62	144,717.34	2,334.15			
RTPJ	Pre-test	1	378.52	378.52	0.19	.67	<.01
	Group	2	18,414.29	9,207.15	4.56	.01	0.10
	Residuals	62	125,284.45	2,020.72			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	62	3.61	13.71	0.26	1	0.08
	MCST-Control	62	-33.57	13.44	-2.50	.05	-0.75
	CST-Control	62	-37.19	13.75	-2.70	.03	-0.83

*A significant interaction effect

Analysis of regression

This analysis evaluates the ERP peak amplitude in the P300 component within the OM region for the three groups, including MCST, CST, and control (see Table 80).

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For the P300 component's peak amplitude in the OM region, the MCST group does not demonstrate a significant relationship (β_1 = -0.30, p = .11, adjusted R^2 = .07), suggesting limited effects of the intervention in modulating the P300 component in this region. In contrast, the CST group exhibits a significant and strong predictive relationship (β_1 = -0.92, p < .001, adjusted R^2 = .36), indicating the intervention's effectiveness in influencing the P300 component during the choice reaction time task. The control group fails to show a significant relationship (β_1 = 0.07, p = .70, adjusted R^2 = -.04), suggesting no meaningful natural predictive capacity for peak amplitude in this region (see Figure 77).

In summary, in the P300 component of the OM region, the CST group exhibits strong predictive power, with significant associations between pre-test performance and peak amplitude. In contrast, both the MCST and control groups fail to demonstrate significant predictive relationships, indicating limited or no modulation of the P300 component in these groups. This suggests that the CST intervention may be particularly effective in enhancing cognitive processing as reflected in the P300 peak amplitude during the choice reaction time task.

Table 80 Regression analysis of ERP components during the choice reaction time task

ROI	Model	Variable	*β*	*SE*	*t*	*P*
P300 – Peak amplitude						
OM	MCST	Constant	-7.57	7.89	-0.96	.35
		Pre-test	-0.30	0.18	-1.67	.11
	CST	Constant	11.37	6.20	1.83	.08
		Pre-test	-0.92	0.26	-3.53	<.01
	Control	Constant	6.15	3.52	1.75	.10
		Pre-test	0.07	0.19	0.39	.70

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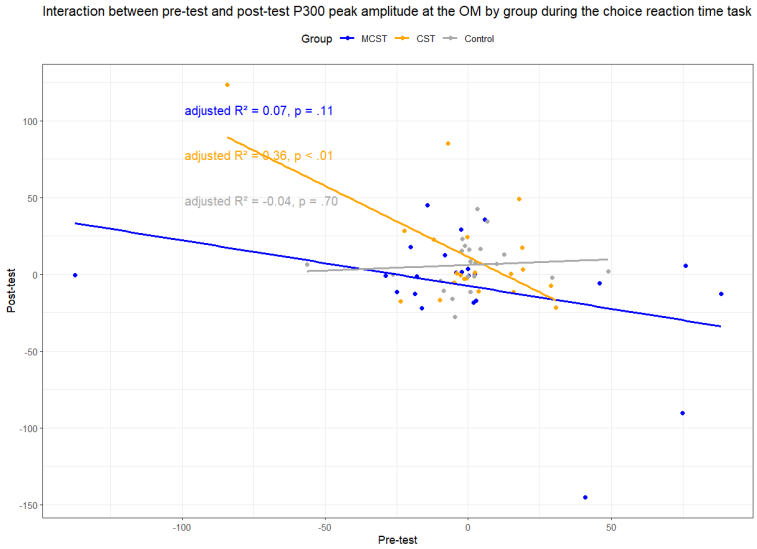

Figure 77 A scatter plot and the regression lines are shows interaction between pre-test and post-test P300 peak amplitude in the occipital lobe (CL) area by group during the choice reaction time task

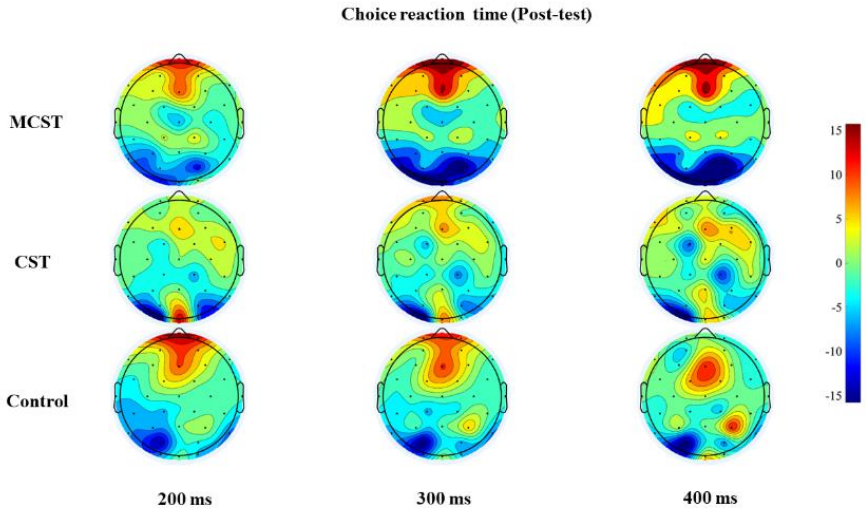

Figure 78 The topographic brain mapping of mean amplitude for each 100 ms latency window during the choice reaction time task at post-test

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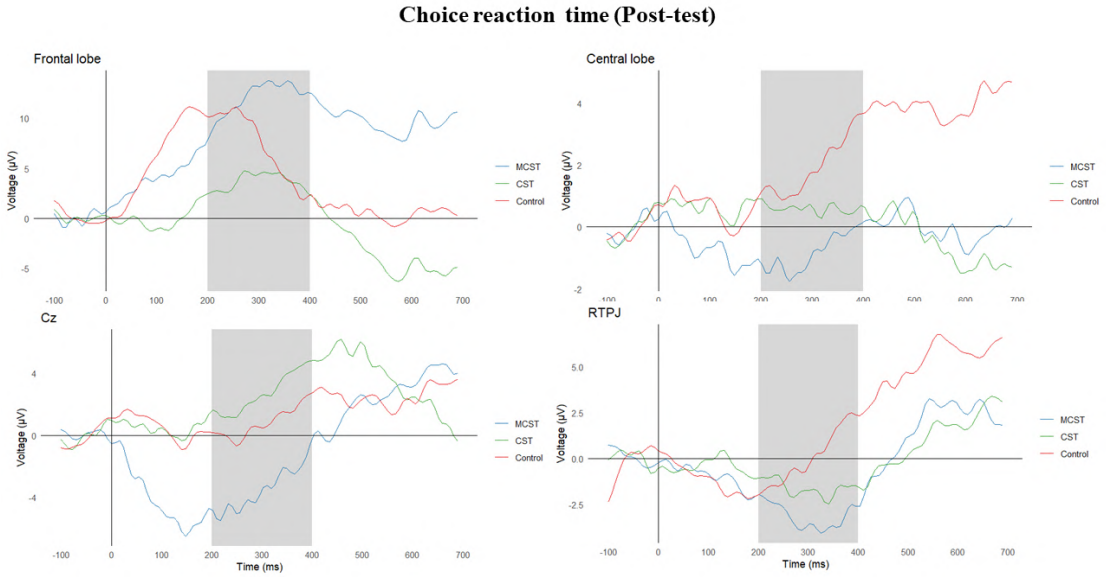

Figure 79 Grand-average ERP waveforms over the frontal and central regions, central midline (Cz), and the right temporoparietal junction (RTPJ) across three groups in the choice reaction time task at post-test

ERP - Sound-induced flash illusion task

Analysis of the amplitude and latency characteristics

N1 component - Mean amplitude

In the frontal region (FL, FM), the MCST group showed a decrease in mean amplitude post-test, indicating reduced neural activity. The CST group also exhibited a decrease, while the control group had mixed changes. For instance, FL showed a decrease, but FM had minor improvements in The control group.

In the central region (CL, CM), the MCST group displayed mixed changes post-test. CL showed a slight increase, but CM had mixed changes with both increases and decreases. The CST group showed a minor decrease, and the control group experienced slight improvements.

In the parietal region (PL, PM), the MCST group demonstrated mixed changes. PL had a minor increase, while PM showed decreases. The CST group showed a slight increase, while the control group exhibited mixed changes, with improvements in PL and decreases in PM.

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In the temporal region (LTL, RTL, LTPJ, RTPJ), the MCST group displayed mixed changes post-test. For instance, LTL showed an increase, but RTL had decreases. The CST group showed minor changes overall, while the control group had mixed results, with improvements in LTPJ but decreases in RTPJ.

N1 component - Peak amplitude

In the frontal region (FL, FM), the MCST group exhibited a decrease in peak amplitude post-test, suggesting weaker neural responses. The CST group also showed a decrease, while the control group experienced slight improvements. For example, FL showed a decrease, but FM had minor improvements in the control group.

In the central region (CL, CM), the MCST group displayed mixed changes post-test. CL showed a decrease, while CM had both increases and decreases. The CST group showed a minor increase, and the control group had mixed changes, with some areas showing improvements and others decreases.

In the parietal region (PL, PM), the MCST group showed minor changes post-test, with a slight increase in PL but mixed changes in PM. The CST group exhibited a slight increase, while the control group showed mixed changes, with improvements in PL but decreases in PM.

In the temporal region (LTL, RTL, LTPJ, RTPJ), the MCST group exhibited mixed changes, with some areas showing increases and others decreases. The CST group showed minor changes overall, while the control group experienced slight improvements. For example, LTPJ had improvements, but RTPJ had decreases.

N1 component - Peak latency

In the frontal region (FL, FM), the MCST group showed a slight increase in peak latency post-test, indicating slower neural responses. The CST group also experienced a minor increase, while the control group showed mixed changes, with some areas showing increases and others decreases.

In the central region (CL, CM), the MCST group displayed mixed changes post-test. CL showed a slight increase, while CM had both

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increases and decreases. The CST group showed minor changes overall, while the control group had mixed changes.

In the parietal region (PL, PM), the MCST group showed a slight increase in peak latency post-test, indicating slower neural responses. The CST group exhibited mixed changes, with some areas showing increases and others decreases, while the control group showed minor changes.

In the temporal region (LTL, RTL, LTPJ, RTPJ), the MCST group displayed mixed changes. For instance, LTL showed an increase, but RTL had decreases. The CST group showed minor changes overall, while the control group experienced slight improvements.

P2 component - Mean amplitude

In the frontal region (FL, FM), the MCST group showed a decrease in mean amplitude post-test, indicating reduced neural activity. The CST group also exhibited a decrease, while the control group experienced mixed changes. For instance, FL showed a decrease, but FM had minor improvements in the control group.

In the central region (CL, CM), the MCST group displayed mixed changes post-test. CL showed a slight increase, but CM had both increases and decreases. The CST group showed a minor decrease, while the control group experienced mixed changes.

In the parietal region (PL, PM), the MCST group demonstrated mixed changes. PL had a minor increase, while PM showed decreases. The CST group showed a slight increase, while the control group exhibited mixed changes, with improvements in PL and decreases in PM.

In the temporal region (LTL, RTL, LTPJ, RTPJ), the MCST group showed mixed changes post-test. For instance, LTL showed an increase, but RTL had decreases. The CST group showed minor changes overall, while the control group had mixed results, with improvements in LTPJ but decreases in RTPJ.

P2 component - Peak amplitude

In the frontal region (FL, FM), the MCST group exhibited a decrease in peak amplitude post-test, suggesting weaker neural responses. The CST group also showed a decrease, while the control group experienced slight

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improvements. For example, FL showed a decrease, but FM had minor improvements in The control group.

In the central region (CL, CM), the MCST group displayed mixed changes post-test. CL showed a decrease, while CM had both increases and decreases. The CST group showed a minor increase, and the control group had mixed changes, with some areas showing improvements and others decreases.

In the parietal region (PL, PM), the MCST group showed minor changes post-test, with a slight increase in PL but mixed changes in PM. The CST group exhibited a slight increase, while the control group showed mixed changes, with improvements in PL but decreases in PM.

In the temporal region (LTL, RTL, LTPJ, RTPJ), the MCST group exhibited mixed changes, with some areas showing increases and others decreases. The CST group showed minor changes overall, while the control group experienced slight improvements. For example, LTPJ had improvements, but RTPJ had decreases.

P2 component - Peak latency

In the frontal region (FL, FM), the MCST group showed a slight increase in peak latency post-test, indicating slower neural responses. The CST group also experienced a minor increase, while the control group showed mixed changes, with some areas showing increases and others decreases.

In the central region (CL, CM), the MCST group displayed mixed changes post-test. CL showed a slight increase, while CM had both increases and decreases. The CST group showed minor changes overall, while the control group had mixed changes.

In the parietal region (PL, PM), the MCST group showed a slight increase in peak latency post-test, indicating slower neural responses. The CST group exhibited mixed changes, with some areas showing increases and others decreases, while the control group showed minor changes.

In the temporal region (LTL, RTL, LTPJ, RTPJ), the MCST group displayed mixed changes. For instance, LTL showed an increase, but

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RTL had decreases. The CST group showed minor changes overall, while the control group experienced slight improvements.

Overall, the MCST group demonstrated various changes in ERP characteristics, with some regions showing improvements in mean and peak amplitudes and latencies, while others exhibited reductions or mixed changes. The CST and control groups generally exhibited minor changes, with some increases or decreases in specific regions.

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Table 81 Characteristic of amplitude and latency of ERPs in the sound-induced flash illusion task

		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
N1 – mean amplitude										
FL	Pre	31	3.06	5.96	30	0.02	6.89	30	-0.34	3.90
	Post	31	-0.49	2.88	30	-3.08	8.10	30	-1.39	5.75
FM	Pre	31	1.70	8.02	30	0.23	10.07	30	-0.80	2.69
	Post	31	-0.25	2.57	30	-0.90	3.28	30	-1.06	4.85
CL	Pre	31	-0.42	7.14	30	-0.10	3.58	30	-0.43	2.85
	Post	31	-0.02	1.34	30	-0.15	1.39	30	-0.44	3.12
CM	Pre	31	-1.67	20.92	30	-4.33	16.98	30	-1.28	6.83
	Post	31	0.04	4.43	30	-0.92	4.49	30	2.41	13.80
PL	Pre	31	-1.54	3.97	30	0.18	4.13	30	1.06	2.90
	Post	31	0.12	1.51	30	0.84	2.05	30	0.63	7.30
PM	Pre	31	-3.29	19.22	30	1.77	3.59	30	1.38	4.44
	Post	31	-0.21	2.17	30	2.22	7.51	30	-1.15	14.68
OL	Pre	31	-0.51	9.27	30	-0.61	4.39	30	0.92	5.08
	Post	31	0.11	4.41	30	0.99	5.47	30	0.46	6.88
OM	Pre	31	0.94	15.81	30	-0.02	10.16	30	0.32	6.76
	Post	31	-1.68	7.99	30	0.71	8.99	30	-0.27	8.56
LTL	Pre	31	-1.13	4.88	30	0.45	2.82	30	-1.24	2.90
	Post	31	0.52	1.37	30	0.58	2.03	30	-0.32	3.65
RTL	Pre	31	0.64	3.49	30	-0.03	3.31	30	0.22	1.40
	Post	31	-0.29	1.57	30	0.58	1.65	30	0.93	2.80
LTPJ	Pre	31	-2.18	7.20	30	1.04	4.85	30	-0.43	3.41
	Post	31	1.32	2.06	30	0.91	2.99	30	-0.82	9.67
RTPJ	Pre	31	0.13	5.46	30	-0.36	4.11	30	1.49	3.54
	Post	31	0.26	2.30	30	1.69	3.68	30	2.25	8.54
N1 – peak amplitude										
FL	Pre	31	7.60	7.90	30	3.25	6.14	30	1.99	4.32
	Post	31	1.80	3.16	30	-0.32	7.87	30	1.02	6.19
FM	Pre	31	4.70	8.36	30	2.71	10.01	30	0.92	2.64

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	31	1.32	2.97	30	1.07	4.19	30	0.50	5.19
CL	Pre	31	3.65	7.03	30	2.67	4.40	30	1.22	2.75
	Post	31	1.37	1.66	30	1.82	2.17	30	1.60	2.16
CM	Pre	31	2.90	20.22	30	-1.01	16.16	30	0.57	6.33
	Post	31	1.60	4.64	30	1.06	4.13	30	4.70	16.79
PL	Pre	31	2.49	5.20	30	2.72	4.31	30	2.81	3.76
	Post	31	1.53	1.61	30	2.64	2.53	30	3.06	6.68
PM	Pre	31	0.57	15.92	30	3.72	4.34	30	2.87	5.57
	Post	31	1.07	2.65	30	3.56	8.79	30	1.11	10.15
OL	Pre	31	3.38	10.92	30	2.06	5.36	30	3.01	6.14
	Post	31	1.68	4.39	30	2.90	5.64	30	2.93	6.17
OM	Pre	31	4.41	16.93	30	1.92	9.15	30	1.76	7.03
	Post	31	-0.05	7.05	30	2.19	9.81	30	1.98	7.61
LTL	Pre	31	2.82	6.14	30	2.95	3.58	30	0.59	2.76
	Post	31	2.05	1.57	30	2.40	2.58	30	1.68	2.22
RTL	Pre	31	4.15	5.07	30	2.48	4.08	30	2.13	2.12
	Post	31	1.31	1.71	30	2.38	2.23	30	2.87	3.92
LTPJ	Pre	31	1.58	7.41	30	3.40	5.54	30	1.37	3.28
	Post	31	2.81	2.57	30	2.56	3.35	30	1.36	6.86
RTPJ	Pre	31	4.09	5.17	30	2.00	4.08	30	3.42	4.66
	Post	31	1.89	2.35	30	3.51	3.91	30	4.28	10.11
N1 – peak latency										
FL	Pre	31	96	25.18	31	98	22.50	30	100	26.71
	Post	31	102	22.27	31	92	20.81	30	98	21.08
FM	Pre	31	87	36.18	31	98	29.05	30	96	30.76
	Post	31	96	34.05	31	91	32.40	30	99	34.27
CL	Pre	31	93	17.44	31	99	22.78	30	97	20.57
	Post	31	92	13.22	31	90	18.03	30	94	16.91
CM	Pre	31	98	33.52	31	98	32.68	30	95	33.43
	Post	31	90	32.49	31	93	31.64	30	94	35.89
PL	Pre	31	93	21.60	31	88	20.43	30	90	17.03
	Post	31	93	15.83	31	97	17.44	30	97	23.83

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
PM	Pre	31	84	34.86	31	84	36.09	30	88	32.59
	Post	31	98	32.37	31	94	31.63	30	98	34.46
OL	Pre	31	97	24.07	31	85	23.73	30	90	25.16
	Post	31	94	15.97	31	94	23.59	30	96	18.79
OM	Pre	31	100	34.56	31	77	30.52	30	86	31.11
	Post	31	95	34.59	31	101	35.94	30	91	35.87
LTL	Pre	31	95	17.45	31	95	17.95	30	97	16.74
	Post	31	97	17.02	31	95	19.02	30	98	16.47
RTL	Pre	31	97	16.80	31	92	18.89	30	95	16.61
	Post	31	95	14.45	31	98	19.19	30	99	15.69
LTPJ	Pre	31	94	17.98	31	90	19.98	30	94	22.78
	Post	31	94	23.94	31	93	20.41	30	98	22.27
RTPJ	Pre	31	97	21.73	31	86	19.76	30	89	22.35
	Post	31	95	21.54	31	96	21.83	30	99	21.44
P2 – mean amplitude										
FL	Pre	31	3.34	6.83	31	-2.19	11.46	30	-0.89	5.37
	Post	31	0.51	4.50	31	-3.46	9.82	30	0.75	14.51
FM	Pre	31	0.96	10.41	31	-1.25	13.42	30	-2.43	4.25
	Post	31	-0.01	4.11	31	-1.08	4.42	30	-0.70	6.37
CL	Pre	31	-1.14	11.35	31	-1.07	5.68	30	-1.67	4.61
	Post	31	-0.01	2.63	31	-0.06	2.30	30	-0.50	3.85
CM	Pre	31	-1.27	30.90	31	-7.12	26.99	30	-3.96	14.15
	Post	31	0.00	7.30	31	-2.32	8.20	30	2.31	15.47
PL	Pre	31	-1.62	8.58	31	0.92	4.88	30	2.19	4.56
	Post	31	-0.31	2.33	31	0.87	2.75	30	-0.22	15.56
PM	Pre	31	-3.58	25.30	31	3.28	5.96	30	2.86	7.63
	Post	31	-1.50	3.78	31	2.19	9.16	30	-2.82	23.15
OL	Pre	31	0.99	11.46	31	1.59	7.25	30	2.49	6.87
	Post	31	-0.53	6.77	31	1.13	6.78	30	0.19	10.89
OM	Pre	31	0.78	23.36	31	2.40	20.84	30	2.16	10.75
	Post	31	-3.18	11.83	31	0.82	12.36	30	-1.95	11.72
LTL	Pre	31	-1.14	8.13	31	0.58	4.70	30	-1.90	3.84

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		MCST			CST			Control	
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
	Post	31	0.95	2.49	31	0.44	3.39	30	-1.21	7.49
RTL	Pre	31	-0.16	5.68	31	0.05	5.47	30	0.13	2.23
	Post	31	-0.67	2.35	31	0.83	2.61	30	1.03	2.94
LTPJ	Pre	31	-1.42	10.11	31	1.79	7.94	30	-0.18	5.63
	Post	31	1.85	3.37	31	0.46	4.33	30	-2.75	19.10
RTPJ	Pre	31	-0.88	8.53	31	0.99	5.00	30	2.88	5.63
	Post	31	-0.17	4.04	31	2.27	4.02	30	2.33	6.54
P2 – peak amplitude										
FL	Pre	31	7.30	8.35	30	1.68	10.68	30	1.56	5.75
	Post	31	2.70	5.10	30	-1.09	10.16	30	3.40	17.13
FM	Pre	31	3.31	10.83	30	2.09	13.14	30	-0.39	4.33
	Post	31	1.51	3.89	30	0.93	5.05	30	0.78	6.62
CL	Pre	31	3.38	10.81	30	2.24	6.29	30	0.58	3.58
	Post	31	1.44	2.76	30	2.01	3.16	30	1.49	3.60
CM	Pre	31	3.82	32.79	30	-3.11	26.52	30	-1.49	10.91
	Post	31	1.58	7.21	30	-0.46	7.01	30	4.30	17.69
PL	Pre	31	2.15	8.44	30	4.14	5.28	30	3.85	5.46
	Post	31	1.15	2.43	30	2.76	3.17	30	1.85	15.24
PM	Pre	31	-0.14	24.14	30	5.77	7.27	30	4.84	8.00
	Post	31	0.11	3.72	30	4.01	8.88	30	-0.77	19.53
OL	Pre	31	5.94	13.53	30	5.53	8.96	30	4.93	7.40
	Post	31	1.43	6.45	30	3.74	8.17	30	2.92	12.16
OM	Pre	31	7.16	27.75	30	7.37	23.50	30	4.24	11.08
	Post	31	-0.95	10.71	30	3.36	12.49	30	0.85	10.11
LTL	Pre	31	3.07	8.24	30	3.69	5.39	30	0.15	3.77
	Post	31	2.50	2.73	30	2.42	3.24	30	0.48	7.22
RTL	Pre	31	3.54	5.63	30	2.99	5.78	30	2.15	2.75
	Post	31	0.93	2.21	30	2.72	3.15	30	3.04	4.30
LTPJ	Pre	31	2.08	10.30	30	5.25	8.44	30	1.56	5.62
	Post	31	3.30	4.01	30	2.47	4.12	30	-1.37	21.33
RTPJ	Pre	31	2.63	9.28	30	4.26	5.30	30	4.94	6.96
	Post	31	1.39	3.48	30	4.10	4.47	30	4.28	7.75

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		MCST			CST			Control		
	test	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
P2 – peak latency										
FL	Pre	31	198	20.95	31	191	26.39	30	200	21.10
	Post	31	204	18.66	31	192	23.31	30	203	18.94
FM	Pre	31	198	34.25	31	208	35.55	30	208	34.05
	Post	31	202	33.52	31	195	30.05	30	203	34.75
CL	Pre	31	209	20.32	31	208	24.89	30	208	19.15
	Post	31	199	15.33	31	193	19.13	30	201	14.52
CM	Pre	31	211	35.32	31	213	37.38	30	197	39.03
	Post	31	195	33.63	31	182	29.54	30	195	33.43
PL	Pre	31	202	17.81	31	198	22.06	30	195	22.21
	Post	31	199	15.31	31	195	19.70	30	200	21.82
PM	Pre	31	193	35.35	31	195	33.93	30	186	34.88
	Post	31	189	32.17	31	201	38.32	30	198	38.45
OL	Pre	31	184	21.74	31	186	24.34	30	190	23.09
	Post	31	193	17.37	31	195	25.70	30	197	21.46
OM	Pre	31	179	36.11	31	184	37.50	30	187	32.24
	Post	31	196	34.85	31	194	38.24	30	188	35.24
LTL	Pre	31	192	16.81	31	193	19.83	30	193	19.91
	Post	31	201	17.57	31	195	19.92	30	199	21.67
RTL	Pre	31	192	17.17	31	193	18.55	30	197	17.45
	Post	31	200	14.39	31	196	17.84	30	204	15.88
LTPJ	Pre	31	195	24.78	31	192	26.13	30	189	21.54
	Post	31	202	23.48	31	191	24.62	30	204	24.22
RTPJ	Pre	31	191	21.52	31	191	23.45	30	195	27.39
	Post	31	204	23.41	31	198	23.04	30	201	23.26

Analysis of assumptions

In the analysis of amplitude and latency of event-related potentials (ERPs) in the Sound-Induced Flash Illusion Task, various parameters were investigated, including mean amplitude, peak amplitude, and peak latency for both N1 and P2 components across different brain regions.

N1 component

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For N1 mean amplitude, the normality assumption was generally violated across all regions (W range = 0.54 - 0.98, all $p < .01$), except for OL and OM. Homoscedasticity was mostly observed (K-squared range = 0.08 - 81.21, all $p < .01$), indicating homogeneous variance. Parallelism was generally met (F range = 0.18 - 4.96, all $p > .05$), except for PL, PM, LTL, and RTL.

Similar results were observed for N1 peak amplitude, with normality assumptions violated (W range = 0.45 - 0.95, all $p < .01$), except for OL and OM. Homoscedasticity was mostly observed (K-squared range = 2.48 - 121.18, all $p < .05$), except for PL and PM. Parallelism was generally met (F range = 0.16 - 6.04, all $p > .05$), except for PL, PM, LTL, and RTL.

Regarding N1 peak latency, normality assumptions were generally met across all regions (W range = 0.94 - 0.98, all $p < .01$). Homoscedasticity was observed (K-squared range = 0.08 - 5.18, all $p > .05$), except for LTL and RTL. Parallelism was generally met (F range = 0.12 - 3.22, all $p > .05$), except for LTPJ and RTPJ.

P2 component

Moving to the P2 component, for mean amplitude, normality assumptions were generally violated (W range = 0.44 - 0.95, all $p < .01$), except for OL and OM. Homoscedasticity was mostly observed (K-squared range = 2.23 - 121.18, all $p < .05$), except for LTL and RTL. Parallelism was generally met (F range = 0.26 - 6.04, all $p > .05$), except for CL and CM.

Similar patterns were observed for P2 peak amplitude, with normality assumptions violated (W range = 0.44 - 0.96, all $p < .01$), except for OL and OM. Homoscedasticity was mostly observed (K-squared range = 0.16 - 108.18, all $p < .05$), except for PL and PM. Parallelism was generally met (F range = 0.26 - 6.04, all $p > .05$), except for CL, CM, LTL, and RTL.

Lastly, for P2 peak latency, normality assumptions were generally met (W range = 0.92 - 0.98, all $p < .01$). Homoscedasticity was observed (K-squared range = 0.08 - 5.18, all $p > .05$), except for LTL and RTL. Parallelism was generally met (F range = 0.02 - 3.22, all $p > .05$), except for LTPJ and RTPJ.

Analysis of group comparisons

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The study investigated the effects of group condition on various parameters of ERPs components during the sound-induced flash illusion task to measure multisensory integration in older adults with MCI.

N1 component

The results of the ANCOVA for the N100 ERP component could not be interpreted due to violations of the regression slope homogeneity assumption. Therefore, separate regression analyses for each group are presented in the following section for the affected ROIs: mean amplitude (FM), peak amplitude (FM), and peak latency (LTPJ). The following are the ANCOVA results for ROIs that met the assumption.

In the analysis of mean amplitude N1 ERP, no significant group effects were found across the frontal lobe (FL), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all $p > .05$, partial $\omega^2 < .01$). These results suggest that the group condition did not significantly influence the mean amplitude N1 ERP in these regions.

Similarly, the peak amplitude N1 ERP did not show significant group effects in the frontal lobe (FL), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all $p > .05$, partial $\omega^2 < .01$). Thus, the group condition did not significantly affect the peak amplitude N1 ERP in these areas.

The analysis of peak latency N1 ERP also did not reveal any significant group effects across the frontal lobe (FL), frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), and right temporal-parietal junction (RTPJ) (all $p > .05$, partial $\omega^2 < .01$). This indicates that the group condition had no significant impact on the peak latency N1 ERP in these regions.

P2 component

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The results of the ANCOVA for the P2 ERP component could not be interpreted due to violations of the regression slope homogeneity assumption. Therefore, separate regression analyses for each group are presented in the following section for the affected ROI: mean amplitude (FM) and peak amplitude (FM). The following are the ANCOVA results for ROIs that met the assumption.

For the mean amplitude P2 ERP, significant group effects were observed in the right temporal lobe (RTL) *(F(*2, 88*)* = 3.76, *p* = .03, partial $\omega^2 = 0.06$), indicating a moderate effect size. Post-hoc comparisons revealed that the MCST group had a significantly lower mean amplitude than the control group *(t(88)* = -2.50, *p* = .04, Cohen's *d* = -0.64). However, the CST group did not significantly differ from the MCST with a medium effect size *(t(88)* = -2.22, *p* = .09, Cohen's *d* = -0.56) or the control group with a tiny effect size *(t(88)* = -0.30, *p* = 1.00, Cohen's *d* = -0.08). For other regions, including the frontal lobe (FL), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ), no significant group effects were found (all $p > .05$, partial $\omega^2 < .01$).

In the analysis of peak amplitude P2 ERP, significant group effects were also found in the right temporal lobe (RTL) *(F(*2, 89*)* = 3.55, *p* = .03, partial $\omega^2 = 0.05$), suggesting a small effect size. Post-hoc comparisons indicated that the MCST group had a significantly lower peak amplitude than the control group with a moderate effect size *(t(89)* = -2.52, *p* = .04, Cohen's *d* = -0.64). However, the CST group did not significantly differ from the MCST with a medium effect size *(t(89)* = -2.02, *p* = .14, Cohen's *d* = -0.51) or the control group with a small effect size *(t(89)* = -0.51, *p* = 1.00, Cohen's *d* = -0.13). No significant group effects were observed in other regions, including the frontal lobe (FL), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe (OL), occipital midline (OM), left temporal lobe (LTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all $p > .05$, partial $\omega^2 < .01$).

The analysis of peak latency P2 ERP did not show significant group effects in the frontal lobe (FL), frontal midline (FM), central lobe (CL), central midline (CM), parietal lobe (PL), parietal midline (PM), occipital lobe

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(OL), occipital midline (OM), left temporal lobe (LTL), right temporal lobe (RTL), left temporal-parietal junction (LTPJ), and right temporal-parietal junction (RTPJ) (all $p > .05$, partial $\omega^2 < .01$). These findings suggest that the group condition did not significantly affect the peak latency P2 ERP in these regions.

Table 82 ANCOVA of amplitude and latency of ERPs in the sound-induced flash illusion task

		df	*SS*	*MS*	*F*	*p*	ω_p^2
N1 – mean amplitude							
FL	Pre-test	1	151.32	151.32	4.44	.04	0.04
	Group	2	64.19	32.09	0.94	.39	<.01
	Residuals	88	3,002.20	34.12			
FM*	Pre-test	1	2.13	2.13	0.16	.69	<.01
	Group	2	10.04	5.02	0.37	.69	<.01
	Residuals	88	1,190.80	13.53			
CL	Pre-test	1	4.07	4.07	0.92	.34	<.01
	Group	2	2.89	1.44	0.33	.72	<.01
	Residuals	88	388.16	4.41			
CM	Pre-test	1	0.17	0.17	0.00	.96	<.01
	Group	2	178.04	89.02	1.17	.32	<.01
	Residuals	88	6,698.33	76.12			
PL	Pre-test	1	34.18	34.18	1.76	.19	0.01
	Group	2	3.04	1.52	0.08	.92	<.01
	Residuals	88	1,708.18	19.41			
PM	Pre-test	1	28.01	28.01	0.31	.58	<.01
	Group	2	169.86	84.93	0.93	.40	<.01
	Residuals	88	8,005.34	90.97			
OL	Pre-test	1	14.67	14.67	0.46	.50	<.01
	Group	2	12.06	6.03	0.19	.83	<.01
	Residuals	88	2,810.74	31.94			
OM	Pre-test	1	30.32	30.32	0.42	.52	<.01
	Group	2	91.98	45.99	0.64	.53	<.01
	Residuals	88	6,350.11	72.16			

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
LTL	Pre-test	1	7.50	7.50	1.19	.28	<.01
	Group	2	12.70	6.35	1.00	.37	<.01
	Residuals	88	556.33	6.32			
RTL	Pre-test	1	0.24	0.24	0.06	.81	<.01
	Group	2	23.71	11.86	2.75	.07	0.04
	Residuals	88	379.94	4.32			
LTPJ	Pre-test	1	14.95	14.95	0.43	.51	<.01
	Group	2	83.29	41.65	1.19	.31	<.01
	Residuals	88	3,077.79	34.97			
RTPJ	Pre-test	1	10.75	10.75	0.36	.55	<.01
	Group	2	59.66	29.83	0.99	.38	<.01
	Residuals	88	2,664.39	30.28			
N1 – peak amplitude							
FL	Pre-test	1	164.75	164.75	4.72	.03	0.04
	Group	2	49.26	24.63	0.71	.50	<.01
	Residuals	89	3,104.12	34.88			
FM*	Pre-test	1	6.11	6.11	0.35	.56	<.01
	Group	2	6.66	3.33	0.19	.83	<.01
	Residuals	89	1,556.69	17.49			
CL	Pre-test	1	3.58	3.58	0.89	.35	<.01
	Group	2	3.51	1.75	0.44	.65	<.01
	Residuals	89	355.87	4.00			
CM	Pre-test	1	11.23	11.23	0.11	.74	<.01
	Group	2	233.49	116.74	1.12	.33	<.01
	Residuals	89	9,312.35	104.63			
PL	Pre-test	1	55.33	55.33	3.21	.08	0.02
	Group	2	29.97	14.99	0.87	.42	<.01
	Residuals	89	1,532.61	17.22			
PM	Pre-test	1	73.83	73.83	1.17	.28	<.01
	Group	2	125.40	62.70	1.00	.37	<.01
	Residuals	89	5,596.35	62.88			
OL	Pre-test	1	10.41	10.41	0.35	.55	<.01
	Group	2	27.58	13.79	0.47	.63	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	89	2,619.33	29.43			
OM	Pre-test	1	0.05	0.05	0.00	.98	<.01
	Group	2	97.79	48.90	0.73	.49	<.01
	Residuals	89	5,981.51	67.21			
LTL	Pre-test	1	0.32	0.32	0.07	.79	<.01
	Group	2	5.20	2.60	0.55	.58	<.01
	Residuals	89	417.63	4.69			
RTL	Pre-test	1	8.60	8.60	1.12	.29	<.01
	Group	2	30.57	15.29	1.99	.14	0.02
	Residuals	89	682.89	7.67			
LTPJ	Pre-test	1	21.24	21.24	1.00	.32	<.01
	Group	2	37.06	18.53	0.88	.42	<.01
	Residuals	89	1,882.14	21.15			
RTPJ	Pre-test	1	1.85	1.85	0.05	.83	<.01
	Group	2	86.24	43.12	1.07	.35	<.01
	Residuals	89	3,594.51	40.39			
N1 – peak latency							
FL	Pre-test	1	164.67	164.67	0.36	.55	<.01
	Group	2	1,564.48	782.24	1.71	.19	0.02
	Residuals	89	40,724.48	457.58			
FM	Pre-test	1	18.45	18.45	0.02	.90	<.01
	Group	2	953.94	476.97	0.42	.66	<.01
	Residuals	89	100,480.09	1,128.99			
CL	Pre-test	1	316.06	316.06	1.21	.27	<.01
	Group	2	337.28	168.64	0.64	.53	<.01
	Residuals	89	23,304.87	261.85			
CM	Pre-test	1	2,662.44	2,662.44	2.41	.12	0.01
	Group	2	487.63	243.82	0.22	.80	<.01
	Residuals	89	98,339.97	1,104.94			
PL	Pre-test	1	356.07	356.07	0.97	.33	<.01
	Group	2	418.69	209.35	0.57	.57	<.01
	Residuals	89	32,708.79	367.51			
PM	Pre-test	1	215.44	215.44	0.20	.66	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	249.81	124.90	0.11	.89	<.01
	Residuals	89	98,210.33	1,103.49			
OL	Pre-test	1	1,560.93	1,560.93	4.17	.04	0.03
	Group	2	122.67	61.33	0.16	.85	<.01
	Residuals	89	33,329.65	374.49			
OM	Pre-test	1	304.57	304.57	0.24	.62	<.01
	Group	2	1,667.01	833.50	0.67	.52	<.01
	Residuals	89	111,457.02	1,252.33			
LTL	Pre-test	1	161.60	161.60	0.52	.47	<.01
	Group	2	169.78	84.89	0.28	.76	<.01
	Residuals	89	27,402.47	307.89			
RTL	Pre-test	1	257.46	257.46	0.92	.34	<.01
	Group	2	196.92	98.46	0.35	.70	<.01
	Residuals	89	24,821.54	278.89			
LTPJ*	Pre-test	1	35.16	35.16	0.07	.79	<.01
	Group	2	249.54	124.77	0.25	.78	<.01
	Residuals	89	44,342.92	498.24			
RTPJ	Pre-test	1	23.90	23.90	0.05	.82	<.01
	Group	2	301.93	150.96	0.32	.72	<.01
	Residuals	89	41,511.40	466.42			
P2 – mean amplitude							
FL	Pre-test	1	184.83	184.83	1.71	.19	0.01
	Group	2	273.71	136.86	1.27	.29	0.01
	Residuals	88	9,489.58	107.84			
FM*	Pre-test	1	0.96	0.96	0.04	.85	<.01
	Group	2	17.49	8.74	0.34	.71	<.01
	Residuals	88	2,267.69	25.77			
CL	Pre-test	1	13.03	13.03	1.46	.23	0.01
	Group	2	3.88	1.94	0.22	.80	<.01
	Residuals	88	783.04	8.90			
CM	Pre-test	1	23.74	23.74	0.20	.66	<.01
	Group	2	319.10	159.55	1.33	.27	0.01
	Residuals	88	10,547.54	119.86			

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
PL	Pre-test	1	11.60	11.60	0.14	.71	<.01
	Group	2	25.03	12.52	0.15	.86	<.01
	Residuals	88	7,403.86	84.13			
PM	Pre-test	1	67.81	67.81	0.32	.57	<.01
	Group	2	395.85	197.93	0.94	.39	<.01
	Residuals	88	18,435.05	209.49			
OL	Pre-test	1	142.62	142.62	2.07	.15	0.01
	Group	2	40.04	20.02	0.29	.75	<.01
	Residuals	88	6,058.20	68.84			
OM	Pre-test	1	269.97	269.97	1.90	.17	0.01
	Group	2	243.01	121.51	0.85	.43	<.01
	Residuals	88	12,513.87	142.20			
LTL	Pre-test	1	19.07	19.07	0.78	.38	<.01
	Group	2	71.10	35.55	1.46	.24	0.01
	Residuals	88	2,146.81	24.40			
RTL	Pre-test	1	0.12	0.12	0.02	.90	<.01
	Group	2	53.10	26.55	3.76	.03	0.06
	Residuals	88	621.75	7.07			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	88	-1.50	0.68	-2.22	.09	-0.56
	MCST-Control	88	-1.70	0.68	-2.50	.04	-0.64
	CST-Control	88	-0.20	0.68	-0.30	1	-0.08
LTPJ	Pre-test	1	0.75	0.75	0.01	.94	<.01
	Group	2	338.07	169.04	1.30	.28	0.01
	Residuals	88	11,479.47	130.45			
RTPJ	Pre-test	1	26.48	26.48	1.06	.31	<.01
	Group	2	107.58	53.79	2.14	.12	0.02
	Residuals	88	2,208.24	25.09			
P2 – peak amplitude							
FL	Pre-test	1	233.18	233.18	1.70	.20	0.01
	Group	2	347.54	173.77	1.27	.29	0.01
	Residuals	89	12,183.09	136.89			
FM*	Pre-test	1	4.13	4.13	0.15	.70	<.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Group	2	6.01	3.00	0.11	.90	<.01
	Residuals	89	2,496.46	28.05			
CL	Pre-test	1	10.75	10.75	1.06	.31	<.01
	Group	2	4.97	2.48	0.24	.78	<.01
	Residuals	89	904.83	10.17			
CM	Pre-test	1	0.00	0.00	0.00	1	<.01
	Group	2	352.88	176.44	1.30	.28	0.01
	Residuals	89	12,058.85	135.49			
PL	Pre-test	1	30.99	30.99	0.38	.54	<.01
	Group	2	28.98	14.49	0.18	.84	<.01
	Residuals	89	7,196.34	80.86			
PM	Pre-test	1	73.42	73.42	0.47	.49	<.01
	Group	2	405.08	202.54	1.30	.28	0.01
	Residuals	89	13,888.53	156.05			
OL	Pre-test	1	100.52	100.52	1.21	.27	<.01
	Group	2	80.37	40.19	0.48	.62	<.01
	Residuals	89	7,402.76	83.18			
OM	Pre-test	1	150.05	150.05	1.23	.27	<.01
	Group	2	273.81	136.91	1.12	.33	<.01
	Residuals	89	10,896.96	122.44			
LTL	Pre-test	1	13.58	13.58	0.59	.45	<.01
	Group	2	57.06	28.53	1.23	.30	<.01
	Residuals	89	2,059.64	23.14			
RTL	Pre-test	1	0.89	0.89	0.08	.78	<.01
	Group	2	77.96	38.98	3.55	.03	0.05
	Residuals	89	977.24	10.98			
	Contrast	*df*	*DM*	*SE*	*t*	*p*	*d*
	MCST-CST	89	-1.70	0.84	-2.02	.14	-0.51
	MCST-Control	89	-2.13	0.85	-2.52	.04	-0.64
	CST-Control	89	-0.43	0.84	-0.51	1	-0.13
LTPJ	Pre-test	1	0.08	0.08	0.00	.98	<.01
	Group	2	389.43	194.71	1.22	.30	<.01
	Residuals	89	14,163.77	159.14			

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
RTPJ	Pre-test	1	1.84	1.84	0.06	.81	<.01
	Group	2	151.41	75.70	2.49	.09	0.03
	Residuals	89	2,701.78	30.36			
P2 – peak latency							
FL	Pre-test	1	901.32	901.32	2.18	.14	0.01
	Group	2	2,282.44	1,141.22	2.76	.07	0.04
	Residuals	89	36,805.53	413.55			
FM	Pre-test	1	4,200.54	4,200.54	4.07	.05	0.03
	Group	2	1,731.94	865.97	0.84	.44	<.01
	Residuals	89	91,808.00	1,031.55			
CL	Pre-test	1	102.07	102.07	0.37	.54	<.01
	Group	2	1,129.93	564.97	2.07	.13	0.02
	Residuals	89	24,294.57	272.97			
CM	Pre-test	1	619.91	619.91	0.59	.45	<.01
	Group	2	3,319.88	1,659.94	1.57	.21	0.01
	Residuals	89	94,207.70	1,058.51			
PL	Pre-test	1	475.76	475.76	1.32	.25	<.01
	Group	2	508.23	254.12	0.71	.50	<.01
	Residuals	89	31,980.69	359.33			
PM	Pre-test	1	2,039.42	2,039.42	1.56	.21	0.01
	Group	2	2,711.43	1,355.71	1.04	.36	<.01
	Residuals	89	116,233.15	1,305.99			
OL	Pre-test	1	2,096.61	2,096.61	4.56	.04	0.04
	Group	2	78.49	39.25	0.09	.92	<.01
	Residuals	89	40,881.39	459.34			
OM	Pre-test	1	3,838.84	3,838.84	3.04	.08	0.02
	Group	2	1,748.53	874.26	0.69	.50	<.01
	Residuals	89	112,347.99	1,262.34			
LTL	Pre-test	1	893.82	893.82	2.35	.13	0.01
	Group	2	683.65	341.82	0.90	.41	<.01
	Residuals	89	33,917.87	381.10			
RTL	Pre-test	1	60.24	60.24	0.23	.63	<.01
	Group	2	861.42	430.71	1.65	.20	0.01

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		df	*SS*	*MS*	*F*	*p*	ω_p^2
	Residuals	89	23,186.55	260.52			
LTPJ	Pre-test	1	602.90	602.90	1.02	.32	<.01
	Group	2	2,602.36	1,301.18	2.20	.12	0.03
	Residuals	89	52,742.11	592.61			
RTPJ	Pre-test	1	93.88	93.88	0.17	.68	<.01
	Group	2	495.41	247.71	0.45	.64	<.01
	Residuals	89	48,474.13	544.65			

*A significant interaction effect

Analysis of regression

The analysis of the N100 and P200 components across different regions reveals varying degrees of predictive relationships for mean amplitude, peak amplitude, and peak latency among the MCST, CST, and control groups.

For the mean amplitude, significant effects are observed primarily in the control group. For the N100 component in the Fz region, the MCST group approaches significance (β_1 = 0.11, p = .06, adjusted R^2 = .09), indicating a possible trend, while the control (β_1 = 0.61, p = .07, adjusted R^2 = .08) and CST (β_1 = -0.09, p = .14, adjusted R^2 = .04) groups show no significant relationships. In the Regarding the peak amplitude, the control group consistently exhibits significant effects in specific conditions. A different pattern is observed for the P200 component in the Fz region, where the control group again shows a significant relationship (β_1 = 0.64, p = .02, adjusted R^2 = .14), while the MCST (β_1 = 0.07, p = .33, adjusted R^2 = .00) and CST (β_1 = -0.09, p = .22, adjusted R^2 = .02) groups fail to demonstrate predictive power (see Figure 80).

For the peak latency, In the LTPJ region for the N100 component, the MCST group approaches significance (β_1 = -0.41, p = .09, adjusted R^2 = .07), but neither the control (β_1 = 0.30, p = .10, adjusted R^2 = .06) nor the CST (β_1 = 0.02, p = .92, adjusted R^2 = -.03) groups demonstrate significant relationships.

Overall, the control group consistently displays significant effects in specific components and regions, while the MCST group occasionally

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shows trends toward significance, and the CST group exhibits limited predictive power.

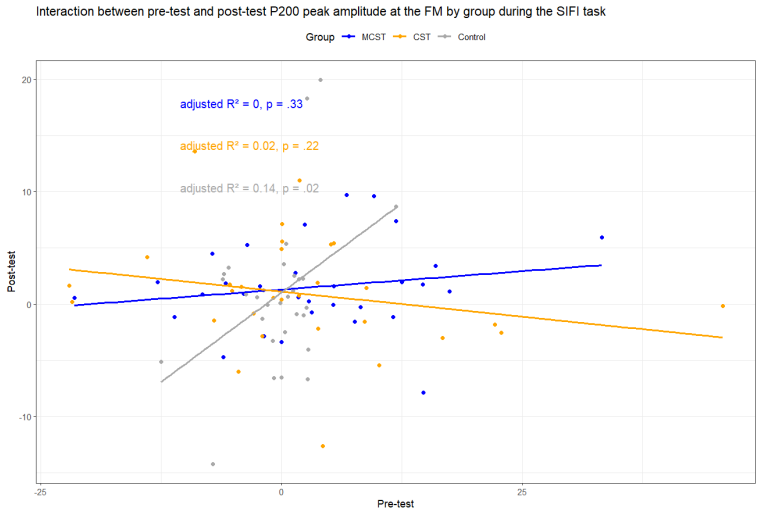

Figure 80 A scatter plot and the regression lines are shows interaction between pre-test and post-test P200 peak amplitude in the frontal midline (FM) area by group during the sound-induced flash illusion task

In summary, in the SIFI task, the control group demonstrates consistent significant relationships for the P200 (Fz) components. This suggests that the natural ability to modulate ERP parameters is higher in the control group. The MCST and CST groups generally fails to show significant relationships.

Table 83 Regression analysis of ERP components during the sound-induced flash illusion task

ROI	Model	Variable	*β*	*SE*	*t*	*p*
N100 – Mean amplitude						
FM	MCST	Constant	-0.43	0.45	-0.96	.35
		Pre-test	0.11	0.06	1.95	.06
	CST	Constant	-0.88	0.59	-1.50	.15
		Pre-test	-0.09	0.06	-1.53	.14
	Control	Constant	-0.58	0.89	-0.65	.52
		Pre-test	0.61	0.32	1.89	.07
N100 – Peak amplitude						
FM	MCST	Constant	0.73	0.59	1.25	.22

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ROI	Model	Variable	*β*	*SE*	*t*	*p*
		Pre-test	0.12	0.06	2.02	.05
	CST	Constant	1.32	0.79	1.67	.11
		Pre-test	-0.09	0.08	-1.16	.26
	Control	Constant	-0.11	0.96	-0.12	.91
		Pre-test	0.66	0.35	1.89	.07
N100 – Peak latency						
LTPJ	MCST	Constant	132.65	22.42	5.92	<.01
		Pre-test	-0.41	0.24	-1.76	.09
	CST	Constant	91.27	17.43	5.24	<.01
		Pre-test	0.020	0.19	0.10	.92
	Control	Constant	69.45	17.03	4.08	<.01
		Pre-test	0.30	0.18	1.69	.10
P200 – Mean amplitude						
FM	MCST	Constant	-0.08	0.74	-0.11	.92
		Pre-test	0.07	0.07	1.01	.32
	CST	Constant	-1.18	0.78	-1.51	.14
		Pre-test	-0.08	0.06	-1.43	.16
	Control	Constant	0.57	1.28	0.44	.66
		Pre-test	0.52	0.27	1.96	.06
P200 – Peak amplitude						
FM	MCST	Constant	1.30	0.73	1.77	.09
		Pre-test	0.07	0.07	0.99	.33
	CST	Constant	1.12	0.92	1.21	.24
		Pre-test	-0.09	0.07	-1.26	.22
	Control	Constant	1.02	1.12	0.91	.37
		Pre-test	0.64	0.26	2.42	.02

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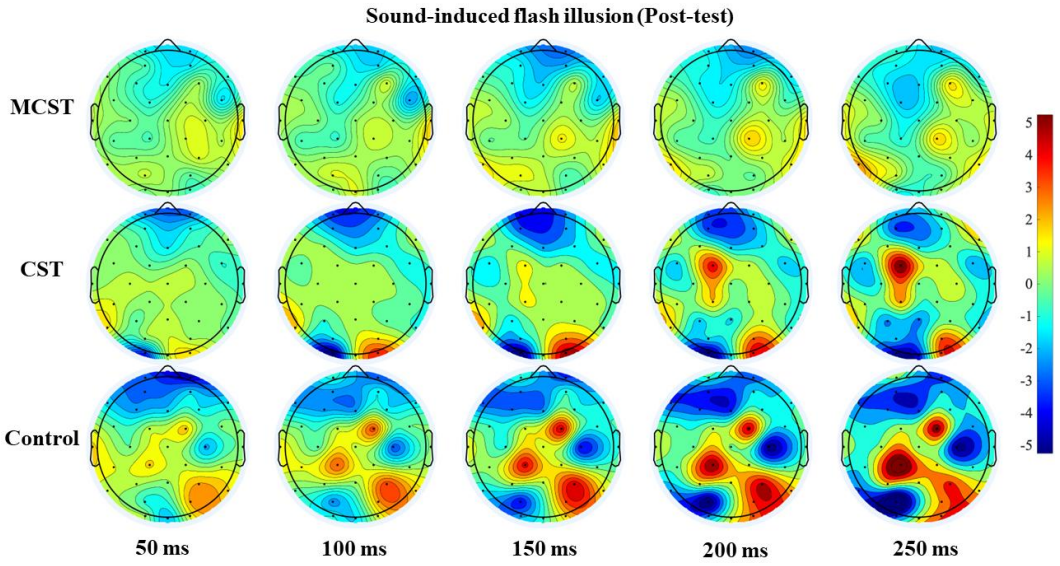

Figure 81 The topographic brain mapping of mean amplitude (illusion condition) for each 50 ms latency window during the Sound-induced flash illusion at post-test

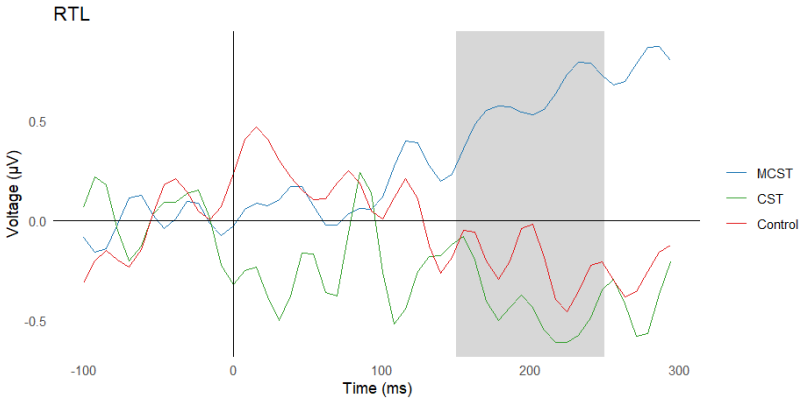

Figure 82 Grand-average P2 waveform over the right temporal lobe (RTL) across three groups in the choice reaction time task at post-test

ERP – Overall result

This study examined the effects of group conditions (MCST, CST, and control) on ERP components during various cognitive tasks in older adults with MCI using ANCOVA regression analyses due to violations of ANCOVA assumptions, such as significant interaction terms or lack of parallelism.

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From the ANCOVA, the results showed that during the verbal paired associates learning task, significant group effects were found for P300 and P3/LPC amplitudes in the frontal lobe, with the MCST group showing higher amplitudes than the CST and control groups. In the non-verbal paired associates learning task, significant group effects were observed for P300 and P3/LPC amplitudes and latencies in the central midline and frontal midline, highlighting differential neural responses in the MCST group. The verbal fluency task revealed limited significant effects, with only the P6 peak latency in the central area showing a notable group difference. During the Corsi block-tapping task, significant effects were observed in the P300 mean amplitude and P3/LPC peak latency in specific midline regions as well as the right TPJ, emphasizing differential neural responses in the MCST group. In the mental rotation task, significant differences were found in P6 amplitudes and latencies, particularly in the frontal midline and temporal lobe in the intervention groups. The Wisconsin card sorting test did not reveal significant group effects, indicating minimal impact of group conditions on ERPs during this task. In the simple reaction time task, significant effects were observed for N1 peak latency in central and temporal-parietal regions, highlighting differential neural responses in the CST group. For the choice reaction time task, significant group effects were found for P3 mean amplitude and peak latency in the frontal lobe, central midline and temporal-parietal junction, especially in the MCST group. Lastly, the sound-induced flash illusion task showed significant effects for P2 amplitudes in the right temporal lobe, suggesting altered multisensory integration in the MCST group. Overall, the MCST intervention appeared to enhance neural activity in specific tasks and regions, reflecting potential benefits for improving cognitive functions in this population.

For the regression analysis, the results showed that during the verbal paired associates learning task, significant effects were observed for P300 and P3/LPC mean and peak amplitudes in the LTPJ region, with the control group consistently showing stronger associations, while the MCST and CST groups demonstrated limited intervention impacts. During the Corsi block-tapping task, the MCST group exhibited significant effects for P3/LPC peak latency at the Cz, indicating enhanced neural processing compared to the CST and control groups. The mental rotation task revealed notable group differences in P600 and N200

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components, particularly in the frontal lobe and parietal regions, with the MCST group showing consistent and significant modulation. In the Wisconsin card sorting test, the CST group demonstrated significant negative relationships for P300 and P3/LPC amplitudes in the CM region, while the control group exhibited positive associations, suggesting different mechanisms underlying task performance. The simple reaction time task highlighted significant effects for the CST group in N100 and P300 components across central and occipital regions, indicating meaningful intervention impacts, while the MCST group showed moderate effects. The choice reaction time task revealed significant P300 peak amplitude differences at the Oz, with the CST group demonstrating the strongest effects. Lastly, the sound-induced flash illusion task showed consistent significant effects in the control group for components like N150 and P200, while the MCST group exhibited trends toward significance in specific regions.

Overall, the MCST intervention showed consistent modulation of ERP components in tasks involving complex cognitive processing, the CST group demonstrated task-specific effects, and the control group displayed natural predictive capacities, highlighting differential impacts of the interventions. Thus, Hypotheses 5 and 6 are partially confirmed. Significant differences in ERP components (N100, P200, P300, N400, and P600) were observed among experimental groups in various computerized neuropsychological tasks, particularly in the verbal paired associates learning task, Corsi block-tapping task, mental rotation task, and choice reaction time task. The MCST intervention consistently modulated ERP amplitudes and latencies, especially for N200, P300, and P600 in tasks requiring complex cognitive processing, while the CST group showed significant effects in specific tasks, such as the simple reaction time and Wisconsin card sorting tests. However, some tasks, such as the Wisconsin card sorting test and sound-induced flash illusion, revealed stronger or comparable effects in the control group, indicating natural predictive capacities rather than intervention-specific effects. Therefore, while ERP components significantly differed in key tasks following CMCS intervention, these findings do not fully support the hypotheses across all tasks and conditions.

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CHAPTER 5
DISCUSSION

This chapter is structured into four sections. The initial section provides a concise summary of the primary findings disclosed throughout this study. Following this, the second section comprehensively discusses the research findings, contextualizing them within the predefined research objectives. Subsequently, the chapter delineates the limitations encountered during the research process. Finally, the concluding section offers implications from the findings and recommendations for future research directions.

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Summary of the study

The development of computerized multicomponent cognitive stimulation (CMCS) program was developed based on cognitive stimulation therapy (CST), approached by Spector and colleagues, the group-based CST program was designed for people with dementia (Spector et al., 2001; Spector et al., 2003). Meanwhile, it has been applied to older adults with MCI to prevent dementia (Niederstrasser et al., 2016; Wenisch et al., 2007). Moreover, computerized approaches were utilized for the CST program to improve cognitive functions in older people with MCI (Djabelkhir-Jemmi et al., 2018; Djabelkhir-Jemmi et al., 2017). These findings demonstrate a significant effect on various cognitive domains and emotions, highlighting the usefulness and acceptability of CST for older adults with MCI.

The current program was adapted from Gomez-Soria et al. (2020) to reduce sessions from the original CST to 10 sessions of 45 min per week for ten weeks. Moreover, multisensory stimulation was included in the CMCS program by adapting the concept of temporal order judgment (Setti et al., 2014) and audio-visual perceptual training (Yang et al., 2018). The participants from the three groups participated in the CMCS program, called the “MCST” group (CST integrated with multisensory stimulation). The other group's participants went to the computerized

CST, called the “CST” group. The last group was the control group, in which the participants received no intervention.

This study assessed specified subdomains of cognitive functions, including learning and memory, language, visuospatial, executive, psychomotor, multisensory integration. The assessment of cognitive functions used for collecting the neuropsychological and electroencephalogram (EEG) data, with band frequency analysis and event-related potential (ERP) analysis, as follows: (1) learning and memory were assessed using paired-associated learning tasks that were separated into two parts: semantic memory used word or verbal stimuli, and non-semantics memory used abstract or non-verbal stimuli. ERPs were explored on P300 and P3/LPC components. (2) Language was measured by verbal fluency tasks with category and letter conditions. ERPs were explored on N4 and P6 components. (3) Visuospatial skills were assessed using the mental rotation and Corsi block-tapping tasks. ERPs were explored on N2 and P6 components for the mental rotation task and P300 and P3/LPC components for the Corsi block-tapping task. (4) Executive function was measured by the Wisconsin card sorting test. ERPs were explored on P300 and P3/LPC components. (5) Psychomotor performance was measured by simple and choice reaction time tasks. ERPs were explored on N1 and P3 components for the simple reaction time task and P3 components for the choice reaction time task. (6) Multisensory integration was measured by the sound-induced flash illusion task. ERPs were explored on N1 and P2 components. Furthermore, participants were also asked to attend the 5-minute resting state session, which was separated into eyes-closed and eyes-open conditions. In the EEG data in each task, the frequency of relative power in delta, theta, lower alpha, upper alpha, full alpha, and beta bands was analyzed. Moreover, quality of life and emotions such as depression and anxiety were assessed in the study.

A pretest-posttest control design was utilized to conduct this experiment. A total of 93 Older adults aged between 60 and 80 years old and an age mean of 67.68 (± 4.78) years who had impaired cognitive functions were included in the study following the inclusion criteria. At the baseline, Participants were randomly assigned to either the MCST group (n = 31), the CST group (n=31), or the control group (n = 31). They were shown to be equivalent in age, schooling years, depression, anxiety,

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gender, diseases, vision, marital status, job, and global cognition (MoCA total score). At the post-intervention, participants were asked to perform tests again, which were completed by 100% of participants engaging in the intervention. However, one subject in the control group was a dropout. ANCOVA and post hoc were conducted to assess the effectiveness of interventions. In addition, effect size was also reported to describe the magnitude of the intervention effect on cognitive functions.

The main findings highlighted the effectiveness of the CMCS program on cognitive functions in older adults with MCI. Learning and memory, language, visuospatial, psychomotor, and multisensory integration were improved as well as depression and anxiety were shown to decrease after the intervention. Moreover, the MCST group was more effective than the CST group, especially in multisensory integration and language. Consequently, it can be confirmed that the use of computerized multicomponent cognitive stimulation intervention positively impacts some cognitive functions, preventing them from becoming more impaired. However, the behavioral, EEG, and ERP results differed from some of them, which will be discussed in the next section.

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Discussion of the research findings

Effects of the developed CMCS program on cognitive functions, emotions, and quality of life in older adults with MCI

The validity of computer-based neuropsychological tests

The study aimed to evaluate the validity of computer-based neuropsychological tests in older adults with MCI. It hypothesized that the tests would correlate with MoCA or MoCA subscales and relate to other neuropsychological measures. Our findings found significant correlations between MoCA scores (and its subscales) and various cognitive performance metrics, demonstrating MoCA's utility in evaluating a broad range of cognitive abilities, particularly executive functions, and visuospatial skills. In particular, participants with higher overall cognitive functioning, as indicated by higher MoCA total scores, tend to perform better across multiple cognitive tasks. These findings emphasize the interconnected nature of cognitive tasks and the importance of comprehensive cognitive assessments. Moreover, our findings also underscore the interconnected

nature of cognitive abilities, with better performance in one task often predicting better performance and fewer errors in related tasks, demonstrating the utility of integrated cognitive assessments.

The strong positive relationship between the verbal paired association learning task (VPAL) immediate and delayed recall suggests that participants who perform well during the learning phase also excel during the test phase. This is further supported by the negative correlation with response errors, indicating that better recall is associated with fewer mistakes. Although the non-verbal paired association learning task (OPAL) immediate recall shows a moderate positive correlation with VPAL immediate recall, the correlation is not statistically significant, suggesting some level of shared cognitive strategies or skills between these tasks. The results were in line with the study of Harel et al. (2011), individuals with aMCI performed worse on the visual PAL than healthy controls, with impairments increasing as memory load increased. This suggests that individuals with aMCI have reduced short-term memory capacity, contributing to their poorer performance, as well as deficits in executive function, in addition to associative learning impairments, contribute to this poor performance (Harel et al., 2011). Furthermore, Pike et al. (2008) found that substantial heterogeneity in memory profiles within the MCI and AD groups. Some participants showed a retrieval profile, characterized by better recognition than recall, while others showed an encoding profile, with poor performance on both recall and recognition tasks. This variability was evident within individuals across different tasks, yes-no recognition and two-alternative forced-choice recognition tasks (Pike et al., 2008). This indicates that the paired association learning tasks relies on association with learning, memory, and executive functions.

In the Wisconsin card sorting test (WCST), higher MoCA total scores are associated with completing more sets, requiring fewer trials to complete the first set, and making more conceptual-level responses while producing fewer response errors and non-perseverative errors. Especially the MoCA Visuospatial/Executive (VE) subscale, which assesses visuospatial and executive functions, strongly correlates with WCST performance. Higher MoCA VE scores correlate with completing more sets, making more conceptual-level responses, and having fewer

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failures to maintain a set and fewer response and non-perseverative errors. This underscores the importance of visuospatial and executive functions in successful WCST performance, which can help clinicians more accurately diagnose cognitive impairments and differentiate between cognitive dysfunctions. Our results are in line with previous studies that older adults with MCI displayed MoCA scores correlated with WCST performance (Schweizer et al., 2012; Yoshii et al., 2017). Moreover, the WCST metrics exhibit significant relationships with VPAL and CRAT scores. Higher performance in VPAL learning and test phases is associated with fewer errors and perseverative errors in WCST. Additionally, better performance in choice reaction tasks is linked to fewer errors in WCST, indicating a relationship between executive function and reaction time tasks. Conceptual-level responses in WCST correlate positively with VPAL and CRAT scores, suggesting that better conceptual thinking abilities are associated with improved verbal learning, memory performance, and choice reaction accuracy. Similarly, the study of Duff et al. (2005) found a robust relationship between executive functioning and both verbal and visual memory capacities, especially measured from WCST and VPAL (Duff et al., 2005). Specifically, the immediate memory and delayed memory indices indicated a strong relationship between executive functioning and memory, with high loadings for various measures, such as TMT-B and WCST (Jurado & Rosselli, 2007). This further supports the notion that executive functions impact immediate and delayed recall, as measured by paired associates' learning tasks.

The Corsi block-tapping task (CBTP) shows significant positive correlations with the MoCA total score and the VE subscale, indicating that better overall cognitive functioning and visuospatial/executive abilities are associated with higher CBTP performance. However, the delayed recall subscale of MoCA does not significantly correlate with CBTP performance, suggesting that delayed recall does not strongly influence this task. Our findings relate to previous studies that tailored visual-spatial cognitive evaluations are important in diagnosing and managing various neurodegenerative diseases (Possin, 2010), especially AD and MCI (deIpolyi et al., 2007). Additionally, the CBTP shows positive correlations with VPAL and OPAL metrics, indicating that better performance on the CBTP is linked to improved learning and test accuracy and fewer errors. This task also correlates positively with

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WCST conceptual-level responses and negatively with non-perseverative errors, suggesting that better performance on CBTP is associated with enhanced executive function and reduced errors. Furthermore, the CBTP also shows positive correlations with mental rotation, indicating that spatial working memory is related to mental rotation ability (Kaufman, 2007). Working memory capacity has been especially linked to greater accuracy and speed in mental rotation tasks (Hyun & Luck, 2007; Kaufman, 2007; Pardo-Vazquez & Fernandez-Rey, 2012).

For the mental rotation task (MTRT), scores are moderately correlated with MoCA, particularly at 50 degrees of rotation, where the correlations with both the total MoCA score and the VE subscale are statistically significant. This suggests that performance on mental rotation tasks, especially at 50 degrees of rotation, is related to cognitive abilities assessed by MoCA, including visuospatial and executive functions. Previous studies showed that the mental rotation task demonstrated high sensitivity in discriminating between MCI patients and healthy controls. Specifically, the study used the run count (RC) ratio, an eye movement parameter, to measure visual exploration strategies. Higher RC ratios, indicating more fixations on incorrect answer choices, were significantly associated with MCI and AD compared to controls during mental rotation tasks (Suzuki et al., 2018). Similarly, mental rotation ability is also correlated with visual-spatial cognitive functions measured by MoCA in healthy people (Yabe et al., 2022). Furthermore, the MTRT measures demonstrate positive associations with learning and test accuracy measures and negative correlations with error rates. This suggests that better performance on the MTRT is linked to improved cognitive accuracy and fewer mistakes. The response time measure of MTRT shows a moderate positive relationship with SRAT and CRAT measures, indicating that faster reaction times and higher correct responses are associated with better mental rotation task performance. Our research related to literature shows that reaction time typically increases with indirectly cued movements, reflecting the additional cognitive demands of mental rotation (Drummond et al., 2015). It suggests that inhibitory mechanisms are more pronounced in tasks with higher cognitive demands, such as those requiring visuomotor mental rotation. Furthermore, The CRAT and SRAT also show significant negative correlations with MoCA scores, indicating that longer reaction times are associated

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with lower cognitive functioning. However, the number of correct choices in the CRAT does not significantly correlate with MoCA scores, highlighting the relevance of reaction time measures in assessing cognitive abilities.

Finally, the sound-induced flash illusion (SIFI) test results show that better cognitive performance, indicated by higher MoCA scores, is associated with faster reaction times and better performance in conditions with shorter stimulus onset asynchronies (SOAs). In line with previous studies, individuals who lacked the ability to resist audiovisual integration showed a lower MoCA score (Hernández et al., 2019). Moreover, these tasks exhibit significant correlations with learning accuracy, error reduction, conceptual responses, and performance on other cognitive tasks such as MTRT and SIFI. Better performance on CRAT and SRAT is associated with fewer errors and improved reaction times, highlighting the importance of quick and accurate responses in various cognitive domains. Additionally, our findings also found that delayed recall correlated with SIFI, which is related to a recent study (Hirst et al., 2022). These indicated that more precise multisensory integration was associated with better cognitive performance, improved cognitive accuracy, and reaction times (Hirst et al., 2022). Specifically, it was linked to faster choice response times. This suggests that the ability to integrate sensory information efficiently is related to better overall cognitive performance.

The pilot study of the CMCS program

This pilot study determined the cognitive function, emotions, and quality of life among older adults with MCI in Thailand. Such improvement was attributed to the tablet- and group-based multicomponent cognitive stimulation therapy (MCST) for 45 minutes per session and once a week over a period of 10 weeks aimed at improving their cognition, emotions, and quality of life. Findings showed that older people showed improvement in global cognitive function, as proven by scores on MoCA-T. Moreover, this study also indicated a reduction in depression and anxiety, as demonstrated by scores on TDGS-15 and STAI-state. However, the intervention can not enhance the quality of life among participants. These findings support the idea that the tablet- and group-based MCST program effectively improves global cognitive function and emotions in older adults with MCI.

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The study findings align with prior research regarding computerized cognitive stimulation using tablet-PCs and social interactions among older adults with MCI (Djabelkhir-Jemmi et al., 2018; Djabelkhir-Jemmi et al., 2017). Djabelkhir et al. employed the KODRO application on Android tablets, incorporating functions like event reminders, cognitive games, communication tools, entertainment features, videos, and a library to engage various cognitive domains in participants with MCI. Each participant engaged individually with the tablet-PC and participated in group discussions. The investigation demonstrates that computerized cognitive stimulation using Android tablet-PCs enhances cognitive function, as measured by the Trail Making Test part B (Djabelkhir-Jemmi et al., 2017), consistent with meta-analytical findings indicating cognitive training's positive impact on global cognitive function, memory, and working memory in elderly MCI patients, though executive function remains unaffected (Zhang et al., 2019). Nonetheless, specific cognitive domains necessitate evaluation in the present study. The subsequent study within this study will utilize neuropsychological assessments and electroencephalography to elucidate the subcomponents contributing to cognitive performance enhancement among older individuals with MCI.

Incorporating culturally relevant elements into the CST is essential for enhancing its effectiveness and participant engagement. By integrating familiar cultural components, such as traditional music, images, and tools, participants can connect more deeply with the therapy, leading to improved cognitive outcomes. For instance, Wong et al. (2018) demonstrated that culturally adapting CST can significantly improve engagement and cognitive outcomes in people with dementia. Tailoring the intervention to match participants' cultural values, such as social harmony and practical engagement, encourages a stronger connection with the therapy and enhances its overall effectiveness (Wong et al., 2018). Furthermore, a study in Thailand examined the effects of a CST program on the cognitive abilities of demented older adults (Sipollo et al., 2019). The program, which was adapted to the local culture, led to significant improvements in cognitive function, underscoring the value of cultural relevance in therapeutic interventions (Sipollo et al., 2019). These studies indicated that the CST approach not only enhances the effectiveness of the

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intervention but also promotes a deeper connection between participants and the therapeutic process.

In terms of emotion, depression and anxiety are common in people with MCI (Lopez et al., 2005; Palmer et al., 2007; Richard et al., 2013). Fascinatingly, emotional symptoms such as depression and anxiety decreased following the session. In contrary to Djabelkhir-Jemmi et al. (2017), there was unchanged post-intervention. Nonetheless, Talassi and colleagues found that not only cognitive functions but also depression and anxiety were improved in people with MCI after they participated in the cognitive rehabilitation program, including computerized cognitive training, occupational therapy, and behavioral training (Talassi et al., 2007). The MCST program might explain this conclusion by incorporating social interaction foundations, such as group discussions and team games. These activities provide opportunities for social support, connection, and disclosure to others with comparable cognitive functioning issues, which are common contributors to emotional well-being. This discovery aligns with previous research, indicating that social interaction has the potential to modify the outcome of cognitive intervention programs (Iizuka et al., 2019).

In contrary to our hypotheses, cognitive stimulation through tablet and group basis had no significant effect on the participants' quality of life. Perhaps because all of our participants were aware of their diagnosis and expressed low satisfaction with their cognition and physical well-being, no change in their quality of life was seen after post-intervention. It has been shown that patients with MCI who are aware of their diagnosis or have high memory complaints have a poorer quality of life than those who are oblivious to their diagnosis or have low memory complaints (Maki et al., 2014; Stites et al., 2017).

Effects of the CMCS program on neuropsychological assessment

Learning and memory

This study assessed two types of memory (i.e., semantic and non-semantic) and found that both showed significant improvement, indicating that the CMCS enhanced learning and memory. The paired-associated learning test was used to measure learning and memory. The effectiveness of the test was found in different cognitive performances in individuals with healthy, MCI and AD (Hedayatjoo et al.,

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2023). The effectiveness of CMCS on learning and memory in MCI was coherent across the CST approach, which was measured across neuropsychological tests. For example, Wenisch et al. (2007) found that word-paired associate learning tasks explored the effect of CST intervention on immediate and delayed recall. Similar to the computerized cognitive training technique studied by Çinar and Şahiner (2020), the CANTAB tests, both in individuals with subjective memory complaint and individuals with early-stage AD, showed improvement in paired associate learning tasks after attending computerized cognitive training (Çinar & Şahiner, 2020). Moreover, Djabelkhir-Jemmi et al. (2018) also applied tablet- and group-based CST, learning and memory measured by the paired associated learning task showed improvement after 3 months of intervention. In addition, in the mild to moderate AD population, it was found that the CST improved word recognition. On the other side, the control group was shown to have decreased memory capacities (López et al., 2022). Regarding the CMCS, providing multimodal perception, such as pictures, sounds, and words/sentences, may improve learning and memory. In similar cases, Iodice et al. (2018) and Iodice et al. (2015) found that the combination of verbal and pictorial stimuli significantly enhances the recall of memory, suggesting that these multimodal cues help in accessing a common conceptual memory storage. The recall was better when items were embedded in sentences compared to when no sentence context was provided (Iodice et al., 2015; Iodice et al., 2018).

In contrast, recent studies did not find a significant change in delayed memory after applying the CST approach (Turana et al., 2024). Moreover, different approaches did not find the impact on learning and memory that implemented technological-based interventions (E. H. Lee et al., 2020). Particularly, Turana et al. (2024) found that CST intervention does not affect the delayed memory accessed by MMSE after three months of participation from older adults with MCI. However, it has been shown to increase immediate memory. It was in line with other scholars, although the study of E. H. Lee et al. (2020) found that the home-based cognitive intervention with a personal robot improved the spatial working memory in MCI patients, memory accessed from the paired associates learning task was not improved after the four-week intervention.

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The benefits and factors that support the success of computerized cognitive stimulation therapies differ depending on the study, despite the fact that their usefulness is supported. Research on computerized CST has indicated that learning and memory have improved. Our study's findings indicate that when 12 items are given, which are tested on learning and memory through the verbal and non-verbal paired associates learning tasks, there is an improvement in the identification of a word-paired list.

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Language

The verbal fluency task, including category and letter production, measured language performance in older adults with MCI. Our findings show that letter production increased in people who participated in the MCST program but did not improve in the control group. Our findings are in line with previous studies. For instance, Gómez-Soria, Ferreira, et al. (2023) found that the CST program impacted the language function accessed by MMSE. Tablet-based cognitive rehabilitation training using a serious game was found to impact language, as measured by the semantic verbal fluency task, after four weeks in a home-based setting (Lim et al., 2023). Moreover, the study of Djabelkhir-Jemmi et al. (2018), learning and memory measured by the verbal fluency tests (“letter” for phonemic fluency and “animals” for categorical fluency), showed improvement after attending the tablet- and group-based CST intervention. Furthermore, the study of Calatayud et al. (2023), it was found that a comprehensive cognitive stimulation program, according to the pre-existing cognitive level as measured with MMSE, led to global cognitive improvements in the specific language domain and verbal fluency after post-intervention but not in follow-up.

A systematic review found that multicomponent therapies, which involve cognitive training, among other strategies, typically improve the verbal fluency of older persons with MCI. However, the results might differ significantly based on the particular elements and unique characteristics of each person (Zou et al., 2024). For instance, Turana et al. (2024) found that CST intervention does not affect the language function accessed with MMSE. Similarly, López et al. (2022) studied in the mild to moderate AD population found that CST was not effective in language functions. This is in line with the study of Wenisch et al. (2007) found that scores in

both letter and category fluency tests were not improved after attending the group-based CST for 12 sessions once a week. Moreover, the study of Moro et al. (2015) Also, the impact of the CST intervention, measured by the category verbal fluency test in people with amnestic MCI (aMCI), did not show, but there was interaction between the group and session that indicated the control group had declined in word generation.

To determine language performance, verbal fluency is a good indicator for identifying cognitive impairment (Maseda et al., 2014). Moreover, Beltrami et al. (2018) investigated whether the analysis of the spontaneous speech performed by Natural Language Processing techniques revealed alterations in language performance in early cognitive decline. Concerning aMCI, it may not be an impairment in verbal fluency performance. However, (Murphy et al., 2006) found that generating words in healthy people was better than aMCI and AD, and aMCI more than AD. In our study, the category fluency selection was considered to be the most common and neutral, even though it is not as discriminatory for the MCI subtype (Maseda et al., 2014). Our findings showed that categorical fluency did not show different scores between groups post-intervention. However, the CST may be a better option than the no-intervention condition. It does not require specifically trained clinicians (Tsantali et al., 2017), and it may have positive impacts on language processing.

Visuospatial

The study investigated the effects of CMCS on visuospatial abilities in older adults with MCI. Visuospatial abilities were assessed through tasks measuring spatial perception and spatial memory, specifically the mental rotation task and the Corsi block test, respectively. The results indicated that the CMCS intervention, particularly in the form of an MCST program, led to increased visuospatial memory among older adults with MCI who participated in the program. However, this improvement was not observed in visuospatial perception as measured by the mental rotation task.

In the previous literature, Turana et al. (2024) found that three months of CST intervention improved visual construction, as measured by MMSE. Moreover, Gómez-Soria et al. (2022) also found that at a follow-up of 12 months, the long-term effects on spatial orientation. Compared to other approaches, route-learning training,

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which is intensive on virtual perception, was found to be effective in visuospatial short-term memory as measured by the forward Corsi blocks test (Mitolo et al., 2017). Furthermore, using semi-immersive virtual reality-assisted cognitive training also found a positive impact on the visuospatial function in patients with states ranging from subjective cognitive decline to MCI (Kang et al., 2021). However, Djabelkhir-Jemmi et al. (2018) who also applied tablet- and group-based CST, visuospatial memory from the Cognitive Efficiency Profile test did not show improvement. Similarly, in populations with mild to moderate AD, it was found that the CST did not impact the improvement of visuospatial function (López et al., 2022).

In conclusion, while CMCS appears to have a positive effect on visuospatial memory in older adults with MCI, its impact on visuospatial perception remains uncertain. Further research is needed to explore the effectiveness of CST interventions compared to alternative approaches and to identify the specific factors that influence their outcomes on visuospatial abilities in different populations.

Executive

This study investigated the effectiveness of CMCS on executive functions in older adults with MCI. The results did not show the intervention's success. Although the previous searches revealed studies on CST, they did not specifically mention using the WCST that was measured in our study.

These studies generally assess a range of cognitive functions on executive functions using various other tests and tools such as the Trail-Making Test (TMT) (Djabelkhir-Jemmi et al., 2018; Djabelkhir-Jemmi et al., 2017; Moro et al., 2015; Wenisch et al., 2007), Tower of London test (ToL) (Moro et al., 2015), the Dual Task (Moro et al., 2015). For example, Wenisch et al. (2007) found that the intervention did not affect executive function, which was explored by the Trail-Making Test (TMT) part B. Similarly to Djabelkhir-Jemmi et al. (2017) also explored executive functions were found specifically assessed using tests such as the TMT parts A and B, which evaluate processing speed and task-switching capabilities, which measure executive control. These tests did not show improvements post-intervention of tablet- and group-based CST. Specifically, the study in populations with mild to moderate AD found that the CST did not improve executive functions, for example, mental flexibility measured by the Wisconsin card sorting test (López et

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al., 2022). Moreover, in cognitive stimulation with specific strategies and metacognitive abilities on executive functions, Moro et al. (2015) were found to improve after six months of intervention on flexibility/attention shifting (measured by the Dual Task) and working memory. However, it turns out that working memory is highly trainable, however progress did not hold over time. Moreover, planning (measured by the Tower of London test) and flexibility (measured by the TMT) were not impacted by the intervention (Moro et al., 2015). In addition, Djabelkhir-Jemmi et al. (2018) explored executive functions in patients with MCI according to the severity of white matter hyperintensities. They found that executive functions specifically assessed using tests such as the TMT parts A and B showed improvements post-intervention in these populations but not in MCI people without white matter hyperintensities. It is important to take this into consideration when analyzing the effects of interventions on patients with MCI in the future (Djabelkhir-Jemmi et al., 2018).

Psychomotor

This study assessed psychomotor skills using simple reaction time (SRT) and choice reaction time (CRT) tasks. The findings show that, regarding behavior data, CMCS did not effectively change response time and accuracy after the intervention compared to the control group. The effectiveness of CMCS on psychomotor in MCI was consistent across the different approaches that were measured across neuropsychological and chronometric tests. For example, Jiang et al. (2019) dit not show statistically significant improvement in psychomotor speed (finger tapping test) in 20 older adults with MCI using ten sessions of limb exercise training structurally designed from task execution capacity, attentiveness, fine motor skills, hand-eye coordination, reaction time, balance, and upper and lower body coordination. However, it shows a change in cognitive functions (global cognition, visuospatial execution, and delayed recall) and a strong relationship with psychomotor speed (Jiang et al., 2019).

Psychomotor dysfunction in older adults with MCI has been the subject of several studies. Reaction time tasks were used to assess attention (Nasiri et al., 2023), mainly focused attention using the choice reaction time task that showed significant access psychomotor dysfunction in the population in MCI and AD

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(Levinoff et al., 2005). It is helpful for identifying attention levels between older adults with cognitive deficits and healthy people (Zancada-Menéndez et al., 2013). However, Bailon et al. (2010) was found that individuals with MCI did not differ from healthy people on digital tapping, the SRT and CRT tests. In keeping with the study of Hartle et al. (2022) shown that low accuracy in predicting MCI using the SRT test as well as correct responses measured by CRT, which was not good at distinguishing from healthy individuals. In contrast, response time in CRT showed high sensitivity and specificity in detecting MCI (Hartle et al., 2022). Thus, it is recommended that patients with MCI should participate in cognitively stimulating activities, especially those involving language and psychomotor coordination (Rosenberg et al., 2006).

Multisensory integration

Multisensory detection tasks could be used as a screening tool for MCI, highlighting the potential of including multisensory integration tasks in the neuropsychological assessment of older adults (Murray et al., 2018; Pinto et al., 2021). Especially the cognitive functional deficits of patients with MCI and AD contribute to the differences in performance enhancements of audiovisual integration compared with healthy older adults (Wu et al., 2012). Furthermore, The sound-induced flash illusion (SIFI) was found to measure multisensory integration in individuals with MCI (Chan, Kaiser, Brandl, Matura, Prvulovic, J Hogan, et al., 2015). Moreover, The study of Hirst et al. (2022) demonstrated that more precise multisensory integration assessed using the SIFI was associated with better cognitive performance in older adults. This relationship was evident in various cognitive domains, including processing speed, attention, and memory. Particularly, older adults with more precise multisensory integration had faster response times on the choice reaction time task and better performance on the Color Trails Test. They also made fewer errors on the Sustained Attention to Response Task, suggesting a broad influence of multisensory integration on cognitive function (Hirst et al., 2022).

This study was used to monitor the effectiveness of the CMCS program using the SIFI test. Our findings show that older adults with MCI who attended the MCST group demonstrated increased correct response performance in multisensory integration. The CST approach was shown to include sensory

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stimulation but did not show integrated multisensory stimulation sessions. Moreover, previous studies were insufficient to report the effectiveness of intervention on neuropsychological assessment of multisensory integration in older adults with MCI. However, relevant studies found that multisensory integration is beneficial for improving cognitive functions in individuals with MCI. For instance, (L. P. Lee et al., 2020) applied audiovisual integrative training in older adults with MCI. This program required participants to process both visual and auditory stimuli, facilitating audiovisual integration. This process involved encoding the stimuli, which necessitated heightened attentional control and motor skills in hand movements to produce the correct responses. Enhancements in attentional control among the MCI group were evidenced by notable improvements in their scores on the Stroop Test from the initial assessment to after the training (L. P. Lee et al., 2020). Moreover, training in perceptual abilities may enhance various cognitive functions in older adults due to the strong link between efficient perception and cognitive performance in aging (Lindenberger & Ghisletta, 2009; Setti et al., 2014). The study of Setti et al. (2014) shows that healthy older adults still possess the capacity for plasticity in their audio-visual perceptual skills, as audio-visual temporal discrimination training significantly improves temporal discrimination in most participants. Furthermore, improved temporal discrimination abilities correlate with reduced susceptibility to the SIFI, suggesting that such training also positively affects other untrained perceptual processes (Setti et al., 2014).

Emotions and quality of life

This study also explored behavior outcomes such as depression and state anxiety. Our findings showed that the CMCS effect improved their moods after participating in the intervention. In line with previous studies, these interventions have demonstrated effectiveness in decreasing depression and state anxiety symptoms (Justo-Henriques et al., 2023; Machado dos Santos et al., 2024; Zubatsky et al., 2023). For example, Machado dos Santos et al. (2024) found that the group-based CST effect reduced depression and anxiety after seven weeks. Similarly, the study of Justo-Henriques et al. (2023) found that people with MCI improved their feelings of depression after participating in the individual CST for 49 sessions once a week. Moreover, Zubatsky et al. (2023) was found that participants in community or

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university-based groups showed a difference in depressive feelings, reflecting better improvements in coping with their mood compared to those in hospital settings.

Although many studies on applying computerized intervention affected cognitive function, moods were not shown to improve or not reported as outcomes (Djabelkhir-Jemmi et al., 2018; Djabelkhir-Jemmi et al., 2017; Dodge et al., 2015; Gomez-Soria et al., 2020; Peretz et al., 2011; Savulich et al., 2017). Particularly, Previous studies that used tablet- and group-based CST interventions were not found effective in modifying emotions such as depression and anxiety. However, motivation, technology acceptance, and self-esteem were positively improved in patients with MCI (Djabelkhir-Jemmi et al., 2018; Djabelkhir-Jemmi et al., 2017) as well as in the previous study that applied a group-based CST approach in older adults with MCI (Gomez-Soria et al., 2020). Additionally, recent research by Gómez-Soria, Ferreira, et al. (2023) indicates significant short-term improvements in anxiety following interventions but not sustained over six months.

Concerning cognitive impairments, depression, and anxiety are common in patients with MCI or Alzheimer's dementia (Elferink et al., 2015; Lee et al., 2019; Richard et al., 2013). Patients with MCI and AD may have different relationships, and the link between depression and cognitive function is stronger in MCI than in AD (Lee et al., 2019). However, people with MCI show better emotional processing than AD but worse than healthy people (Elferink et al., 2015). Specifically, several studies have indicated positive outcomes in mood intervention. Both Meeten et al. (2015) and M. Williams et al. (2018) observed enhanced levels of well-being and decreased severity of depression and anxiety after group mindfulness-based cognitive therapy. In a similar vein, Wuthrich and Rapee (2013) and Wuthrich et al. (2016) demonstrated the effectiveness of group cognitive behavioral therapy in alleviating depression and anxiety among older adults. Furthermore, studies by Zerhusen (1991) and Barrowclough (2001) revealed significant reductions in anxiety and depression following group cognitive therapy and cognitive-behavioral therapy, respectively.

The original CST was shown to be designed to improve cognition, depressive symptoms, and quality of life in older people with dementia (Spector et al., 2001; Spector et al., 2003; Woods et al., 2006). Research indicates that CST, which

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involves engaging patients in activities designed to stimulate cognitive functioning within a social context, can enhance cognitive performance, reduce symptoms of depression, and improve overall quality of life. Moreover, CST and computerized cognitive intervention have been shown to possibly improve the quality of life in older adults with MCI (Chao et al., 2020; Nicole T.M. Hill et al., 2017).

Specifically, one study by Gil et al. (2022) demonstrated significant improvements in cognitive performance and quality of life measures following reminiscence therapy that are relevant to CST, emphasizing its potential benefits in community-based settings for older adults experiencing cognitive decline. Although people with MCI were not worse in activities of daily life, a cognitive stimulation program has been shown for basic activities of daily living in MCI (Gomez-Soria et al., 2020). Furthermore, Carcelén-Fraile et al. (2022) reported improvements in quality of life in some subscales, such as social functioning and physical and mental health, in older adults with MCI after CST post-intervention. Furthermore, the goal-oriented rehabilitation program in MCI was shown to improve the overall score in quality of life measured by the Quality of life of AD but not show significant improvement in the subscale such as self and mood (Londos et al., 2008).

It is important to consider that the cognitive improvements observed in our study may not solely result from the specific content of the intervention but also from the broader benefits of increased social engagement and mental stimulation. This consideration aligns with recent research indicating that social engagement itself can have a protective effect against cognitive decline. For example, a systematic review and meta-analysis indicated that social interaction interventions have a significant effect on cognitive functions in older adults, emphasizing the potential cognitive benefits of social engagement (Wei et al., 2024). This aligns with recent findings that reduced social engagement is linked to reduced cognitive function over time (Ni et al., 2024). Therefore, enhancing social interaction should be considered in cognitive intervention programs, as it may also help reduce depressive symptoms and slow cognitive decline.

The study underscores the efficacy of CMCS in enhancing mood and improving symptoms of depression and anxiety among individuals with MCI. While computerized interventions mostly improve cognitive functions, targeted CST, both in

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individual and group settings, also positively affects emotions. The findings suggest variability in mood improvement based on the intervention setting, indicating better outcomes in community or university-based groups compared to hospital settings. This aligns with earlier observations that while cognitive enhancements are often reported, emotional improvements are less consistent unless specific quality of life and mood-targeted interventions are applied. Moreover, these results imply that while group-based cognitive stimulation therapy may not directly influence emotions and quality of life, it proves beneficial when integrated with certain therapeutic techniques.

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Effects of the CMCS program on EEG and ERP assessment

Resting-state EEG

The analysis shows that CMCS influences resting-state EEG with eyes closed (EC) and eyes open (EO) sessions. Our findings indicate that the relative theta power over the occipital region and the lower alpha's relative power over the frontal lobe at the EC condition have been shown to change post-intervention. In addition, our findings also suggest that the relative beta power over the right TPJ at the EO condition has been shown to change post-intervention. Those are in line with empirical evidence from previous studies to distinguish AD from healthy people and MCI, providing a potential biomarker for monitoring brain change post-intervention.

In a recent study by Deng et al. (2024), medium frontal, medial parietal, and occipital areas brain regions that were found to be most important in the ROI analysis were those that are most often cited as involved in MCI deterioration (Deng et al., 2024). According to recent studies on 2-year longitudinal resting-state EEG emphasizing amyloid-positive patients, theta signal variability and parieto-occipital peak frequency significantly decreased with time in AD dementia patients (Scheijbeler et al., 2023). Specifically, the relative power spectral densitiey of theta waves during EC resting-state at the occipital area differed among healthy individuals, those with MCI, AD, and other dementia subtypes such as frontotemporal dementia, dementia with Lewy bodies, and vascular cognitive impairment, with improved cognitive performance in individuals with cognitive impairment being specifically linked to greater instantaneous fluctuations of EEG signals at the occipital regions (Jiao et al., 2023). Similarly, the identification of early biomarkers of AD pathology

using resting-state EEG ICA-based network graph analysis in the theta band could help distinguish MCI patients, as indicated by an increase in theta band density, achieving good diagnostic accuracy (Cecchetti et al., 2021). Musaeus, Engedal, et al. (2018) suggest that an increase in relative theta power may represent the earliest detectable change in patients with dementia due to AD. This relative theta power was significantly correlated with several neuropsychological measures, showing the strongest correlation with total tau, particularly in the EC condition (Musaeus, Engedal, et al., 2018). Moreover, MMSE overall, attention, and calculation scores among patients with moderate-to-severe cognitive impairment are significantly correlated with alpha relative power in the frontral area during the EC condition (Torabinikjeh et al., 2022). In addition, Musaeus, Nielsen, et al. (2018) indicate that MCI patients who progress to AD showed decreased relative beta power in the parietal area as well as correlated with amyloid-β42 and anterograde memory. Furthermore, Miraglia et al. (2016) also found that aMCI subjects showed an increase of brain connectivity in theta and a decrease in lower alpha band, whereas AD patiens showed a decrease in upper alpha in the EC condition with respect to EO condition. In addition, the brain network of normal elderly is characterized lower connectivity in the beta band during the EO condition (Miraglia et al., 2016). These differences highlight potential neurophysiological markers that may contribute to understanding the neural underpinnings in AD. However, the lack of significant differences between MCI and HC groups invites further investigation into the subtleties of brain connectivity in varying cognitive states.

Recent clinical studies demonstrated that older adults showed an increase in theta waves during multimodal brain empowerment, including tDCS, light therapy, computerized cognitive therapy, and other solutions, including robot-assisted gait training, music therapy, and core exercise. Especially using computerized cognitive therapy, older adults demonstrated event-related synchronization activation in the frontal and parietal regions (Oh et al., 2023). Moreover, after noninvasive brain stimulation, MCI patients in the treatment group showed hyperactivation in the right precuneus and decreased activity in precuneus, cuneus, and supplementary motor area (Wang et al., 2023). In contrast to the evidence, Azami et al. (2023) found that theta relative power over the occipital area is lower in healthy people than in AD. In the

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same way, MCI was also shown to be lower than in AD (Azami et al., 2023). Concerning unusual activation compared to the healthy population, MCI individuals showed greater use of the dorsal attention network during rest, which is atypical for this state. This could indicate an adaptive or compensatory mechanism in response to cognitive decline as the brain attempts to maintain functional connectivity and cognitive capabilities (Caravaglios et al., 2023).

EEG power bands such as theta and theta/alpha band have been shown to be significantly associated with cholinergic damage (Arjmandi-Rad et al., 2024; Moretti et al., 2008). According to the ACh index reflecting the cholinergic activity, it has been linked to attention and sensory processing (Johannsson et al., 2015; Solari & Hangya, 2018). Therefore, cholinergic disruption is associated with characterized MCI and AD (Johannsson et al., 2015; Robbins, 2002). It is characterized by an impairment of the cholinergic neurotransmission associated with a pathological production of beta-amyloid and phosphorylated tau that can be observed by resting-state EEG (Babiloni, Del Percio, et al., 2013).

Learning and memory

Sematic and non-sematic learning and memory were assessed using verbal and non-verbal paired associated learning tasks. Our finding showd that not only relative theta band during performing tasks but also the ERP assessment, short segments of EEG data during particular events of paired stimuli serial recall, shows that the CMCS program does affect learning and sematic and non-semantic memory in older adults with MCI.

The EEG anaysis shows that CMCS supported changes in learning and memory in both semantic and non-semantic contexts. Our findings proved that the relative theta and alpha bands affected by the CMCS program showed changes in the area of the occipital lobe and temporal-parietal junction but not in the control group. Moreover, the ERP analysis shows that CMCS demonstrated changes in learning and memory in both semantic and non-semantic contexts. Our findings proved that the amplitude of P300 (300-500ms) and P3/LPC (500-700ms) affected by the CMCS program showed changes in the area of the frontal and central regions when compared to the control group.

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Numerous studies utilizing electrophysiological methods have indicated that alterations in frontal, central, and parietal activations are linked to memory impairment in the elderly. For example, the study of Fide et al. (2023) underscored distinct patterns during performing working memory task of intra-hemispheric coherence across different groups, with AD individuals showing consistently lower theta interconnectivity coherence values than MCI at several critical electrode pairs (e.g., frontal-temporal, central-occipital, parietal-occipital, temporal-parietal), The MCI group showed lower or similar theta interconnectivity coherence values compared to healthy people but was not statistically significant (Fide et al., 2023). Especially, Significant suppression of event-related potential components and diminished performance during memory tasks are correlated in MCI patients compared with healthy (Waninger et al., 2018). Moreover, higher cognitive loads in individuals with MCI are associated with prolonged P300 amplitude and latency, indicating a delay in cognitive processing. For instance, Task difficulty and task emphasis are highlighted as key factors affecting P3 amplitude (Kok, 2001). Increased task difficulty often leads to reduced P3 amplitude, potentially due to increased cognitive demands exceeding processing capacity. Furthermore, the effect was observed during tasks that required increased mental effort, suggesting that P3 in the frontal midline (Fz) and central midline (Cz) can be a useful marker for assessing cognitive function under different levels of cognitive demand (Demirayak et al., 2023). In addition, Hogan et al. (2011) indicated an increase in P3 amplitude in the right parietal cortex from early to late encoding stages in older declined adults. Moreover, Porcaro et al. (2019) also identified that the P300 peak amplitude was larger in older adults with high memory performance compared to those with low abilities. In addition, late component potential (LPP, 430-600 ms) components and diminished performance during sustained attention and memory tasks are correlated in MCI patients (Waninger et al., 2018).

Concerning EEG frequency domain measurement, our finding shows that CMCS determined unchanged in learning and memory in both semantic and non-semantic stimuli. Previous studies on the relative spectral power changing after CST treatment on these functions were lacking, but we found that researchers using paired associated learning used ERP techniques for measuring learning and memory (Curran

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& Doyle, 2011; Gui et al., 2017; Honda et al., 1996). However, fMRI was found to assess the task, showing increased brain activity during learning within the hippocampus and adjacent parahippocampal and right perirhinal cortices. Moreover, the medial temporal lobe memory system exhibited both learning-related changes in activity and responses to novel stimuli, evident throughout several frontal regions. (Law et al., 2005). Our results support the idea that the amplitude showed activation in the frontal lobe area during the test observation.

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Language

The verbal fluency task, which includes category and letter creation, measures language performance in older adults with MCI. Our findings found no effect of the CMCS program on language function in EEG and ERP assessment. Previous research has found noticeable changes in EEG frequency domain analysis following cognitive interventions in older adults with MCI during tasks such as verbal fluency to be challenging. Several studies have shown mixed results, as shown in the previous section in neuropsychological data, which might align with our findings of no significant changes in EEG data.

Concerning EEG frequency domain analysis on the task, which allows participation in speaking. It can lead to found artifacts such as tongue movements producing notable scalp potentials, complicating the interpretation of slow EEG phenomena (Vanhatalo et al., 2003). Likewise, ERP measurement stimuli on the verbal fluency task in our study, two events per condition (ex., the category of animal and fruit) were shown as a stimulus that may not be enough to assess the language performance related to noise and the number of trials (Luck, 2014). However, in previous studies that related to the measurement used in our study, resting-state EEG over the occipito-parietal area, multiscale entropy was strongly correlated with verbal fluency (Yang et al., 2013). In other areas, the researchers found that the measures of both frontal and temporal theta wave activity power at rest and letter fluency performance were not associated, but only performance on animal naming was considered (Brickman et al., 2005).

In other neuroimaging techniques, localized activity was observed in the anterior cingulate cortex and the left inferior frontal gyrus during verbal fluency tasks in the fMRI investigation. The region around the superior frontal sulcus showed

more activity (Phelps et al., 1997). In line with the study of Herrmann et al. (2003), they used near-infrared spectroscopy to measure frontal brain activation during the verbal fluency test. It shows increased oxygenated hemoglobin and decreased deoxygenated hemoglobin in both the left and right prefrontal areas during the test (Herrmann et al., 2003). These studies implied that the prefrontal area makes unique contributions to the cognitive functions related to verbal fluency. Further studies on EEG/ERP should focus more specifically on artifacts related to this issue of the test.

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Visuospatial

The Corsi block-tapping task was applied to assess visuospatial working memory capacities. Meanwhile, the mental rotation task was used to evaluate visuospatial perception performance. Our findings found that the CMCS program affects visuospatial memory in EEG frequency and ERP assessment. Similarly, our findings also show the effect of the CMCS on visuospatial perception in both EEG and ERP assessments. Our findings proved that the relative delta, upper alpha, and beta bands affected by the CMCS program showed changes in the area of the frontal, temporal and occipital lobes as well as temporal-parietal junction but not in the control group.

The EEG based brain connectivity measures were found effective to assess visuospatial abilities during performing the visuospatial working memory tasks. Previous research showed that participants performing the tasks mainly increased brain connectivity in occipital and temporal cortices (Daniel et al., 2018; Muthukrishnan et al., 2020). Specifically, scholars indicated that the occipital neuronal dynamics supporting visuospatial processing in healthy adults are uniquely affected in patients on the aMCI and AD. Patients, in particular, exhibited reduced alpha responses alongside stronger gamma frequency synchronizations (Wiesman et al., 2021). AD patients showed higher spectral power in alpha frequencies during object-location memory encoding and in alpha frequencies during retrieval, alongside increased connectivity strengths in alpha bands, with significant differences observed in frontal-parietal alpha regions during encoding (Han et al., 2017). In addition, scholars suggested that reduced oscillatory activity in high-frequency bands, particularly in the beta band, in the frontal an tempral areas which showed significant differences between AD patients and healthy individuals, may reflect electromagnetic

brain alterations associated with visual-object working memory impairments in early AD (Kurimoto et al., 2012). Furthermore, scholars also found that negative correlation was observed between the Corsi span forward score and the amplitude of occipital and temporal delta sources across MCI and AD subjects (Babiloni et al., 2007; Babiloni, Lizio, et al., 2013). AD patients increased connectivity strengths in delta band, with significant differences observed in frontal-temporal regions during encoding and frontal-temporal regions during retrieval, highlighting the role of slow EEG oscillations in modulating object-location memory processes (Han et al., 2017).

The mental rotation task was shown to measure visuospatial function effectively that motor imagery occurs during mental rotation and may be identified and investigated using EEG technology (Osuagwu & Vuckovic, 2014), which is relevant to other neuroimaging techniques. For example, scholars described activation of the left temporal region during the mental rotation task observed by fMRI (Zacks et al., 2003). Other studies also noted that, throughout the experiment, electrophysiological data tended to demonstrate right-lateralized posterior responses (Yoshino et al., 2000). Moreover, other researchers propose from fMRI results that activity occurs in both primary motor and premotor regions but that premotor activation is more pronounced due to strong posterior parietal input that helps direct a possible movement spatially (Vingerhoets et al., 2002). Whereas perspective changes produced selective increases in the left temporal cortex, rotation selectively increased the right parietal cortex and decreased the left parietal cortex (Zacks et al., 2003).

Previous research underline that the proposed mechanism underlying the negative correlation between occipital and temporal delta sources and visuospatial immediate memory is linked to the loss of cortical neurons typically influenced by cholinergic inputs. This cortical atrophy is thought to represent disrupted input and output information processing within the cortex in individuals with MCI and AD (Babiloni et al., 2007; Babiloni, Lizio, et al., 2013). Moreover, when performing the color Stroop task, neurophysiological representing low delta and high alpha power is associated with better conflict control and working memory in low anxiety individuals (Jaiswal et al., 2019). In the theory that in MCI patients, the most difficult mental imagery procedures are notably hindered. Because they considered the direction of the stimulus yet were deficient in the most difficult mental rotations. For instance, the

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mistake rate appears to confirm the worsening in mental imagery processes in the MCI group, with MCI patients having a larger error rate than healthy people (Bourrelier et al., 2015). In terms of brain connectivity, alpha 2 (10.5–13 Hz) network activity shows that MCI and AD patients presented lower connectivity than healthy populations after the learning task, sensory-motor learning task consisting of a visual rotation paradigm (Vecchio et al., 2018). Furthermore, Stipacek et al. (2003) demonstrated that an increasing relative power in the upper alpha is a function of increasing cognitive load. Our results relate to the fact that participants in the MCST group had increased upper alpha but decreased delta over the temporal area compared to the control group when participants perfoming the Corsi block-taping task and stimulus imagery conflicts during mental rotation.

In this study, ERP results showed that people who attended the CMCS program faced a change in latency in the 500-700ms time range over the right temporo-parietal junction (TPJ) after post-intervention while performing the Corsi block tapping task. The results related to previous evidence regarding the neural mechanisms of spatial rehearsal in working memory. The literature shows that the P300/P300 ERP, which peaks between 300 and 700 ms following stimulus presentation, is thought to have partly originated from TPJ (DiQuattro et al., 2013). Visuospatial cognition is composed of a multi-faceted set of functions mediated by a predominantly right-hemisphere network (Possin, 2010), the right temporal lobe appears to be specifically important for spatial perception (Kaski et al., 2015). Specifically, Visuospatial impairment was seen in MCI patients, namely in the identification of landmarks and spatial location recall (Mitolo et al., 2013). Moreover, Missonnier et al. (2005) demonstrated that stable and progressive MCI shows similar visuospatial performance after a one-year follow-up but a difference in attention (measured by TMT part A) and language (measured by verbal fluency). Concerning the subdomain, The parietal P300 ERP latency increased significantly in the single domain with dysexecutive compared to multiple domains with amnestic and single domain with amnestic (Missonnier et al., 2012). In a similar vein, participants in the MCST group showed a change in the P6 ERP latency (550-750ms) over the right temporal lobe after post-intervention while performing the mental rotation time task. Thus, these measures support our finding that temporal latency is significant given the

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role of the right hemisphere, particularly the right temporal lobe, in mediating complex visuospatial functions essential for tasks like spatial perception and landmark identification.

Executive

The Wisconsin Card Sorting Task (WCST) measures executive functions in older adults with MCI. Our findings found no effect of the CMCS program on executive functions in EEG and ERP assessment.

Older adults with MCI presented a reduction in executive function performances compared to healthy elderly (Clemente et al., 2023). Previous EEG studies showed that the WCST induces significant changes in brain oscillations across various frequency bands. Specifically, there was an increase in delta, theta, beta2, and gamma oscillations, with a decrease in alpha oscillations. These changes reflect the brain's dynamic adjustment to the cognitive demands of the task (González-Hernández et al., 2002). During the WCST, lower alpha power in the left frontal region correlated with better task performance, highlighting the role of the left dorsolateral prefrontal cortex in cognitive processes required for the task (Çiçek & Nalçacı, 2001). On the other hand, the strength of the right frontal event-related coherence was positively correlated with the number of categories achieved and negatively correlated with the number of perseverative errors. This indicates that right frontal activity is crucial for maintaining cognitive strategies and inhibiting repetitive incorrect responses (Carrillo-de-la-Peña & García-Larrea, 2007).

Moving to ERP measurement, the meta-analysis indicates that P300 event-related potentials, specifically amplitude and latency, are effective markers for diagnosing and predicting the progression of MCI. Patients with MCI showed decreased P300 amplitude and prolonged latency compared to the healthy population, and these changes were more pronounced when compared with AD patients (Jiang et al., 2015) Specifically, the amplitude and latency of the P300/P300 components reflect changes in how older adults process and respond to cognitive tasks like the WCST. For example, there is an increase in P300 latency and a decrease in P300. These changes in ERP components are indicative of broader neurocognitive shifts with aging (Dimitriadis et al., 2015; Fernandes et al., 2015).

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The above literature confirms that EEG/ERP assessment can be used to measure executive functions in older adults with MCI. However, The sensitivity of the EEG and ERP measures used to detect changes due to the intervention might not be adequate. Perhaps the tools or the specific metrics analyzed were not sensitive enough to pick up subtle changes that might have occurred. For example, several studies used TMT part B to measure the effectiveness of the intervention (Djabelkhir-Jemmi et al., 2018; Wenisch et al., 2007). Furthermore, variability in the degree of cognitive impairment among participants can affect the outcomes. For illustration, Djabelkhir-Jemmi et al. (2018) demonstrated a difference in performance in TMT part B when participants with MCI according to the severity of white matter hyperintensities. Moreover, The P300 ERP difference is significant in the single domain with dysexecutive compared to multiple domains with amnestic and single domain with amnestic (Missonnier et al., 2012)Understanding these factors requires a detailed analysis of the program's design, implementation, and participant group characteristics. It would be beneficial to examine individual differences in response to the intervention.

Psychomotor

This study used simple and choice reaction time tasks to measure processing speed. Especially choice reaction times show marked slowing with age and processing speed in high levels of cognitive decline.

EEG frequency domain analysis shows that CMCS has the main direct change in psychomotor skills. Our finding, especially in the choice reaction time task, was that the beta's relative power over the frontal lobe was shown to change post-intervention. In line with previous studies, for instance, healthy elderly individuals exhibited greater beta power during cognitive tasks compared to aMCI patients. Especially, aMCI patients had more pronounced event-related desynchronization, indicating reduced efficiency in information exchange across large-scale neural networks during cognitive processing (Caravaglios et al., 2018). More specifically, decreased beta inter-trial coherence in deteriorating MCI relative to stable MCI indicated early cognitive changes before clinical symptoms become apparent, pointing to the potential of beta inter-trial coherence as a sensitive marker for early-stage cognitive decline. Moreover, increased relative beta in deteriorating MCI compared to

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stable MCI suggests enhanced recruitment of attentional resources in those experiencing early cognitive changes (Deiber et al., 2015). Our finding is also in line with Robins's study on cholinergic neurotransmission, which was investigated using the 5-choice serial reaction time task established as a reliable method for evaluating attentional performance. It measures the effects of central manipulations, such as neurochemical lesions, on various aspects of attentional control, including sustained, selective, and divided attention. These attentional processes are related to neural systems centered on the prefrontal cortex, cingulate cortex, and striatum (Robbins, 2002).

Based on the analysis of ERP features, our findings demonstrated that the CMCS program affected the amplitude and latency of P3, changing the area of the right TPJ and frontal lobe compared to the control group. Firstly, the findings show that participants in the MCST group had decreased latency P3 over the right TPJ, but the decrease was not significant. It can be implied that the CMCS program can not extensively impact processing speed. However, it has shown increased latency in the frontal lobe compared to the no-intervention control group. This means that after post-intervention, the participants in the MCST group were slowing down to make decisions on choice. It shows a significant change in ERP latency at the frontal lobe, and it can be described that the CST intervention can induce changes in brain hippocampal connectivity (Behfar et al., 2023). Because the individuals completed the task so fast, the hippocampus waveform's latency followed the instructions for each movement. The availability of a shot-cut of communication between secondary motor centers engaged in movement programming areas may account for this (Roman et al., 2013). In terms of output pathways, the posterior parietal area is tightly associated with the premotor regions of the frontal cortex, which are directly involved in ocular control, reaching motions of the limb, and gripping actions of the hand and fingers. (Goodale & Milner, 1992). This is consistent with the discovery that the frontal brain processes visual discrimination task input early on (Brázdil et al., 1999).

Secondly, our findings also show that participants in the MCST group had decreased amplitude P300 over the right TPJ. It can be implied that the CMCS program can impact processing speed to reduce efficient processing, which could be due to reduced attention or requiring less cognitive effort during the choice reaction

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time task (Luck, 2014). Specifically, Goal-directed and voluntary attention controls were activated in an interaction between the dorsal and ventral attention networks, especially the TPJ area. These networks are activated by stimuli that are behaviorally relevant and require a response (Corbetta & Shulman, 2002; Kincade et al., 2005). Moreover, more efficient working memory performance was associated with larger P3 amplitudes at parietal sites, indicating effective allocation of attentional resources and response selection (Luck, 2014; Polich, 2007; Saliasi et al., 2013). In line with the study of Mendes et al. (2024), decreasing P3 amplitude was affected by transcranial direct current stimulation over the right inferior frontal gyrus, which recruits across a range of task conditions requiring sustained attention.

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Multisensory integration

Sound-induced flash illusion was used to measure multisensory integration in older adults with MCI. The ERP assessment shows that the CMCS program does have an effect on multisensory integration performance after intervention. However, this study does not show that EEG frequency domains were changed post-intervention.

According to frequency domain analysis, previous studies on SIFI did not contribute to the study of MCI patients. However, some studies show potential for investigation. For example, Cecere et al. (2015) provided evidence that the alpha oscillation frequency acts as a neurophysiological substrate for the temporal integration of sensory stimuli (Cecere et al., 2015). Moreover, The study of Keil et al. (2014) found that increased beta-band power in the left middle temporal gyrus prior to stimulus presentation was associated with a higher likelihood of experiencing the sound-induced flash illusion. The research also highlighted the role of phase synchrony between different brain regions in shaping perception. Specifically, increased beta-band phase synchrony between the left middle temporal gyrus and auditory areas and decreased synchrony with visual areas were observed in trials where participants experienced the illusion (Keil et al., 2014). This finding suggests that differences in alpha and beta-band activity could be a key factor in how older adults integrate information across senses, potentially explaining variability in susceptibility to multisensory integration.

ERP analysis shows that CMCS has demonstrated the main direct change in multisensory integration. Our finding indicated that the amplitude of P2 affected by the CMCS program decreased in the area of the right temporal lobe compared to the control group. In agreement with previous studies, early auditory ERPs like N1 and P2 are suppressed and accelerated due to interactions between visual and auditory perception (Sorati & Behne, 2021). Several ideas have previously been proposed to thoroughly describe the mechanisms driving improved audiovisual integration in older persons. Based on the meta-analysis, different theories propose distinct brain circuits for audiovisual integration. One theory suggests direct connections between the auditory cortex and visual cortex, while another points to subcortical regions like the thalamus or superior colliculus. A third theory implicates higher association areas, such as the prefrontal regions and superior temporal cortex (Gao et al., 2022). Audiovisual asynchrony detection is involved in temporal processing that shows interactions between unisensory areas, bottom-up processes where sensory inputs and prediction errors move from the primary sensory cortex to the superior temporal sulcus (STS) and prefrontal cortex (PFC), and top-down modulations where the PFC sends conflict-solving signals back to the STS to reduce prediction errors in the auditory and visual cortex. Deficits in any of these phases could impair asynchrony sensitivity and expand the temporal binding window (Zhou et al., 2020).

Significantly, Patients with MCI and AD have improved audiovisual integration, although not at the same level as healthy older persons. MCI patients had a lower audiovisual integration benefit in auditory-only or audiovisual speech perception circumstances than healthy older controls, indicating problems with audiovisual integration (Liu et al., 2023). Strong evidence has developed to support the hypothesis that multisensory integration is linked to cognitive function. As previously noted regarding aging, extended vulnerability to the SIFI across a lengthy, short temporal interval (stimulus onset asynchrony) is related to poor overall cognitive performance. Several more lines of evidence support SIFI as a measure of cognitive function in the elderly and MCI patients (Hirst et al., 2020). The finding suggests that the ERP study revealed that CMCS affects multisensory integration, reducing the right temporal lobe's P2 amplitude. According to the literature on

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audiovisual integration, the temporal lobe is one of the brain circuits and areas that may be involved. Compared to the control no-intervention group, MCI patients in the MCST group show enhanced audiovisual integration, suggesting cognitive function improvement in multisensory processing.

Effects of computerized cognitive stimulation programs with and without multisensory integration on cognitive functions in older adults with MCI

This study also questioned the differences between the MCST and CST groups after post-intervention on cognitive functions in older adults with MCI. Both groups are based on computerized CST approaches that have been shown to enhance overall cognitive abilities in older adults, whether they are cognitively healthy or dealing with conditions like MCI (Gómez-Soria, Iguacel, et al., 2023). However, in the MCST group, multisensory stimulation was utilized to train on multisensory integration.

Our results show that MoCA, TDGS, and STAI indicated the same effectiveness from interventions. In line with previous research, studies have shown that various forms of CST, including reminiscence therapy, reality orientation, and multisensory stimulation, have demonstrated effectiveness in improving cognitive functioning. These interventions not only improve general cognitive abilities but also target specific domains such as memory, orientation, language, praxis, and calculation (Djabelkhir-Jemmi et al., 2018; Djabelkhir-Jemmi et al., 2017; Gómez-Soria, Iguacel, et al., 2023). According to improved emotions, this finding also supported previous studies that Group-based CST is a type of treatment that utilizes social interaction to enhance cognitive functions (Iizuka et al., 2019) as well as depression and anxiety (Justo-Henriques et al., 2023; Zubatsky et al., 2023).

The result of this study show that various cognitive functions reported from neuropsychological assessment, such as learning and memory, visuospatial, and multisensory integration, were shown differently between the MCST and CST groups when compared to the control group. Moreover, ERP assessment also demonstrated different changes in learning and memory, as well as visuospatial and psychomotor skills. Our findings suggested that multisensory stimulation effectively improves sensory processing and impacts related cognitive functions such as learning and memory, visuospatial and psychomotor. This study is consistent with previous research (Djabelkhir-Jemmi et al., 2018; Djabelkhir-Jemmi et al., 2017) that the

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computerized CST can be improved in various cognitive functions and emotions. Moreover, very few studies investigating CST for MCI, AD or dementia on structural and functional changes in the brain (Behfar et al., 2023; Djabelkhir-Jemmi et al., 2018). For example, Behfar et al. (2023) found that the CST intervention induced changes in brain connectivity using fMRI, especially in memory-related left hippocampal connectivity (Behfar et al., 2023).

This study also contributes to the scientific literature by successfully integrating multisensory stimulation into the computerized CST. Although the study in the short- or long-term, multisensory stimulation was not shown to be more helpful than an exercise in modifying the behavior, mood, or cognitive abilities of moderate to severe dementia patients (Baker et al., 2003). Our findings confirm that multisensory stimulation can improve cognitive functioning in older adults with MCI. As suggested, multicomponent approaches successfully combine the positive effects of specific treatments (Lissek & Suchan, 2021). However, Turana et al. (2024) described that CST intervention with and without exercise sessions could successfully improve global cognition, immediate memory, and visual construction in Indonesian older adults with MCI (Turana et al., 2024). In addition, compared to another approach that correlated with the CST approach, Virtual reality-based cognitive stimulation was found in many studies applied to improve cognitive functions in people with MCI (Kang et al., 2021; Mancuso et al., 2020; Manenti et al., 2020; Tarnanas et al., 2014). It is important to note that CST with another component can show different levels of effectiveness in cognitive functions.

Effects of the CMCS program in congruent and incongruent on behavioral, EEG, and ERP assessment

To understand the behavioral, EEG, and ERP impacts of the CMCS program on cognitive functions in older persons with MCI, it is critical to investigate both congruent and incongruent results across various measurement modalities.

Behaviorally, the CMCS program demonstrated improvements in learning and memory, particularly in paired-associate tasks, consistent with earlier studies using similar CST approaches (Çinar & Şahiner, 2020; Djabelkhir-Jemmi et al., 2018; Wenisch et al., 2007). This congruence is reflected in the ERP results, where P300 amplitude and latency changes indicate enhanced cognitive processing during

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memory tasks. The amplitude changes in the frontal and central regions, particularly in the P3/LPC components, support the behavioral findings, suggesting improved cognitive efficiency and resource allocation (Hogan et al., 2011; Waninger et al., 2018). However, the EEG frequency domain analysis did not show significant changes between groups, indicating a potential dissociation between the observed behavioral improvements and underlying neural oscillatory activity. This incongruence might be due to the specificity of EEG measures to detect subtle cognitive changes or the variability in individual responses to the intervention. Previous studies have also noted the difficulty in detecting EEG frequency changes in cognitive interventions, highlighting the need for more sensitive measures or different methodological approaches to fully capture neural changes (Curran & Doyle, 2011; Gui et al., 2017; Gui et al., 2018).

Language function outcomes, assessed through verbal fluency tasks, present a more complex illustration. Behaviorally, there was no significant improvement in language performance, consistent with the findings from EEG and ERP assessments, where no substantial changes were detected. This aligns with mixed results from previous neuropsychological data, indicating variability in the effectiveness of cognitive interventions on language functions (López et al., 2022; Turana et al., 2024; Wenisch et al., 2007). Conversely, fMRI and NIRS studies have shown localized prefrontal activation during verbal fluency tasks, highlighting the prefrontal cortex's role in language processing (Herrmann et al., 2003; Phelps et al., 1997). Increased oxygenated hemoglobin in the prefrontal areas during these tasks suggests active involvement in language functions (Herrmann et al., 2003). This indicates that while CMCS might enhance memory and attention, its impact on language performance might require more specific or prolonged interventions or sensitive assessment methods.

Visuospatial abilities showed congruence between behavioral and ERP findings. CMCS enhanced visuospatial memory, indicated by changes in P300 latency and amplitude in the right TPJ during the Corsi block task. The behavioral improvements in visuospatial tasks align with ERP results, suggesting enhanced spatial rehearsal and working memory processes (Missonnier et al., 2012; Waninger et al., 2018). These ERP findings highlight the role of the right temporal lobe in

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complex spatial functions. However, the lack of significant changes in EEG frequency measures for visuospatial perception tasks complicates the understanding of how CMCS impacts cognitive processing. EEG artifacts during body movement tasks and motor imagery further complicate interpretation (Vanhatalo et al., 2003). Tasks like the mental rotation task effectively measure visuospatial functions but can introduce motor imagery artifacts that obscure EEG analysis (Osuagwu & Vuckovic, 2014). This discrepancy between ERP and EEG findings suggests that while ERPs capture specific event-related changes in visuospatial processing, broader EEG measures might not be as sensitive.

The finding for executive function showed incongruences across behavioral, EEG, and ERP assessments. Behaviorally, there were no significant improvements post-intervention, consistent with EEG and ERP findings, which also did not detect substantial changes. This aligns with studies indicating that executive functions might be less responsive to short-term cognitive interventions (Djabelkhir-Jemmi et al., 2018; Wenisch et al., 2007). The sensitivity of EEG and ERP measures to detect subtle changes in executive functions might be limited, suggesting the need for more robust or targeted interventions. Tasks like the WCST and TMT did not show improvements post-intervention, highlighting potential limitations in these assessment tools (Djabelkhir-Jemmi et al., 2018; Moro et al., 2015; Wenisch et al., 2007). (Wenisch et al., 2007; Djabelkhir-Jemmi et al., 2018; Moro et al., 2015). Additionally, variability in cognitive impairment severity among participants and the specificity of the tasks could influence outcomes. For example, Djabelkhir-Jemmi et al. (2018) demonstrated that TMT part B performance varied based on the severity of white matter hyperintensities. Meta-analyses indicate that P300 ERP components, specifically amplitude and latency, are effective markers for diagnosing and predicting MCI progression but showed no significant changes post-intervention in this study (Dimitriadis et al., 2015; Jiang et al., 2015).

The examination of multisensory integration through the SIFI task shows a mix of congruent and incongruent findings between behavioral, EEG, and ERP results. Behaviorally, the CMCS program improved multisensory integration performance, evidenced by increased correct response rates in the MCST group. This behavioral improvement is congruent with ERP results, which showed significant

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changes in P2 amplitude over the right temporal lobe, indicating enhanced audiovisual integration (Sorati & Behne, 2021). However, the EEG frequency domain analysis did not show significant changes post-intervention, leading to incongruence between the behavioral/ERP findings and overall brain oscillatory activity. The sensitivity of ERP components like P2 in detecting changes in multisensory integration provides a more precise measure of event-related changes. In contrast, broader EEG frequency measures might not capture these specific improvements. Studies by Cecere et al. (2015) and Keil et al. (2014) highlight the role of temporal lobe regions in audiovisual integration, supporting the ERP findings and emphasizing the complexity of capturing these effects in EEG frequency domains.

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Limitations

Computerized CST for older adults with MCI offer several advantage including cognitive improvement and negative mood reducing. However, there are notable limitations and challenges associated with its delivery. Fistly, not all older adults have access to the necessary technology (i.e., tablets and internet connection). Some older adults may lack the skills or confidence to use digital devices, which can obstruct their ability to engage with computerized CST. Secondly, while computerized CST can be personalized, it requires careful adaptation to ensure the content is suitable for the cognitive levels and interests of each individual in different culture or experience. Lastly, while the current study focuses on group-based CST, it should be noted that computerized individual CST may lack the social engangement, may reducing its usefulness for some individuals.

Methodologically, the pretest-posttest control design was applied to this study. It is commonly used to measure the effects of interventions by comparing results before and after the intervention. However, one significant limitation of this design, particularly when examining both short-term and long-term effects, is the potential for transient effects and the challenge of capturing sustained outcomes over time (Visser et al., 2017). Multiple follow-up assessments over extended periods (e.g., 6 months, 1 year) are often needed. For example, Gómez-Soria, Ferreira, et al. (2023) implemented a cognitive stimulation program that included short-, medium-, and long-term assessments, demonstrating improvements over time. Specifically, older

adults with MCI showed improvements in global cognition at post-intervention and six months later. While our findings demonstrate significant short-term benefits, similar to the computerized CST study by Djabelkhir-Jemmi et al. (2017), it remains unclear whether these gains persist over time or require ongoing reinforcement. The duration of improvement is a critical factor for determining the practical applicability of such interventions, particularly in clinical settings where sustained benefits are essential. While this study was exploratory in nature, it allowed for adjustments to the protocol, such as adding a 6-month follow-up to investigate long-term effects in future studies. Addressing this limitation is necessary to establish the full potential and practicality of the training approach.

In terms of instruments, neuropsychological assessments were based specifically on previous research. For example, executive functions most frequently used by research groups worldwide to evaluate older adults include Trail Making Test part B, the Verbal Fluency Test (VFT) with letter and animals category, the Clock Drawing Test, Digits Forward and Backward subtests, the Stroop Test, and Wisconsin Card Sorting Test (WCST). Mental flexibility, verbal fluency, planning, working memory, and inhibitory control were the most commonly tested executive function domains (Faria et al., 2015). Moreover, current studies have applied WCST to measure executive functions and VFT to measure language.

EEG and ERP collected from Emotiv Flex 32 saline devices may have inherent limitations, such as sensitivity to detecting subtle cognitive changes and potential variability in EEG signal quality due to the saline electrode system (if compared to gel) and low sampling rate (129 Hz). Moreover, EEG data have been collected using the Emotiv Flex, which is not capable of native hardware event-marking that can lead to an effect on time-lock stimuli to EEG data (Williams et al., 2020). The sample size might be too small (e.g., n = 40 on the ERP features of verbal fluency test) to generalize findings broadly, and variability in participant engagement with the CMCS could affect results according to preprocessing and measuring procedures that remove noise/outliers of many subjects.

Moreover, the EEG study tested the effect of only one type of frequency-domain method, particularly relative spectrum power for each relative power spectrum band. However, previous studies have shown various features or methods,

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such as coherence (Fide et al., 2023), the ratio between bands (Moretti et al., 2012), and asymmetry (Çiçek & Nalçacı, 2001). Moreover, time-frequency domain and machine learning methods were shown to be applied as a novel method (Deng et al., 2024; Sanei & Chambers, 2021).

This study excluded the gamma band, as most research has done, due to its low power and susceptibility to noise, with only a few examining EEG frequencies up to 40-50 Hz (Baker et al., 2008; Hua-ying & Xin, 2005; Lee et al., 2022; Missonnier et al., 2010; van Deursen et al., 2008). However, previous research highlights its importance in understanding and diagnosing mild brain injury. Early disruptions in gamma dynamics have been observed in MCI, possibly reflecting compensatory activation during cognitive decline. Additionally, increased gamma activity (30-100 Hz) in AD and MCI patients during cognitive tasks suggests its potential as a diagnostic biomarker (van Deursen et al., 2008).

Future directions

A range of studies have explored the effectiveness of cognitive stimulation interventions MCI. It found positive effects, with the former showing improvements in associative memory and demonstrating cognitive function improvements. The current study focuses on computerized CST interventions with and without multisensory stimulation, and reports a positive impact on cognitive functions and emotional improvements in performance across various tasks. However, behavioral and physiological data in our study found mixed results, showing some domain-specific effects and the difference reporting no significant improvements. These results collectively suggest that computerized multicomponent cognitive stimulation interventions can be effective in MCI. However, further research is needed to understand their more specific impacts and potential differences by replicating our study in different contexts or with other assessment tools as well as different EEG/ERP methods.

Further research should explore the long-term effects of CST on mood and cognitive functions to ascertain the sustainability of benefits over time. Studies could also investigate the differential impacts of CST in varied settings to better understand the environmental influences on efficacy. Another valuable avenue would be to

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examine technology integration in CST, assessing how digital tools can be optimized to support emotional and cognitive stimulation in MCI more effectively. Additionally, exploring the underlying mechanisms between depression, anxiety, and cognitive impairment in MCI versus AD could provide deeper insights into tailored therapeutic strategies. Further studies should also consider the role of other psychosocial factors like motivation, technology acceptance, and self-esteem in enhancing these patients' overall quality of life. Additionally, research should examine how cultural factors may support or strengthen specific cognitive domains, allowing for more culturally tailored interventions.

Further research on MCI treatment should consider including cognitive and multisensory stimulation. The correlation between multisensory integration and cognitive function underscores the importance of sensory processing in overall cognitive functions in older adults with MCI. Our findings support multiple theories of audiovisual integration involving direct cortical connections, subcortical regions, and higher association areas. Understanding these mechanisms can inform more effective cognitive training strategies for MCI patients. Moreover, future research should explore how these interventions can be adapted for other types of dementia, such as frontotemporal or mixed dementia, to assess their broader applicability. This relationship highlights the potential for multisensory integration-based interventions to yield wider cognitive benefits not only for individuals with MCI but also for those with AD.

Further research on predicting outcomes using EEG can be used to measure baseline brain activity and identify neural markers that may predict how individuals will respond to an intervention. For example, differences in baseline neural activity in specific brain regions have been associated with better or worse outcomes in cognitive and behavioral interventions. Furthermore, this study has shown that EEG/ERP patterns, such as relative power or P3 ERP, can predict treatment response in various neuropsychological assessments and interventions, including cognitive stimulation with and without multisensory stimulation.

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APPENDICES

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APPENDIX A

Assumption testing of neuropsychological tasks

Table 84 Assumption testing of psychological and behavioural scores on paper-based and computerized neuropsychological tests

Variables	Normality		Homoscedasticity		Parallelism	
	W	*p*	*K-squared*	*p*	*F*	*p*
MoCA	0.98	.10	0.45	.80	0.82	.44
TDGS	0.80	<.01	13.48	<.01	0.86	.43
STAI	0.99	.74	0.99	.61	1.70	.19
QOL	0.98	.16	0.11	.94	0.30	.77
Paired associates learning tasks						
VPAL	0.71	<.01	4.20	.12	2.66	.08
OPAL	0.98	.16	.77	.68	0.75	.46
The verbal fluency task						
'Kor'	0.96	<.01	0.76	.69	1.39	.26
'Or'	0.98	.35	0.94	.63	1.13	.33
Animal	0.97	.04	1.02	.60	0.48	.62
Fruit	0.99	.98	0.11	.95	0.37	.69
The Corsi block tapping task						
Span	0.98	.19	7.21	.01	2.74	.07
The mental rotation task						
Correct	0.92	<.01	4.35	.11	1.10	.21
The Wisconsin card sorting test						
Percent errors	0.99	.67	3.17	.20	0.18	.84
Perseverative errors	0.92	<.01	0.16	.92	0.39	.68
Nonperseverative errors	0.97	.09	8.44	.02	0.47	.63
Conceptual level responses	0.98	.31	7.52	.02	0.07	.94
Categories completed	0.90	<.01	14.72	<.01	0.07	.94
Trials to complete the first	0.76	<.01	1.34	.51	1.82	.17
Failure to maintain the set	0.99	.71	0.35	.84	0.89	.41
Reaction time tasks						
Simple reaction time	0.92	<.01	2.16	.34	2.12	.13
Choice reaction time	0.72	<.01	5.71	.06	2.50	.09
Correct response	0.95	<.01	17.76	<.01	2.05	.14
The sound induced flash illustion task						
RT 1 beep 2 flash	0.97	.07	1.21	.55	1.39	.26
RT 2 beep 1 flash	0.95	<.01	1.75	.42	2.72	.07

Table 85 Assumption testing of relative spectral power bands

Variables	Normality		Homoscedasticity		Parallelism	
	W	*p*	*K-squared*	*p*	*F*	*p*
eyes closed resting-state						
Delta						
FL	0.94	<.01	0.28	.87	0.33	.72
FM	0.91	<.01	0.52	.77	0.83	.44
CL	0.94	<.01	0.58	.75	0.01	1
CM	0.90	<.01	0.20	.90	0.07	.93
PL	0.94	<.01	0.90	.64	0.37	.69

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Variables	Normality		Homoscedasticity		Parallelism	
	W	*p*	*K-squared*	*p*	*F*	*p*
PM	0.88	<.01	0.51	.77	0.15	.86
OL	0.87	<.01	4.42	.11	2.21	.12
OM	0.91	<.01	3.08	.21	2.30	.11
LTL	0.96	.01	1.28	.53	0.11	.89
RTL	0.97	.02	0.71	.70	2.13	.13
LTPJ	0.95	<.01	1.00	.61	1.14	.33
RTPJ	0.88	<.01	0.19	.91	0.37	.70
Theta						
FL	0.78	<.01	17.49	<.01	0.58	.56
FM	0.86	<.01	12.02	<.01	0.06	.94
CL	0.87	<.01	4.10	.13	2.46	.09
CM	0.85	<.01	7.50	.02	0.51	.60
PL	0.92	<.01	7.15	.03	0.18	.83
PM	0.87	<.01	16.49	<.01	1.22	.30
OL	0.85	<.01	19.85	<.01	1.03	.36
OM	0.90	<.01	16.71	<.01	1.77	.18
LTL	0.88	<.01	4.76	.09	1.59	.21
RTL	0.97	.03	4.96	.08	0.55	.58
LTPJ	0.89	<.01	7.17	.03	1.57	.21
RTPJ	0.85	<.01	19.50	<.01	0.03	.97
Lower Alpha						
FL	0.83	<.01	4.03	.13	8.00	<.01
FM	0.80	<.01	5.57	.06	2.69	.07
CL	0.84	<.01	1.24	.54	1.82	.17
CM	0.80	<.01	0.38	.83	0.43	.65
PL	0.82	<.01	5.85	.05	11.90	<.01
PM	0.70	<.01	7.59	.02	21.34	<.01
OL	0.74	<.01	15.08	<.01	11.36	<.01
OM	0.75	<.01	13.87	<.01	10.71	<.01
LTL	0.86	<.01	1.63	.44	4.61	.01
RTL	0.82	<.01	9.00	.01	5.73	<.01
LTPJ	0.85	<.01	1.68	.43	7.55	<.01
RTPJ	0.74	<.01	5.19	.08	3.03	.05
Upper Alpha						
FL	0.81	<.01	0.89	.64	1.32	.27
FM	0.84	<.01	5.47	.07	0.35	.71
CL	0.89	<.01	2.90	.23	0.88	.42
CM	0.82	<.01	1.51	.47	0.94	.39
PL	0.81	<.01	4.55	.10	0.28	.76
PM	0.68	<.01	0.52	.77	0.95	.39
OL	0.78	<.01	20.00	<.01	5.38	<.01
OM	0.82	<.01	12.58	<.01	4.64	.01
LTL	0.90	<.01	0.20	.90	0.25	.78
RTL	0.89	<.01	1.55	.46	0.87	.42
LTPJ	0.87	<.01	1.57	.46	0.37	.69
RTPJ	0.69	<.01	4.49	.11	0.63	.53
Full Alpha						
FL	0.89	<.01	0.46	.80	3.96	.02
FM	0.85	<.01	1.51	.47	1.36	.26
CL	0.88	<.01	0.03	.98	0.45	.64

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Variables	Normality		Homoscedasticity		Parallelism	
	W	*p*	*K-squared*	*p*	*F*	*p*
CM	0.85	<.01	0.06	.97	0.11	.90
PL	0.88	<.01	1.28	.53	3.03	.05
PM	0.78	<.01	0.36	.83	5.79	<.01
OL	0.78	<.01	6.80	.03	5.20	<.01
OM	0.81	<.01	4.98	.08	4.73	.01
LTL	0.91	<.01	0.02	.99	1.48	.23
RTL	0.89	<.01	3.39	.18	2.77	.07
LTPJ	0.90	<.01	0.43	.81	4.40	.02
RTPJ	0.78	<.01	1.36	.51	1.13	.33
Beta						
FL	0.91	<.01	0.06	.97	0.53	.59
FM	0.87	<.01	1.01	.61	0.96	.39
CL	0.90	<.01	0.50	.78	0.14	.87
CM	0.85	<.01	0.14	.93	1.20	.31
PL	0.86	<.01	0.99	.61	1.56	.22
PM	0.83	<.01	0.97	.62	0.74	.48
OL	0.80	<.01	1.06	.59	1.03	.36
OM	0.84	<.01	0.94	.63	2.40	.10
LTL	0.89	<.01	1.94	.38	0.18	.83
RTL	0.92	<.01	2.76	.25	0.84	.43
LTPJ	0.84	<.01	0.79	.67	1.06	.35
RTPJ	0.85	<.01	4.64	.10	3.92	.02
eyes open resting-state						
Delta						
FL	0.95	<.01	1.52	.47	1.25	.29
FM	0.93	<.01	0.62	.73	0.09	.92
CL	0.94	<.01	2.36	.31	0.73	.48
CM	0.92	<.01	2.24	.33	0.45	.64
PL	0.89	<.01	2.30	.32	0.54	.59
PM	0.87	<.01	1.09	.58	1.79	.17
OL	0.84	<.01	1.79	.41	0.19	.83
OM	0.82	<.01	0.84	.66	0.03	.97
LTL	0.96	.01	1.73	.42	0.79	.46
RTL	0.95	<.01	1.29	.52	1.25	.29
LTPJ	0.91	<.01	1.41	.49	1.00	.37
RTPJ	0.89	<.01	0.65	.72	2.91	.06
Theta						
FL	0.98	.21	0.16	.92	0.26	.77
FM	0.94	<.01	0.37	.83	0.71	.50
CL	0.92	<.01	4.16	.13	0.89	.42
CM	0.94	<.01	2.89	.24	0.25	.78
PL	0.96	.01	2.07	.35	0.14	.87
PM	0.95	<.01	1.64	.44	0.64	.53
OL	0.95	<.01	0.05	.98	0.05	.96
OM	0.96	.01	0.04	.98	0.07	.94
LTL	0.96	.02	0.39	.82	1.31	.27
RTL	0.99	.86	2.18	.34	0.67	.52
LTPJ	0.98	.20	1.05	.59	1.65	.20
RTPJ	0.97	.03	1.17	.56	0.77	.46
Lower Alpha						

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Variables	Normality		Homoscedasticity		Parallelism	
	W	*p*	*K-squared*	*p*	*F*	*p*
FL	0.70	<.01	3.07	.22	0.10	.90
FM	0.72	<.01	0.48	.79	0.26	.77
CL	0.81	<.01	0.85	.65	0.63	.53
CM	0.76	<.01	5.40	.07	0.71	.50
PL	0.70	<.01	6.79	.03	0.36	.70
PM	0.55	<.01	26.90	<.01	1.11	.33
OL	0.57	<.01	6.82	.03	0.85	.43
OM	0.52	<.01	6.16	.05	0.45	.64
LTL	0.79	<.01	0.65	.72	0.48	.62
RTL	0.79	<.01	2.07	.36	1.39	.26
LTPJ	0.75	<.01	0.83	.66	2.29	.11
RTPJ	0.70	<.01	5.68	.06	2.09	.13
Upper Alpha						
FL	0.85	<.01	5.75	.06	0.26	.77
FM	0.88	<.01	3.69	.16	1.25	.29
CL	0.90	<.01	4.89	.09	0.85	.43
CM	0.90	<.01	8.86	.01	0.87	.42
PL	0.86	<.01	5.54	.06	0.41	.67
PM	0.80	<.01	3.02	.22	1.09	.34
OL	0.74	<.01	0.43	.81	0.13	.88
OM	0.70	<.01	0.68	.71	0.20	.82
LTL	0.90	<.01	4.54	.10	0.16	.85
RTL	0.90	<.01	0.02	.99	1.07	.35
LTPJ	0.87	<.01	2.09	.35	0.68	.51
RTPJ	0.84	<.01	0.66	.72	2.77	.07
Full Alpha						
FL	0.78	<.01	1.27	.53	0.09	.92
FM	0.80	<.01	1.07	.59	0.93	.40
CL	0.88	<.01	1.68	.43	0.38	.69
CM	0.86	<.01	5.66	.06	0.25	.78
PL	0.81	<.01	4.23	.12	0.04	.96
PM	0.69	<.01	7.70	.02	1.46	.24
OL	0.64	<.01	2.15	.34	0.74	.48
OM	0.59	<.01	1.60	.45	0.47	.63
LTL	0.86	<.01	0.61	.74	0.05	.96
RTL	0.87	<.01	0.89	.64	0.61	.55
LTPJ	0.83	<.01	0.77	.68	1.38	.26
RTPJ	0.79	<.01	2.62	.27	1.75	.18
Beta						
FL	0.89	<.01	2.51	.29	3.08	.05
FM	0.88	<.01	7.15	.03	0.08	.92
CL	0.92	<.01	0.05	.98	0.12	.89
CM	0.85	<.01	0.31	.86	1.82	.17
PL	0.82	<.01	2.41	.30	2.32	.10
PM	0.77	<.01	1.40	.50	1.88	.16
OL	0.77	<.01	2.67	.26	0.72	.49
OM	0.79	<.01	1.93	.38	1.13	.33
LTL	0.94	<.01	1.28	.53	1.25	.29
RTL	0.94	<.01	2.02	.36	2.77	.07
LTPJ	0.87	<.01	2.34	.31	0.45	.64

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Variables	Normality		Homoscedasticity		Parallelism	
	W	*p*	*K-squared*	*p*	*F*	*p*
RTPJ	0.79	<.01	0.13	.94	5.36	<.01
the non-verbal paired associates learning task						
Delta						
FL	0.91	<.01	1.53	.47	0.09	.91
FM	0.94	<.01	2.60	.27	1.49	.23
CL	0.91	<.01	0.07	.96	2.10	.13
CM	0.87	<.01	0.47	.79	2.52	.09
PL	0.87	<.01	1.98	.37	0.08	.92
PM	0.82	<.01	0.69	.71	3.95	.02
OL	0.76	<.01	0.89	.64	0.47	.63
OM	0.74	<.01	2.43	.30	1.15	.32
LTL	0.90	<.01	1.14	.57	1.72	.19
RTL	0.89	<.01	1.87	.39	0.44	.64
LTPJ	0.90	<.01	3.04	.22	4.19	.02
RTPJ	0.86	<.01	1.83	.40	0.17	.84
Theta						
FL	0.97	0.02	0.23	.89	3.85	.03
FM	0.97	0.02	0.03	.98	1.87	.16
CL	0.96	0.01	0.46	.79	2.71	.07
CM	0.93	<.01	0.14	.93	2.17	.12
PL	0.93	<.01	0.40	.82	3.04	.05
PM	0.91	<.01	1.01	.60	1.45	.24
OL	0.86	<.01	2.14	.34	6.92	<.01
OM	0.83	<.01	2.87	.24	5.27	<.01
LTL	0.97	0.02	0.06	.97	4.99	<.01
RTL	0.98	0.11	1.37	.50	1.74	.18
LTPJ	0.98	0.24	4.05	.13	9.34	<.01
RTPJ	0.95	<.01	1.55	.46	2.11	.13
Lower Alpha						
FL	0.90	<.01	3.59	.17	0.27	.76
FM	0.83	<.01	18.62	<.01	1.22	.30
CL	0.81	<.01	7.95	.02	2.70	.07
CM	0.81	<.01	4.76	.09	3.17	.05
PL	0.73	<.01	15.01	<.01	0.32	.72
PM	0.75	<.01	12.99	<.01	1.67	.20
OL	0.60	<.01	17.65	<.01	0.41	.66
OM	0.61	<.01	17.20	<.01	1.70	.19
LTL	0.80	<.01	1.32	.52	0.21	.81
RTL	0.77	<.01	7.36	.03	0.11	.90
LTPJ	0.73	<.01	4.74	.09	2.26	.11
RTPJ	0.70	<.01	12.99	<.01	0.27	.76
Upper Alpha						
FL	0.89	<.01	0.49	.78	0.04	.96
FM	0.87	<.01	4.21	.12	0.67	.52
CL	0.83	<.01	0.58	.75	1.08	.35
CM	0.80	<.01	1.14	.57	3.52	.03
PL	0.74	<.01	3.55	.17	0.03	.97
PM	0.72	<.01	0.98	.61	5.05	<.01
OL	0.63	<.01	5.29	.07	0.19	.83
OM	0.64	<.01	6.86	.03	0.52	.59

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Variables	Normality		Homoscedasticity		Parallelism	
	W	*p*	*K-squared*	*p*	*F*	*p*
LTL	0.85	<.01	2.21	.33	2.60	.08
RTL	0.83	<.01	2.21	.33	0.96	.39
LTPJ	0.79	<.01	2.14	.34	3.38	.04
RTPJ	0.74	<.01	1.87	.39	0.08	.92
Full Alpha						
FL	0.90	<.01	0.95	.62	0.08	.92
FM	0.88	<.01	9.41	<.01	1.14	.32
CL	0.84	<.01	2.86	.24	1.74	.18
CM	0.82	<.01	1.68	.43	3.69	.03
PL	0.74	<.01	7.07	.03	0.08	.92
PM	0.74	<.01	3.30	.19	3.19	.05
OL	0.62	<.01	10.33	<.01	0.24	.79
OM	0.62	<.01	11.11	<.01	0.96	.39
LTL	0.84	<.01	1.32	.52	0.99	.37
RTL	0.82	<.01	2.77	.25	0.19	.83
LTPJ	0.77	<.01	2.72	.26	2.76	.07
RTPJ	0.72	<.01	5.15	.08	0.01	.99
Beta						
FL	0.89	<.01	1.46	.48	0.27	.76
FM	0.90	<.01	4.02	.13	0.54	.59
CL	0.88	<.01	0.48	.79	1.40	.25
CM	0.82	<.01	0.15	.93	2.17	.12
PL	0.82	<.01	5.43	.07	1.65	.20
PM	0.72	<.01	4.05	.13	5.80	<.01
OL	0.69	<.01	6.06	.05	2.48	.09
OM	0.68	<.01	6.58	.04	0.77	.47
LTL	0.82	<.01	3.58	.17	1.90	.16
RTL	0.82	<.01	0.84	.66	0.43	.65
LTPJ	0.84	<.01	2.61	.27	1.65	.20
RTPJ	0.78	<.01	2.76	.25	0.60	.55
the verbal fluency learning task						
Delta						
FL	0.92	<.01	6.86	.03	0.74	.48
FM	0.95	0.01	9.61	<.01	1.16	.32
CL	0.94	<.01	16.79	<.01	1.96	.15
CM	0.91	<.01	18.83	<.01	1.09	.34
PL	0.89	<.01	19.55	<.01	1.38	.26
PM	0.89	<.01	11.82	<.01	1.86	.16
OL	0.73	<.01	18.15	<.01	0.11	.89
OM	0.74	<.01	24.25	<.01	0.09	.92
LTL	0.90	<.01	9.30	.01	2.41	.10
RTL	0.91	<.01	9.09	.01	0.73	.48
LTPJ	0.91	<.01	11.44	<.01	2.03	.14
RTPJ	0.84	<.01	14.95	<.01	1.52	.23
Theta						
FL	0.96	.01	7.94	.02	0.88	.42
FM	0.92	<.01	1.94	.38	1.44	.24
CL	0.95	<.01	1.84	.40	2.35	.10
CM	0.95	<.01	0.24	.89	0.08	.92
PL	0.97	.02	0.22	.90	0.88	.42

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Variables	Normality		Homoscedasticity		Parallelism	
	W	*p*	*K-squared*	*p*	*F*	*p*
PM	0.95	<.01	2.47	.29	1.23	.30
OL	0.91	<.01	2.72	.26	0.39	.68
OM	0.94	<.01	8.97	.01	0.34	.71
LTL	0.92	<.01	6.57	.04	3.18	.05
RTL	0.98	.11	0.21	.90	2.75	.07
LTPJ	0.96	.01	4.67	.10	2.09	.13
RTPJ	0.97	.06	0.50	.78	0.90	.41
Lower Alpha						
FL	0.91	<.01	2.75	.25	1.29	.28
FM	0.88	<.01	5.84	.05	1.42	.25
CL	0.83	<.01	9.07	.01	2.36	.10
CM	0.86	<.01	14.26	<.01	1.51	.23
PL	0.87	<.01	17.50	<.01	2.43	.09
PM	0.87	<.01	18.35	<.01	4.26	.02
OL	0.66	<.01	22.64	<.01	0.37	.69
OM	0.68	<.01	21.52	<.01	0.04	.96
LTL	0.76	<.01	6.41	.04	1.31	.28
RTL	0.85	<.01	6.61	.04	0.86	.43
LTPJ	0.83	<.01	0.17	.92	1.71	.19
RTPJ	0.72	<.01	25.53	<.01	1.63	.20
Upper Alpha						
FL	0.90	<.01	3.58	017	0.40	.67
FM	0.83	<.01	3.58	.17	0.33	.72
CL	0.84	<.01	13.31	<.01	2.23	.11
CM	0.79	<.01	11.20	<.01	2.66	.08
PL	0.81	<.01	11.56	<.01	1.71	.19
PM	0.82	<.01	10.30	<.01	3.43	.04
OL	0.55	<.01	22.11	<.01	0.26	.77
OM	0.57	<.01	24.01	<.01	0.15	.86
LTL	0.87	<.01	5.44	.07	0.98	.38
RTL	0.85	<.01	4.32	.12	0.41	.67
LTPJ	0.85	<.01	7.27	.03	0.72	.49
RTPJ	0.76	<.01	10.99	<.01	1.43	.25
Full Alpha						
FL	0.91	<.01	3.43	.18	0.60	.55
FM	0.89	<.01	4.35	.11	0.83	.44
CL	0.88	<.01	10.75	<.01	2.17	.12
CM	0.88	<.01	11.60	<.01	1.85	.16
PL	0.86	<.01	13.77	<.01	2.18	.12
PM	0.86	<.01	13.27	<.01	4.13	.02
OL	0.61	<.01	21.67	<.01	0.33	.72
OM	0.62	<.01	23.84	<.01	0.09	.91
LTL	0.85	<.01	0.51	.78	1.44	.24
RTL	0.87	<.01	6.48	.04	0.60	.55
LTPJ	0.86	<.01	2.36	.31	1.29	.28
RTPJ	0.76	<.01	17.60	<.01	1.67	.19
Beta						
FL	0.87	<.01	11.32	<.01	0.20	.82
FM	0.91	<.01	23.09	<.01	0.59	.56
CL	0.90	<.01	29.21	<.01	1.15	.32

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Variables	Normality		Homoscedasticity		Parallelism	
	W	*p*	*K-squared*	*p*	*F*	*p*
CM	0.84	<.01	41.39	<.01	1.21	.30
PL	0.82	<.01	34.09	<.01	1.13	.33
PM	0.76	<.01	35.75	<.01	2.29	.11
OL	0.63	<.01	32.27	<.01	0.14	.87
OM	0.61	<.01	43.84	<.01	0.11	.89
LTL	0.85	<.01	21.09	<.01	1.10	.34
RTL	0.85	<.01	13.73	<.01	0.85	.43
LTPJ	0.87	<.01	27.09	<.01	1.13	.33
RTPJ	0.75	<.01	19.78	<.01	1.54	.22
the Corsi block-tapping task.						
Delta						
FL	0.94	<.01	5.77	.06	1.68	.19
FM	0.94	<.01	4.71	.10	0.78	.46
CL	0.94	<.01	2.56	.28	0.21	.81
CM	0.89	<.01	1.77	.41	0.08	.92
PL	0.90	<.01	8.38	.02	1.56	.22
PM	0.87	<.01	4.30	.12	0.96	.39
OL	0.77	<.01	5.22	.07	2.16	.12
OM	0.78	<.01	9.59	<.01	6.92	<.01
LTL	0.93	<.01	0.38	.83	0.55	.58
RTL	0.92	<.01	0.42	.81	0.17	.84
LTPJ	0.89	<.01	3.06	.22	2.40	.10
RTPJ	0.84	<.01	4.67	.10	2.11	.13
Theta						
FL	0.91	<.01	10.33	<.01	2.40	.10
FM	0.87	<.01	14.08	<.01	0.52	.59
CL	0.85	<.01	8.68	.01	0.58	.56
CM	0.87	<.01	7.30	.03	0.18	.84
PL	0.95	<.01	6.44	.04	0.70	.50
PM	0.91	<.01	0.16	.92	0.43	.65
OL	0.89	<.01	3.21	.20	0.85	.43
OM	0.84	<.01	7.68	.02	1.14	.33
LTL	0.83	<.01	5.66	.06	0.38	.68
RTL	0.87	<.01	14.88	<.01	0.08	.93
LTPJ	0.97	0.03	1.78	.41	1.21	.30
RTPJ	0.93	<.01	5.16	.08	1.83	.17
Lower Alpha						
FL	0.55	<.01	41.06	<.01	0.25	.78
FM	0.61	<.01	19.74	<.01	0.23	.80
CL	0.66	<.01	9.64	<.01	0.07	.93
CM	0.72	<.01	9.47	<.01	0.42	.66
PL	0.86	<.01	6.64	.04	1.02	.37
PM	0.84	<.01	4.18	.12	2.20	.12
OL	0.72	<.01	9.30	.01	1.39	.25
OM	0.71	<.01	18.48	<.01	2.39	.10
LTL	0.65	<.01	12.96	<.01	0.31	.73
RTL	0.74	<.01	19.93	<.01	0.05	.95
LTPJ	0.78	<.01	0.26	.88	2.74	.07
RTPJ	0.81	<.01	10.19	<.01	1.69	.19
Upper Alpha						

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Variables	Normality		Homoscedasticity		Parallelism	
	W	*p*	*K-squared*	*p*	*F*	*p*
FL	0.87	<.01	1.08	.58	0.01	.99
FM	0.91	<.01	2.98	.23	0.02	.98
CL	0.88	<.01	6.49	.04	0.31	.74
CM	0.85	<.01	2.70	.26	0.02	.98
PL	0.81	<.01	8.67	.01	2.40	.10
PM	0.81	<.01	6.16	.05	2.66	.08
OL	0.70	<.01	5.17	.08	3.61	.03
OM	0.72	<.01	7.68	.02	11.54	<.01
LTL	0.89	<.01	0.41	.81	0.58	.56
RTL	0.88	<.01	0.67	.72	0.49	.61
LTPJ	0.82	<.01	4.24	.12	3.01	.05
RTPJ	0.76	<.01	3.91	.14	1.20	.31
Full Alpha						
FL	0.78	<.01	14.24	<.01	0.09	.92
FM	0.81	<.01	9.34	<.01	0.11	.89
CL	0.84	<.01	3.11	.21	0.04	.96
CM	0.85	<.01	2.05	.36	0.13	.88
PL	0.85	<.01	8.26	.02	1.81	.17
PM	0.84	<.01	5.65	.06	2.09	.13
OL	0.72	<.01	6.70	.04	2.51	.09
OM	0.74	<.01	10.47	<.01	6.11	<.01
LTL	0.84	<.01	3.56	.17	0.33	.72
RTL	0.87	<.01	4.72	.09	0.20	.82
LTPJ	0.83	<.01	1.27	.53	3.11	.05
RTPJ	0.79	<.01	6.64	.04	1.52	.22
Beta						
FL	0.91	<.01	5.25	.07	1.76	.18
FM	0.89	<.01	5.57	.06	1.10	.34
CL	0.91	<.01	4.91	.09	0.44	.65
CM	0.82	<.01	5.08	.08	0.22	.80
PL	0.83	<.01	8.90	.01	2.13	.13
PM	0.77	<.01	8.72	.01	1.58	.21
OL	0.67	<.01	5.99	.05	3.16	.05
OM	0.66	<.01	12.47	<.01	12.82	<.01
LTL	0.88	<.01	3.01	.22	0.62	.54
RTL	0.87	<.01	0.20	.90	0.11	.90
LTPJ	0.82	<.01	7.88	.02	2.11	.13
RTPJ	0.78	<.01	3.77	0.15	1.52	0.23
the mental rotation task						
Delta						
FL	0.93	<.01	1.64	.44	0.12	.89
FM	0.93	<.01	1.96	.38	3.58	.03
CL	0.95	<.01	0.23	.89	0.05	.96
CM	0.91	<.01	0.05	.98	0.25	.78
PL	0.90	<.01	0.95	.62	0.39	.68
PM	0.89	<.01	1.93	.38	1.09	.34
OL	0.78	<.01	10.22	<.01	0.30	.74
OM	0.77	<.01	6.26	.04	0.70	.50
LTL	0.94	<.01	0.53	.77	1.26	.29
RTL	0.92	<.01	0.98	.61	0.59	.56

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Variables	Normality		Homoscedasticity		Parallelism	
	W	*p*	*K-squared*	*p*	*F*	*p*
LTPJ	0.95	<.01	0.85	.65	0.21	.81
RTPJ	0.84	<.01	1.67	.44	0.31	.73
Theta						
FL	0.98	0.16	3.14	.21	0.51	.60
FM	0.96	0.01	0.88	.64	1.25	.29
CL	0.96	0.01	4.16	.13	0.80	.45
CM	0.92	<.01	2.89	.24	0.14	.87
PL	0.95	<.01	1.73	.42	0.17	.84
PM	0.93	<.01	0.43	.81	0.79	.46
OL	0.88	<.01	2.63	.27	0.39	.68
OM	0.84	<.01	1.28	.53	0.68	.51
LTL	0.97	0.03	3.57	.17	0.65	.52
RTL	0.98	0.14	0.05	.98	0.93	.40
LTPJ	0.98	0.14	0.43	.81	0.03	.97
RTPJ	0.93	<.01	0.13	.94	0.38	.69
Lower Alpha						
FL	0.85	<.01	3.65	.16	0.61	.55
FM	0.74	<.01	6.24	.04	2.06	.13
CL	0.68	<.01	17.41	<.01	0.56	.57
CM	0.62	<.01	14.70	<.01	0.37	.69
PL	0.65	<.01	12.31	<.01	0.48	.62
PM	0.73	<.01	8.25	.02	0.04	.96
OL	0.69	<.01	1.87	.39	0.47	.63
OM	0.65	<.01	0.30	.86	0.53	.59
LTL	0.73	<.01	10.79	<.01	2.03	.14
RTL	0.66	<.01	10.71	<.01	1.12	.33
LTPJ	0.70	<.01	6.40	.04	1.69	.19
RTPJ	0.60	<.01	12.60	<.01	0.60	.55
Upper Alpha						
FL	0.90	<.01	2.07	.36	0.16	.85
FM	0.86	<.01	8.30	.02	2.55	.08
CL	0.89	<.01	1.53	.47	0.02	.98
CM	0.89	<.01	0.59	.74	0.90	.41
PL	0.82	<.01	6.28	.04	0.27	.76
PM	0.77	<.01	8.73	.01	1.06	.35
OL	0.70	<.01	10.39	<.01	0.34	.71
OM	0.71	<.01	6.70	.04	0.34	.71
LTL	0.91	<.01	0.43	.81	3.29	.04
RTL	0.87	<.01	2.45	.29	0.18	.83
LTPJ	0.90	<.01	1.53	.47	0.55	.58
RTPJ	0.78	<.01	5.40	.07	0.40	.67
Full Alpha						
FL	0.90	<.01	0.06	.97	0.04	.97
FM	0.84	<.01	2.05	.36	1.75	.18
CL	0.84	<.01	4.11	.13	0.25	.78
CM	0.79	<.01	3.95	.14	0.57	.57
PL	0.79	<.01	0.55	.76	0.43	.65
PM	0.81	<.01	0.15	.93	0.28	.76
OL	0.72	<.01	5.41	.07	0.45	.64
OM	0.70	<.01	2.43	.30	0.46	.63

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Variables	Normality		Homoscedasticity		Parallelism	
	W	*p*	*K-squared*	*p*	*F*	*p*
LTL	0.88	<.01	1.46	.48	2.51	.09
RTL	0.82	<.01	0.56	.76	0.45	.64
LTPJ	0.86	<.01	0.05	.97	1.21	.30
RTPJ	0.74	<.01	0.65	.72	0.58	.56
Beta						
FL	0.89	<.01	5.73	.06	0.27	.76
FM	0.85	<.01	11.49	<.01	7.56	<.01
CL	0.93	<.01	0.46	.79	0.72	.49
CM	0.90	<.01	3.54	.17	0.48	.62
PL	0.85	<.01	5.29	.07	0.54	.58
PM	0.77	<.01	14.57	<.01	1.65	.20
OL	0.65	<.01	31.61	<.01	0.05	.95
OM	0.69	<.01	26.84	<.01	0.18	.84
LTL	0.89	<.01	5.60	.06	1.49	.23
RTL	0.86	<.01	1.96	.38	0.42	.66
LTPJ	0.89	<.01	3.60	.17	0.06	.94
RTPJ	0.77	<.01	8.73	.01	0.05	.95
the wisconsin coard sorting task						
Delta						
FL	0.95	<.01	1.15	.56	0.94	.40
FM	0.93	<.01	0.03	.99	1.54	.22
CL	0.94	<.01	0.93	.63	0.32	.73
CM	0.89	<.01	0.57	.75	0.21	.81
PL	0.88	<.01	1.09	.58	0.55	.58
PM	0.82	<.01	0.28	.87	4.92	<.01
OL	0.76	<.01	5.52	.06	2.03	.14
OM	0.70	<.01	2.19	.34	3.37	.04
LTL	0.94	<.01	0.22	.90	0.42	.66
RTL	0.94	<.01	0.49	.78	0.32	.72
LTPJ	0.91	<.01	2.02	.37	1.56	.22
RTPJ	0.85	<.01	0.76	.68	0.19	.83
Theta						
FL	0.97	.04	3.06	.22	1.27	.29
FM	0.98	.19	0.45	.80	1.34	.27
CL	0.97	.06	0.18	.92	0.60	.55
CM	0.95	<.01	1.20	.55	0.48	.62
PL	0.97	.02	1.67	.44	1.39	.26
PM	0.91	<.01	0.84	.66	0.88	.42
OL	0.95	<.01	0.28	.87	0.50	.61
OM	0.89	<.01	1.80	.41	0.15	.86
LTL	0.96	<.01	1.14	.57	1.87	.16
RTL	1.00	1	0.55	.76	1.96	.15
LTPJ	0.98	.34	1.76	.42	2.72	.07
RTPJ	0.97	.03	0.45	.80	0.25	.78
Lower Alpha						
FL	0.77	<.01	2.73	.26	0.23	.80
FM	0.78	<.01	8.53	.01	0.27	.76
CL	0.70	<.01	14.84	<.01	0.31	.74
CM	0.60	<.01	23.42	<.01	0.55	.58
PL	0.74	<.01	1.52	.47	0.10	.91

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Variables	Normality		Homoscedasticity		Parallelism	
	W	*p*	*K-squared*	*p*	*F*	*p*
PM	0.62	<.01	15.13	<.01	1.66	.20
OL	0.71	<.01	4.22	.12	0.82	.44
OM	0.66	<.01	3.39	.18	0.64	.53
LTL	0.78	<.01	6.70	.04	0.72	.49
RTL	0.74	<.01	1.45	.48	0.13	.88
LTPJ	0.84	<.01	2.39	.30	1.91	.15
RTPJ	0.67	<.01	0.01	.99	0.00	.00
Upper Alpha						
FL	0.87	<.01	5.52	.06	1.76	.18
FM	0.87	<.01	0.06	.97	1.68	.19
CL	0.85	<.01	0.44	.80	0.96	.39
CM	0.83	<.01	2.13	.35	0.06	.94
PL	0.76	<.01	8.74	.01	0.39	.68
PM	0.64	<.01	4.77	.09	11.12	<.01
OL	0.66	<.01	10.31	<.01	2.50	.09
OM	0.63	<.01	3.68	.16	4.27	.02
LTL	0.82	<.01	4.26	.12	0.51	.60
RTL	0.81	<.01	5.17	.08	1.54	.22
LTPJ	0.81	<.01	4.15	.13	1.37	.26
RTPJ	0.72	<.01	5.09	.08	0.64	.53
Full Alpha						
FL	0.86	<.01	0.61	.74	1.08	.34
FM	0.86	<.01	1.85	.40	0.81	.45
CL	0.83	<.01	1.58	.45	0.07	.93
CM	0.78	<.01	3.35	.19	0.25	.78
PL	0.80	<.01	3.10	.21	0.20	.82
PM	0.67	<.01	0.88	.64	4.96	<.01
OL	0.69	<.01	4.73	.09	1.68	.19
OM	0.66	<.01	0.73	.69	2.30	.11
LTL	0.85	<.01	3.28	.19	0.70	.50
RTL	0.82	<.01	1.91	.39	0.71	.49
LTPJ	0.85	<.01	2.75	.25	1.65	.20
RTPJ	0.73	<.01	2.28	.32	0.22	.81
Beta						
FL	0.91	<.01	1.26	.53	0.47	.63
FM	0.86	<.01	0.16	.92	1.80	.17
CL	0.91	<.01	1.36	.51	0.99	.38
CM	0.85	<.01	1.54	.46	1.08	.35
PL	0.79	<.01	1.70	.43	3.03	.05
PM	0.70	<.01	4.53	.10	9.74	<.01
OL	0.59	<.01	18.30	<.01	4.55	.01
OM	0.54	<.01	14.80	<.01	9.70	<.01
LTL	0.90	<.01	2.13	.35	0.50	.61
RTL	0.90	<.01	1.26	.53	1.07	.35
LTPJ	0.86	<.01	2.38	.30	0.86	.43
RTPJ	0.76	<.01	2.35	.31	1.05	.36
the simple reaction time task						
Delta						
FL	0.93	<.01	0.39	.82	0.26	.77
FM	0.93	<.01	0.99	.61	1.18	.31

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Variables	Normality		Homoscedasticity		Parallelism	
	W	*p*	*K-squared*	*p*	*F*	*p*
CL	0.93	<.01	0.39	.82	1.01	.37
CM	0.87	<.01	1.84	.40	0.11	.90
PL	0.88	<.01	0.06	.97	0.22	.81
PM	0.86	<.01	0.61	.74	0.12	.89
OL	0.75	<.01	1.80	.41	0.06	.94
OM	0.76	<.01	3.08	.21	0.31	.74
LTL	0.94	<.01	0.64	.73	0.62	.54
RTL	0.93	<.01	2.09	.35	0.35	.70
LTPJ	0.91	<.01	0.17	92	1.75	.18
RTPJ	0.84	<.01	0.91	.63	0.24	.78
Theta						
FL	0.91	<.01	1.84	.40	1.61	.21
FM	0.98	0.09	0.24	.89	1.31	.28
CL	0.92	<.01	0.69	.71	0.28	.75
CM	0.92	<.01	0.65	.72	0.10	.91
PL	0.94	<.01	0.25	.88	0.01	.99
PM	0.93	<.01	1.59	.45	0.50	.61
OL	0.89	<.01	0.31	.86	1.54	.22
OM	0.87	<.01	0.36	.84	0.39	.68
LTL	0.90	<.01	2.87	.24	1.06	.35
RTL	0.96	<.01	1.09	.58	0.88	.42
LTPJ	0.95	<.01	0.50	.78	1.39	.26
RTPJ	0.94	<.01	0.07	.96	0.26	.77
Lower Alpha						
FL	0.84	<.01	3.48	.18	1.20	.31
FM	0.83	<.01	7.31	.03	1.05	.36
CL	0.79	<.01	10.41	<.01	0.00	1
CM	0.76	<.01	10.38	<.01	0.27	.76
PL	0.76	<.01	12.16	<.01	0.20	.82
PM	0.66	<.01	35.74	<.01	0.07	.93
OL	0.63	<.01	7.04	.03	0.47	.63
OM	0.67	<.01	6.19	.05	0.24	.79
LTL	0.82	<.01	4.48	.11	1.20	.31
RTL	0.79	<.01	1.80	.41	0.43	.65
LTPJ	0.79	<.01	4.52	.10	2.28	.11
RTPJ	0.77	<.01	0.45	.80	0.45	.64
Upper Alpha						
FL	0.89	<.01	0.29	.87	0.46	.63
FM	0.85	<.01	2.35	.31	0.90	.41
CL	0.84	<.01	3.54	.17	0.24	.79
CM	0.84	<.01	1.53	.47	0.70	.50
PL	0.78	<.01	2.09	.35	0.03	.97
PM	0.79	<.01	3.34	.19	0.15	.86
OL	0.65	<.01	0.63	.73	0.56	.57
OM	0.68	<.01	0.77	.68	0.09	.92
LTL	0.88	<.01	1.95	.38	1.10	.34
RTL	0.87	<.01	0.60	.74	0.57	.57
LTPJ	0.84	<.01	0.29	.87	1.02	.36
RTPJ	0.75	<.01	0.57	.75	0.00	1
Full Alpha						

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Variables	Normality		Homoscedasticity		Parallelism	
	W	*p*	*K-squared*	*p*	*F*	*p*
FL	0.87	<.01	0.31	.86	0.84	.44
FM	0.87	<.01	3.43	.18	0.89	.41
CL	0.85	<.01	5.12	.08	0.09	.92
CM	0.83	<.01	4.04	.13	0.41	.66
PL	0.80	<.01	5.14	.08	0.09	.91
PM	0.76	<.01	14.79	<.01	0.00	1
OL	0.65	<.01	1.53	.47	0.49	.61
OM	0.69	<.01	1.80	.41	0.03	.98
LTL	0.87	<.01	1.68	.43	1.19	.31
RTL	0.88	<.01	0.11	.95	0.24	.79
LTPJ	0.83	<.01	1.06	.59	1.79	.17
RTPJ	0.78	<.01	1.10	.58	0.12	.89
Beta						
FL	0.90	<.01	0.58	.75	0.04	.96
FM	0.88	<.01	0.13	.94	1.02	.37
CL	0.92	<.01	0.50	.78	2.31	.11
CM	0.85	<.01	2.41	.30	0.62	.54
PL	0.82	<.01	2.88	.24	0.89	.41
PM	0.78	<.01	2.29	.32	0.54	.58
OL	0.66	<.01	13.49	<.01	0.62	.54
OM	0.65	<.01	14.67	<.01	2.10	.13
LTL	0.93	<.01	3.67	.16	0.71	.50
RTL	0.89	<.01	4.82	.09	1.01	.37
LTPJ	0.88	<.01	2.20	.33	1.43	.25
RTPJ	0.78	<.01	5.88	.05	1.14	.32
the choice reaction time task						
Delta						
FL	0.94	<.01	0.01	1	1.87	.16
FM	0.94	<.01	1.25	.54	2.48	.09
CL	0.91	<.01	0.02	.99	0.48	.62
CM	0.87	<.01	0.19	.91	1.12	.33
PL	0.87	<.01	0.94	.63	0.36	.70
PM	0.87	<.01	4.29	.12	0.47	.62
OL	0.77	<.01	2.11	.35	1.06	.35
OM	0.76	<.01	4.73	.09	3.55	.03
LTL	0.93	<.01	0.02	.99	0.27	.77
RTL	0.94	<.01	0.65	.72	0.15	.86
LTPJ	0.90	<.01	0.83	66	0.40	.67
RTPJ	0.87	<.01	0.66	.72	0.39	.68
Theta						
FL	0.97	.07	0.08	.96	0.84	.44
FM	0.97	.05	2.39	.30	1.54	.22
CL	0.94	<.01	0.61	.74	0.39	.68
CM	0.92	<.01	0.25	.88	0.13	.88
PL	0.93	<.01	2.20	.33	0.29	.75
PM	0.91	<.01	1.44	.49	0.02	.98
OL	0.89	<.01	1.85	.40	0.91	.41
OM	0.89	<.01	3.18	.20	3.09	.05
LTL	0.97	.08	0.06	.97	0.16	.85
RTL	0.98	.35	1.41	.49	2.09	.13

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Variables	Normality		Homoscedasticity		Parallelism	
	W	*p*	*K-squared*	*p*	*F*	*p*
LTPJ	0.95	<.01	0.65	.72	0.21	.81
RTPJ	0.93	<.01	0.81	.67	0.51	.60
Lower Alpha						
FL	0.89	<.01	0.25	.88	0.24	.79
FM	0.85	<.01	3.05	.22	1.03	.36
CL	0.83	<.01	1.16	.56	0.25	.78
CM	0.81	<.01	0.41	.81	0.67	.51
PL	0.83	<.01	2.38	.30	0.68	.51
PM	0.84	<.01	5.21	.07	0.42	.66
OL	0.67	<.01	9.38	<.01	0.32	.73
OM	0.70	<.01	5.68	.06	0.54	.59
LTL	0.88	<.01	0.93	.63	0.16	.85
RTL	0.83	<.01	4.10	.13	0.46	.63
LTPJ	0.83	<.01	2.39	.30	0.28	.76
RTPJ	0.78	<.01	5.96	.05	0.53	.59
Upper Alpha						
FL	0.89	<.01	0.03	.98	0.53	.59
FM	0.87	<.01	1.23	.54	0.72	.49
CL	0.85	<.01	0.29	.87	0.17	.85
CM	0.79	<.01	1.36	.51	2.02	.14
PL	0.82	<.01	0.31	.86	0.24	.79
PM	0.81	<.01	3.34	.19	1.10	.34
OL	0.66	<.01	0.77	.68	0.63	.53
OM	0.68	<.01	3.37	.19	3.78	.03
LTL	0.89	<.01	1.54	.46	1.06	.35
RTL	0.85	<.01	0.44	.80	0.05	.96
LTPJ	0.84	<.01	0.70	.71	0.40	.67
RTPJ	0.80	<.01	1.20	.55	0.25	.78
Full Alpha						
FL	0.89	<.01	0.01	1	0.23	.80
FM	0.88	<.01	1.12	.57	0.40	.67
CL	0.86	<.01	0.20	.91	0.21	.81
CM	0.82	<.01	0.07	.97	1.11	.34
PL	0.83	<.01	0.82	.67	0.42	.66
PM	0.83	<.01	4.33	.12	0.72	.49
OL	0.68	<.01	2.86	.24	0.45	.64
OM	0.70	<.01	3.12	.21	1.58	.21
LTL	0.89	<.01	0.70	.71	0.75	.48
RTL	0.87	<.01	1.46	.48	0.20	.82
LTPJ	0.85	<.01	1.10	.58	0.23	.79
RTPJ	0.81	<.01	3.09	.21	0.27	.76
Beta						
FL	0.93	<.01	0.17	.92	3.24	.04
FM	0.91	<.01	1.94	.38	4.16	.02
CL	0.92	<.01	0.50	.78	0.19	.82
CM	0.84	<.01	0.98	.61	2.17	.12
PL	0.85	<.01	0.52	.77	0.11	.90
PM	0.83	<.01	7.60	.02	0.73	.49
OL	0.72	<.01	3.39	.18	1.47	.24
OM	0.70	<.01	6.75	.03	4.90	<.01

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Variables	Normality		Homoscedasticity		Parallelism	
	W	*p*	*K-squared*	*p*	*F*	*p*
LTL	0.92	<.01	0.33	.85	0.34	.71
RTL	0.92	<.01	1.13	.57	0.67	.51
LTPJ	0.88	<.01	0.64	.73	0.65	.53
RTPJ	0.84	<.01	0.02	.99	0.30	.74
the sound-induced flash illusion task						
Delta						
FL	0.96	.01	0.39	.83	0.17	.84
FM	0.94	<.01	1.43	.49	0.10	.91
CL	0.95	<.01	1.71	.43	0.65	.52
CM	0.91	<.01	1.92	.38	1.57	.21
PL	0.91	<.01	0.21	.90	0.19	.83
PM	0.86	<.01	0.88	.64	1.64	.20
OL	0.84	<.01	0.98	.61	0.04	.96
OM	0.84	<.01	0.38	.83	0.02	.98
LTL	0.95	<.01	0.08	.96	0.19	.83
RTL	0.95	<.01	1.16	.56	0.13	.88
LTPJ	0.92	<.01	0.01	.99	0.31	.73
RTPJ	0.87	<.01	0.22	.90	0.06	.94
Theta						
FL	0.92	<.01	4.41	.11	1.31	.28
FM	0.94	<.01	8.98	.01	0.87	.42
CL	0.97	.03	1.63	.44	1.34	.27
CM	0.96	<.01	2.92	.23	0.06	.94
PL	0.89	<.01	4.17	.12	0.31	.74
PM	0.94	<.01	2.71	.26	0.20	.82
OL	0.91	<.01	2.08	.35	0.55	.58
OM	0.93	<.01	0.10	.95	0.11	.90
LTL	0.91	<.01	6.90	.03	0.72	.49
RTL	0.92	<.01	4.76	.09	0.79	.46
LTPJ	0.93	<.01	9.62	<.01	1.52	.22
RTPJ	0.89	<.01	4.25	.12	0.40	.67
Lower Alpha						
FL	0.75	<.01	10.98	<.01	0.13	.88
FM	0.71	<.01	15.51	<.01	0.16	.86
CL	0.75	<.01	14.75	<.01	0.62	.54
CM	0.72	<.01	18.67	<.01	0.67	.51
PL	0.59	<.01	19.84	<.01	0.13	.88
PM	0.44	<.01	54.49	<.01	0.12	.89
OL	0.70	<.01	8.29	0.02	1.79	.17
OM	0.68	<.01	10.57	<.01	2.36	.10
LTL	0.83	<.01	1.86	.39	1.04	.36
RTL	0.71	<.01	2.21	.33	0.59	.56
LTPJ	0.80	<.01	0.46	.80	2.12	.13
RTPJ	0.62	<.01	0.56	.75	0.18	.84
Upper Alpha						
FL	0.89	<.01	0.79	.68	0.48	.62
FM	0.87	<.01	0.00	1	0.44	.64
CL	0.91	<.01	2.30	.32	0.64	.53
CM	0.88	<.01	2.27	.32	1.51	.23
PL	0.86	<.01	0.43	.81	0.08	.92

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Variables	Normality		Homoscedasticity		Parallelism	
	W	*p*	*K-squared*	*p*	*F*	*p*
PM	0.75	<.01	0.86	.65	0.98	.38
OL	0.78	<.01	3.18	.20	0.20	.82
OM	0.78	<.01	3.11	.21	0.10	.91
LTL	0.92	<.01	0.94	.62	0.27	.76
RTL	0.92	<.01	0.63	.73	0.27	.76
LTPJ	0.87	<.01	0.27	88	0.51	.60
RTPJ	0.83	<.01	1.01	.60	0.08	.92
Full Alpha						
FL	0.87	<.01	1.18	.55	0.23	.79
FM	0.82	<.01	4.54	.10	0.10	.90
CL	0.88	<.01	6.41	.04	0.27	.76
CM	0.84	<.01	7.41	.03	0.65	.52
PL	0.78	<.01	4.24	.12	0.08	.92
PM	0.65	<.01	13.39	<.01	0.50	.61
OL	0.77	<.01	0.32	.85	0.89	.41
OM	0.75	<.01	2.06	.36	0.86	.43
LTL	0.91	<.01	0.66	.72	0.70	.50
RTL	0.85	<.01	0.05	.97	0.37	.69
LTPJ	0.87	<.01	0.06	97	1.16	.32
RTPJ	0.76	<.01	0.10	.95	0.07	.93
Beta						
FL	0.92	<.01	2.58	.28	1.14	.33
FM	0.81	<.01	8.42	.02	0.14	.87
CL	0.89	<.01	0.89	.64	1.47	.24
CM	0.85	<.01	0.23	.89	4.06	.02
PL	0.85	<.01	0.29	.86	0.32	.72
PM	0.77	<.01	0.94	.63	2.45	.09
OL	0.74	<.01	4.63	.10	0.44	.65
OM	0.75	<.01	5.54	.06	0.12	.88
LTL	0.92	<.01	0.43	.81	0.41	.66
RTL	0.90	<.01	2.87	.24	0.17	.84
LTPJ	0.88	<.01	0.67	.72	0.10	.90
RTPJ	0.80	<.01	0.41	.81	0.25	.78

Table 86 Assumption testing of amplitude and latency of ERPs

Variables	Normality		Homoscedasticity		Parallelism	
	W	*p*	*K-squared*	*p*	*F*	*p*
the verbal paired associates learning task						
P300 – mean amplitude						
FL	0.91	<.01	18.81	<.01	0.90	.41
FM	0.65	<.01	47.55	<.01	0.01	.99
CL	0.87	<.01	9.70	<.01	0.90	.41
CM	0.89	<.01	5.54	.06	1.83	.17
PL	0.76	<.01	29.69	<.01	0.20	.82
PM	0.54	<.01	56.52	<.01	0.36	.70
OL	0.86	<.01	13.78	<.01	0.23	.80
OM	0.93	<.01	5.14	.08	0.11	.90
LTL	0.95	.02	3.60	.17	1.81	.17
RTL	0.85	<.01	4.12	.13	0.47	.63

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Variables	Normality		Homoscedasticity		Parallelism	
	W	*p*	*K-squared*	*p*	*F*	*p*
LTPJ	0.87	<.01	11.85	<.01	2.44	.10
RTPJ	0.94	.01	10.18	<.01	0.59	.56
P300 – peak amplitude						
FL	0.91	<.01	19.65	<.01	0.92	.40
FM	0.68	<.01	43.01	<.01	0.18	.83
CL	0.88	<.01	8.95	.01	1.13	.33
CM	0.89	<.01	5.07	.08	1.39	.26
PL	0.84	<.01	17.74	<.01	0.51	.60
PM	0.56	<.01	53.93	<.01	0.27	.76
OL	0.89	<.01	11.44	<.01	1.79	.18
OM	0.90	<.01	10.50	<.01	0.26	.77
LTL	0.92	<.01	9.17	.01	2.18	.12
RTL	0.80	<.01	4.19	.12	0.32	.73
LTPJ	0.83	<.01	22.84	<.01	4.73	.01
RTPJ	0.95	.01	4.36	.11	1.50	.23
P300 – peak latency						
FL	0.98	.47	0.59	.74	0.23	.79
FM	0.96	.03	0.52	.77	0.44	.65
CL	0.98	.30	3.85	.15	1.47	.24
CM	0.94	.01	0.11	.95	1.11	.34
PL	0.98	.60	3.08	.22	0.48	.62
PM	0.96	.03	0.28	.87	1.08	.35
OL	0.98	.43	5.89	.05	0.44	.65
OM	0.93	<.01	1.65	.44	1.55	.22
LTL	0.98	.60	4.54	.10	0.42	.66
RTL	0.96	.03	0.46	.80	1.87	.16
LTPJ	0.97	.10	1.38	.50	0.96	.39
RTPJ	0.97	.08	0.28	.87	0.97	.39
P3/LPC – mean amplitude						
FL	0.96	.04	11.01	<.01	0.46	.63
FM	0.56	<.01	76.80	<.01	0.25	.78
CL	0.86	<.01	11.54	<.01	0.60	.55
CM	0.92	<.01	4.49	.11	0.45	.64
PL	0.81	<.01	18.85	<.01	0.48	.62
PM	0.60	<.01	41.19	<.01	0.38	.69
OL	0.96	.05	5.89	.05	0.17	.84
OM	0.85	<.01	4.86	.09	0.25	.78
LTL	0.92	<.01	6.94	.03	0.43	.66
RTL	0.91	<.01	3.34	.19	2.46	.09
LTPJ	0.84	<.01	16.00	<.01	3.37	.04
RTPJ	0.95	.01	3.39	.18	0.25	.78
P3/LPC – peak amplitude						
FL	0.91	<.01	21.09	<.01	0.64	.53
FM	0.68	<.01	57.36	<.01	0.34	.71
CL	0.85	<.01	8.49	.01	0.30	.74
CM	0.88	<.01	6.49	.04	0.23	.80
PL	0.90	<.01	8.67	.01	0.74	.48
PM	0.61	<.01	34.96	<.01	0.11	.90
OL	0.92	<.01	5.48	.07	0.04	.96
OM	0.83	<.01	3.28	.19	0.31	.74

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Variables	Normality		Homoscedasticity		Parallelism	
	W	*p*	*K-squared*	*p*	*F*	*p*
LTL	0.88	<.01	15.72	<.01	0.34	.71
RTL	0.88	<.01	2.50	.29	1.54	.22
LTPJ	0.79	<.01	25.17	<.01	4.78	.01
RTPJ	0.93	<.01	1.56	.46	0.49	.62
P3/LPC – peak latency						
FL	0.98	.54	0.78	.68	0.35	.71
FM	0.90	<.01	0.16	.93	0.26	.77
CL	0.99	.74	6.94	.03	0.51	.60
CM	0.96	.06	0.80	.67	1.93	.15
PL	0.98	.43	0.55	.76	1.76	.18
PM	0.95	.02	0.81	.67	0.67	.52
OL	0.99	.85	0.33	.85	1.78	.18
OM	0.96	.04	0.56	.75	1.01	.37
LTL	0.98	.55	4.47	.11	0.61	.55
RTL	0.97	.14	0.16	.92	1.68	.19
LTPJ	0.96	.04	5.61	.06	0.32	.73
RTPJ	0.99	.88	4.03	.13	0.28	.76
the non-verbal paired associates learning task						
P300 – mean amplitude						
FL	0.96	.04	2.35	.31	0.49	.61
FM	0.85	<.01	31.54	<.01	0.28	.76
CL	0.76	<.01	1.79	.41	0.11	.90
CM	0.93	<.01	5.70	.06	0.58	.56
PL	0.92	<.01	2.96	.23	0.03	.97
PM	0.90	<.01	6.14	.05	0.01	.99
OL	0.99	.64	6.20	.05	0.74	.48
OM	0.70	<.01	22.89	<.01	0.02	.98
LTL	0.88	<.01	0.79	.67	1.19	.31
RTL	0.98	.60	6.14	.05	2.76	.07
LTPJ	0.98	.28	2.63	.27	2.71	.07
RTPJ	0.93	<.01	4.40	.11	0.92	.40
P300 – peak amplitude						
FL	0.97	.19	0.61	.74	0.19	.82
FM	0.69	<.01	35.49	<.01	0.35	.71
CL	0.68	<.01	0.06	.97	0.07	.94
CM	0.96	.05	13.41	<.01	2.11	.13
PL	0.95	.01	2.27	.32	0.11	.90
PM	0.86	<.01	6.36	.04	0.05	.95
OL	0.96	.03	3.47	.18	1.33	.27
OM	0.69	<.01	25.36	<.01	0.02	.98
LTL	0.92	<.01	1.21	.55	1.40	.25
RTL	0.97	.09	8.15	.02	3.11	.05
LTPJ	0.97	.17	1.74	.42	1.59	.21
RTPJ	0.95	.01	2.14	.34	0.54	.59
P300 – peak latency						
FL	0.99	.70	5.50	.06	1.24	.30
FM	0.94	<.01	4.17	.13	0.10	.91
CL	0.99	.88	4.85	.09	3.08	.05
CM	0.97	.06	2.66	.26	0.75	.48
PL	0.98	.44	2.90	.23	1.33	.27

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Variables	Normality		Homoscedasticity		Parallelism	
	W	*p*	*K-squared*	*p*	*F*	*p*
PM	0.94	<.01	0.73	.69	0.02	.98
OL	0.99	.85	0.26	.88	0.81	.45
OM	0.96	.02	0.91	.64	0.58	.56
LTL	0.96	.02	0.29	.87	0.01	.99
RTL	0.97	.14	0.06	.97	0.01	.99
LTPJ	0.98	.47	0.60	.74	0.54	.59
RTPJ	0.97	.18	0.49	.78	1.30	.28
P3/LPC – mean amplitude						
FL	0.97	.17	5.76	.06	1.14	.33
FM	0.82	<.01	28.93	<.01	0.01	.99
CL	0.85	<.01	3.51	.17	0.11	.90
CM	0.92	<.01	5.69	.06	0.39	.68
PL	0.90	<.01	4.15	.13	0.27	.76
PM	0.90	<.01	4.10	.13	0.35	.70
OL	0.95	.01	11.09	<.01	0.02	.98
OM	0.74	<.01	17.03	<.01	0.38	.68
LTL	0.81	<.01	8.83	.01	0.08	.92
RTL	0.98	.33	5.49	.06	0.08	.93
LTPJ	0.93	<.01	3.13	.21	0.96	.39
RTPJ	0.94	<.01	1.45	.48	2.22	.12
P3/LPC – peak amplitude						
FL	0.97	.07	3.37	.19	2.05	.14
FM	0.87	<.01	15.98	<.01	0.09	.91
CL	0.79	<.01	2.64	.27	0.22	.81
CM	0.84	<.01	11.02	<.01	0.43	.65
PL	0.92	<.01	5.50	.06	0.19	.83
PM	0.89	<.01	3.26	.20	0.33	.72
OL	0.91	<.01	7.03	.03	0.36	.70
OM	0.76	<.01	16.37	<.01	0.09	.91
LTL	0.86	<.01	5.55	.06	0.05	.95
RTL	0.95	.01	10.00	<.01	0.16	.85
LTPJ	0.96	.03	0.23	.89	1.07	.35
RTPJ	0.96	.03	1.60	.45	2.46	.09
P3/LPC – peak latency						
FL	0.96	.02	1.57	.46	0.09	.92
FM	0.97	.09	0.13	.94	0.37	.69
CL	0.98	.22	0.34	.85	0.40	.67
CM	0.91	<.01	2.40	.30	0.33	.72
PL	0.97	.12	1.67	.43	1.88	.16
PM	0.93	<.01	0.04	.98	2.25	.11
OL	0.99	.64	1.86	.40	0.08	.92
OM	0.93	<.01	0.68	.71	0.17	.85
LTL	0.98	.25	1.48	.48	0.28	.76
RTL	0.97	.11	5.38	.07	0.10	.90
LTPJ	0.97	.06	2.03	.36	1.27	.29
RTPJ	0.98	.55	0.20	.91	0.78	.46
The verbal fluency task						
N4 – mean amplitude						
FL	0.96	.48	0.42	.81	1.87	.18
FM	0.87	<.01	0.02	.99	0.45	.65

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Variables	Normality		Homoscedasticity		Parallelism	
	W	*p*	*K-squared*	*p*	*F*	*p*
CL	0.85	<.01	7.80	.02	0.01	.99
CM	0.69	<.01	21.35	<.01	0.03	.97
PL	0.91	.03	3.29	.19	0.14	.87
PM	0.84	<.01	4.76	.09	0.22	.81
OL	0.97	.60	4.63	.10	0.65	.53
OM	0.94	.15	3.11	.21	0.56	.58
LTL	0.88	<.01	0.17	.92	0.34	.72
RTL	0.91	.03	2.62	.27	0.16	.85
LTPJ	0.95	.30	0.46	.80	0.86	.44
RTPJ	0.91	.03	10.70	<.01	1.54	.24
N4 – peak amplitude						
FL	0.96	.33	0.50	.78	0.61	.55
FM	0.86	<.01	0.10	.95	0.47	.63
CL	0.87	<.01	6.81	.03	0.07	.93
CM	0.72	<.01	20.96	<.01	0.01	.99
PL	0.90	.02	3.53	.17	0.23	.80
PM	0.87	<.01	4.42	.11	0.16	.85
OL	0.97	.51	3.92	.14	0.71	.50
OM	0.94	.17	6.49	.04	0.44	.65
LTL	0.87	<.01	0.11	.95	0.46	.64
RTL	0.93	.08	3.12	.21	0.01	.99
LTPJ	0.94	.17	0.59	.75	0.88	.43
RTPJ	0.97	.63	5.50	.06	0.96	.40
N4 – peak latency						
FL	0.96	.43	5.06	.08	0.88	.43
FM	0.89	.01	0.60	.74	0.99	.39
CL	0.97	.51	0.32	.85	3.95	.04
CM	0.94	.13	1.65	.44	0.93	.41
PL	0.96	.32	0.05	.97	1.52	.24
PM	0.96	.33	0.78	.68	0.11	.90
OL	0.97	.75	0.30	.86	0.74	.49
OM	0.95	.26	0.87	.65	0.19	.83
LTL	0.99	.98	1.57	.46	1.34	.28
RTL	0.95	.24	0.27	.87	0.13	.88
LTPJ	0.98	.94	2.34	.31	0.54	.59
RTPJ	0.97	.69	2.30	.32	0.73	.49
P6 – mean amplitude						
FL	0.98	.86	1.27	.53	0.74	.49
FM	0.85	<.01	0.21	.90	2.27	.13
CL	0.80	<.01	11.93	<.01	0.03	.97
CM	0.77	<.01	17.60	<.01	0.21	.81
PL	0.94	.13	1.30	.52	0.40	.68
PM	0.92	.05	3.39	.18	0.85	.44
OL	0.98	.87	8.99	.01	0.32	.73
OM	0.97	.56	1.97	.37	1.31	.29
LTL	0.90	.01	1.20	.55	1.69	.21
RTL	0.93	.09	7.16	.03	0.04	.96
LTPJ	0.96	.36	0.72	.70	0.01	.99
RTPJ	0.85	<.01	7.86	.02	0.70	.51
P6 – peak amplitude						

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Variables	Normality		Homoscedasticity		Parallelism	
	W	*p*	*K-squared*	*p*	*F*	*p*
FL	0.98	.96	2.76	.25	0.64	.54
FM	0.87	<.01	0.36	.83	1.90	.18
CL	0.82	<.01	8.85	.01	0.08	.92
CM	0.73	<.01	19.90	<.01	0.06	.94
PL	0.94	.15	3.18	.20	0.22	.80
PM	0.90	.02	4.09	.13	0.86	.44
OL	0.96	.48	10.47	<.01	0.25	.78
OM	0.95	.22	3.33	.19	0.89	.43
LTL	0.90	.01	1.80	.41	1.65	.22
RTL	0.95	.27	6.85	.03	0.01	.99
LTPJ	0.92	.05	3.91	.14	0.30	.74
RTPJ	0.86	<.01	6.94	.03	1.35	.28
P6 – peak latency						
FL	0.95	.19	1.12	.57	1.07	.36
FM	0.96	.37	0.37	.83	0.21	.81
CL	0.93	.10	0.31	.86	0.61	.55
CM	0.97	.72	5.42	.07	0.11	.89
PL	0.92	.06	2.22	.33	2.69	.09
PM	0.94	.13	0.32	.85	1.77	.20
OL	0.96	.42	1.04	.60	0.37	.70
OM	0.97	.64	1.05	.59	2.37	.12
LTL	0.95	.20	0.26	.88	0.67	.52
RTL	0.98	.78	1.96	.38	0.15	.86
LTPJ	0.93	.10	0.32	.85	2.21	.14
RTPJ	0.96	.42	0.53	.77	0.61	.55
The Corsi block tapping task						
P300 – mean amplitude						
FL	0.87	<.01	2.69	.26	2.71	.07
FM	0.73	<.01	12.86	<.01	0.16	.85
CL	0.94	<.01	4.50	.11	1.52	.23
CM	0.87	<.01	0.99	.61	0.68	.51
PL	0.98	.22	1.30	.52	0.77	.47
PM	0.90	<.01	5.06	.08	0.48	.62
OL	0.92	<.01	2.69	.26	0.11	.90
OM	0.83	<.01	10.51	<.01	0.51	.60
LTL	0.96	.02	4.37	.11	0.02	.98
RTL	0.94	<.01	6.45	.04	0.44	.64
LTPJ	0.93	<.01	3.29	.19	1.33	.27
RTPJ	0.96	.02	8.23	.02	0.67	.52
P300 – peak amplitude						
FL	0.93	<.01	0.69	.71	1.64	.20
FM	0.86	<.01	6.88	.03	1.23	.30
CL	0.93	<.01	5.99	.05	1.23	.30
CM	0.89	<.01	0.77	.68	1.02	.37
PL	0.97	.17	3.17	.21	0.96	.39
PM	0.89	<.01	3.77	.15	0.42	.66
OL	0.92	<.01	2.23	.33	0.21	.81
OM	0.83	<.01	10.16	<.01	1.31	.28
LTL	0.97	.13	3.39	.18	0.16	.85
RTL	0.89	<.01	10.84	<.01	0.78	.46

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Variables	Normality		Homoscedasticity		Parallelism	
	W	*p*	*K-squared*	*p*	*F*	*p*
LTPJ	0.90	<.01	3.14	.21	0.91	.41
RTPJ	0.93	<.01	7.87	.02	0.07	.93
P300 – peak latency						
FL	0.98	.47	0.42	.81	1.37	.26
FM	0.94	.01	0.45	.80	0.58	.56
CL	0.98	.36	3.37	.19	0.94	.40
CM	0.91	<.01	1.23	.54	0.16	.85
PL	0.98	.60	3.07	.22	2.32	.11
PM	0.95	.01	1.88	.39	0.01	.99
OL	0.97	.13	2.77	.25	0.02	.98
OM	0.96	.04	0.46	.79	2.33	.11
LTL	0.98	.34	4.57	.10	2.04	.14
RTL	0.97	.13	0.07	.97	2.07	.13
LTPJ	0.98	.32	6.53	.04	2.84	.07
RTPJ	0.97	.07	1.64	.44	1.31	.28
P3/LPC – mean amplitude						
FL	0.88	<.01	3.00	.22	1.13	.33
FM	0.75	<.01	15.25	<.01	1.10	.34
CL	0.95	.02	3.13	.21	0.34	.71
CM	0.90	<.01	0.69	.71	1.24	.30
PL	0.98	.25	2.04	.36	1.06	.35
PM	0.87	<.01	18.38	<.01	1.70	.19
OL	0.86	<.01	4.17	.12	0.58	.56
OM	0.83	<.01	9.20	.01	0.79	.46
LTL	0.97	.14	5.59	.06	0.70	.50
RTL	0.90	<.01	9.73	<.01	0.05	.95
LTPJ	0.92	<.01	5.75	.06	1.41	.25
RTPJ	0.94	<.01	10.31	<.01	0.08	.93
P3/LPC – peak amplitude						
FL	0.90	<.01	1.67	.43	1.68	.20
FM	0.77	<.01	12.25	<.01	1.95	.15
CL	0.90	<.01	6.11	.05	0.51	.60
CM	0.87	<.01	1.22	.54	0.88	.42
PL	0.95	.01	2.15	.34	1.30	.28
PM	0.93	<.01	7.15	.03	1.40	.25
OL	0.91	<.01	2.26	.32	0.66	.52
OM	0.88	<.01	3.89	.14	0.33	.72
LTL	0.97	.06	6.63	.04	0.15	.86
RTL	0.88	<.01	7.05	.03	0.17	.85
LTPJ	0.91	<.01	5.52	.06	0.96	.39
RTPJ	0.94	<.01	6.21	.05	0.61	.55
P3/LPC – peak latency						
FL	0.93	<.01	1.44	.49	0.01	.99
FM	0.92	<.01	0.27	.88	2.25	.11
CL	0.99	.80	1.89	.39	0.14	.87
CM	0.95	.01	0.45	.80	3.86	.03
PL	0.99	.79	0.64	.73	0.88	.42
PM	0.96	.04	0.16	.92	1.91	.16
OL	0.98	.25	0.78	.68	1.33	.27
OM	0.91	<.01	0.02	.99	0.22	.80

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Variables	Normality		Homoscedasticity		Parallelism	
	W	*p*	*K-squared*	*p*	*F*	*p*
LTL	0.97	.18	1.30	.52	0.39	.68
RTL	0.99	.79	2.98	.23	0.80	.45
LTPJ	0.99	.96	0.12	.94	0.05	.95
RTPJ	0.97	.13	0.48	.79	2.20	.12
The mental rotation task						
N2 – mean amplitude						
FL	0.81	<.01	8.80	.01	0.22	.80
FM	0.94	<.01	3.33	.19	0.38	.69
CL	0.85	<.01	20.96	<.01	0.30	.74
CM	0.74	<.01	32.23	<.01	5.71	<.01
PL	0.90	<.01	10.90	<.01	0.08	.92
PM	0.72	<.01	22.85	<.01	0.01	.99
OL	0.83	<.01	16.68	<.01	3.22	.05
OM	0.83	<.01	24.82	<.01	2.40	.10
LTL	0.70	<.01	61.72	<.01	0.13	.88
RTL	0.93	<.01	8.49	.01	0.57	.57
LTPJ	0.82	<.01	17.76	<.01	0.08	.93
RTPJ	0.89	<.01	12.96	<.01	0.19	.83
N2 – peak amplitude						
FL	0.83	<.01	10.78	<.01	0.66	.52
FM	0.94	<.01	5.14	.08	0.49	.61
CL	0.86	<.01	22.77	<.01	0.97	.38
CM	0.77	<.01	36.37	<.01	8.22	<.01
PL	0.93	<.01	9.06	.01	0.26	.78
PM	0.67	<.01	30.33	<.01	0.04	.96
OL	0.80	<.01	17.48	<.01	5.05	<.01
OM	0.82	<.01	20.87	<.01	1.43	.25
LTL	0.76	<.01	48.90	<.01	0.36	.70
RTL	0.96	.01	3.64	.16	1.01	.37
LTPJ	0.87	<.01	10.20	<.01	0.01	.99
RTPJ	0.90	<.01	13.00	<.01	0.12	.89
N2 – peak latency						
FL	0.99	.77	2.93	.23	1.32	.27
FM	0.94	<.01	0.95	.62	0.58	.56
CL	0.98	.30	1.61	.45	1.15	.32
CM	0.92	<.01	1.39	.50	0.59	.56
PL	0.98	.48	1.09	.58	1.29	.28
PM	0.94	<.01	1.48	.48	3.20	.05
OL	0.99	.84	0.46	.79	0.31	.73
OM	0.96	.02	0.07	.97	0.45	.64
LTL	0.99	.54	2.78	.25	1.15	.32
RTL	0.98	.27	3.32	.19	1.05	.35
LTPJ	0.99	.51	3.34	.19	0.82	.44
RTPJ	0.99	.56	1.71	.43	0.23	.79
P6 – mean amplitude						
FL	0.91	<.01	24.70	<.01	10.10	<.01
FM	0.91	<.01	3.82	.15	0.64	.53
CL	0.91	<.01	6.78	.03	0.03	.97
CM	0.84	<.01	28.98	<.01	12.45	<.01
PL	0.76	<.01	17.42	<.01	0.14	.87

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Variables	Normality		Homoscedasticity		Parallelism	
	W	*p*	*K-squared*	*p*	*F*	*p*
PM	0.71	<.01	41.43	<.01	0.66	.52
OL	0.86	<.01	10.91	<.01	3.12	.05
OM	0.83	<.01	32.29	<.01	0.52	.60
LTL	0.80	<.01	24.70	<.01	0.76	.47
RTL	0.85	<.01	10.26	<.01	1.13	.33
LTPJ	0.90	<.01	12.68	<.01	0.88	.42
RTPJ	0.84	<.01	6.05	.05	4.24	.02
P6 – peak amplitude						
FL	0.93	<.01	22.82	<.01	9.93	<.01
FM	0.90	<.01	4.80	.09	0.43	.65
CL	0.88	<.01	9.38	<.01	0.19	.83
CM	0.78	<.01	27.68	<.01	8.18	<.01
PL	0.77	<.01	17.99	<.01	0.44	.65
PM	0.75	<.01	32.41	<.01	0.04	.96
OL	0.78	<.01	29.51	<.01	1.13	.33
OM	0.80	<.01	38.34	<.01	0.23	.80
LTL	0.88	<.01	7.01	.03	1.16	.32
RTL	0.92	<.01	13.73	<.01	0.31	.73
LTPJ	0.90	<.01	7.28	.03	1.09	.34
RTPJ	0.87	<.01	3.72	.16	4.46	.01
P6 – peak latency						
FL	0.99	.60	0.23	.89	0.34	.71
FM	0.93	<.01	0.68	.71	0.20	.82
CL	0.99	.54	0.25	.88	2.01	.14
CM	0.94	<.01	0.16	.92	4.64	.01
PL	0.99	.90	0.86	.65	5.55	<.01
PM	0.94	<.01	1.37	.50	0.92	.40
OL	0.98	.26	2.29	.32	0.96	.39
OM	0.96	.02	0.32	.85	1.01	.37
LTL	0.96	.01	0.33	.85	0.68	.51
RTL	0.97	.05	0.23	.89	0.79	.46
LTPJ	0.98	.20	0.57	.75	0.94	.40
RTPJ	0.98	.22	0.08	.96	1.16	.32
The Wisconsin card sorting test						
P300 – mean amplitude						
FL	0.95	.01	1.23	.54	0.37	.70
FM	0.81	<.01	16.32	<.01	1.15	.32
CL	0.93	<.01	4.69	.10	0.09	.92
CM	0.87	<.01	4.32	.12	11.32	<.01
PL	0.89	<.01	6.66	.04	0.21	.81
PM	0.95	.01	0.30	.86	1.53	.22
OL	0.92	<.01	10.60	<.01	0.02	.98
OM	0.81	<.01	3.98	.14	0.17	.84
LTL	0.91	<.01	10.25	<.01	0.27	.77
RTL	0.88	<.01	12.46	<.01	1.45	.24
LTPJ	0.97	.17	0.99	.61	0.19	.83
RTPJ	0.94	<.01	2.13	.34	0.38	.69
P300 – peak amplitude						
FL	0.68	<.01	17.01	<.01	0.23	.79
FM	0.82	<.01	6.00	.05	1.81	.17

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Variables	Normality		Homoscedasticity		Parallelism	
	W	*p*	*K-squared*	*p*	*F*	*p*
CL	0.93	<.01	1.31	.52	0.14	.87
CM	0.80	<.01	8.73	.01	7.46	<.01
PL	0.89	<.01	9.92	<.01	0.59	.56
PM	0.90	<.01	3.77	.15	0.49	.61
OL	0.91	<.01	4.30	.12	0.80	.45
OM	0.87	<.01	5.06	.08	0.17	.84
LTL	0.91	<.01	12.69	<.01	0.36	.70
RTL	0.88	<.01	7.51	.02	0.39	.68
LTPJ	0.98	.45	2.72	.26	0.03	.97
RTPJ	0.95	.01	2.65	.27	0.42	.66
P300 – peak latency						
FL	0.99	.84	0.43	.81	0.81	.45
FM	0.97	.18	1.18	.56	0.64	.53
CL	0.98	.59	3.33	.19	0.52	.59
CM	0.94	.01	0.20	.90	2.12	.13
PL	0.97	.12	0.03	.98	3.10	.05
PM	0.95	.01	0.54	.76	1.43	.25
OL	0.98	.54	1.62	.44	2.03	.14
OM	0.95	.01	0.17	.92	0.55	.58
LTL	0.99	.68	0.62	.74	0.51	.60
RTL	0.96	.05	0.63	.73	1.45	.24
LTPJ	0.98	.64	0.09	.96	0.95	.39
RTPJ	0.99	.67	2.00	.37	0.09	.91
P3/LPC – mean amplitude						
FL	0.95	.01	1.21	.55	0.47	.63
FM	0.70	<.01	31.88	<.01	0.34	.71
CL	0.88	<.01	28.67	<.01	0.68	.51
CM	0.90	<.01	1.43	.49	6.59	<.01
PL	0.92	<.01	5.90	.05	1.13	.33
PM	0.90	<.01	0.39	.82	2.15	.13
OL	0.83	<.01	13.41	<.01	0.12	.89
OM	0.80	<.01	2.59	.27	0.07	.93
LTL	0.87	<.01	18.13	<.01	4.08	.02
RTL	0.80	<.01	30.08	<.01	0.92	.40
LTPJ	0.94	.01	5.05	.08	0.22	.80
RTPJ	0.85	<.01	9.74	<.01	0.31	.73
P3/LPC – peak amplitude						
FL	0.70	<.01	11.74	<.01	0.17	.84
FM	0.67	<.01	25.56	<.01	0.26	.77
CL	0.88	<.01	26.53	<.01	0.46	.64
CM	0.93	<.01	3.67	.16	9.34	<.01
PL	0.92	<.01	5.42	.07	1.82	.17
PM	0.85	<.01	2.27	.32	1.37	.26
OL	0.88	<.01	10.21	<.01	0.51	.60
OM	0.83	<.01	3.16	.21	0.01	.99
LTL	0.89	<.01	16.83	<.01	1.93	.16
RTL	0.81	<.01	21.78	<.01	0.62	.54
LTPJ	0.89	<.01	5.89	.05	1.38	.26
RTPJ	0.91	<.01	7.03	.03	0.20	.82
P3/LPC – peak latency						

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Variables	Normality		Homoscedasticity		Parallelism	
	W	*p*	*K-squared*	*p*	*F*	*p*
FL	0.94	.01	1.35	.51	1.41	.25
FM	0.95	.01	1.03	.60	0.85	.43
CL	0.98	.59	3.22	.20	0.36	.70
CM	0.93	<.01	0.11	.95	0.04	.96
PL	0.96	.03	5.25	.07	0.49	.61
PM	0.94	<.01	0.36	.83	0.89	.42
OL	0.98	.40	0.20	.91	0.04	.96
OM	0.93	<.01	0.16	.92	0.53	.59
LTL	0.96	.03	0.55	.76	0.02	.98
RTL	0.95	.02	0.46	.79	1.40	.26
LTPJ	0.95	.01	0.19	.91	0.34	.72
RTPJ	0.97	.20	2.48	.29	0.29	.75
The simple reaction time task						
N1 – mean amplitude						
FL	0.77	<.01	8.30	.02	1.87	.16
FM	0.63	<.01	19.64	<.01	0.43	.65
CL	0.85	<.01	17.46	<.01	5.83	<.01
CM	0.75	<.01	35.87	<.01	0.32	.73
PL	0.90	<.01	0.89	.64	0.48	.62
PM	0.62	<.01	20.39	<.01	2.12	.13
OL	0.80	<.01	9.92	<.01	4.61	.01
OM	0.92	<.01	1.71	.43	1.41	.25
LTL	0.95	.01	12.61	<.01	1.53	.23
RTL	0.75	<.01	11.14	<.01	0.51	.60
LTPJ	0.81	<.01	1.83	.40	0.07	.93
RTPJ	0.90	<.01	4.94	.09	1.10	.34
N1 – peak amplitude						
FL	0.64	<.01	28.84	<.01	1.47	.24
FM	0.67	<.01	11.54	<.01	1.90	.16
CL	0.76	<.01	3.82	.15	0.61	.55
CM	0.77	<.01	19.61	<.01	1.85	.17
PL	0.76	<.01	15.43	<.01	0.67	.52
PM	0.52	<.01	42.52	<.01	1.04	.36
OL	0.86	<.01	3.41	.18	5.53	<.01
OM	0.87	<.01	0.52	.77	2.34	.11
LTL	0.76	<.01	16.74	<.01	2.87	.07
RTL	0.67	<.01	8.35	.02	0.19	.83
LTPJ	0.70	<.01	2.57	.28	0.89	.42
RTPJ	0.80	<.01	3.76	.15	3.05	.06
N1 – peak latency						
FL	0.98	.38	4.36	.11	0.46	.64
FM	0.95	.02	0.40	.82	2.19	.12
CL	0.97	.17	0.64	.73	0.66	.52
CM	0.97	.12	0.50	.78	0.19	.83
PL	0.98	.50	0.58	.75	0.66	.52
PM	0.97	.09	0.58	.75	0.67	.51
OL	0.99	.93	3.38	.19	2.49	.09
OM	0.94	.01	1.36	.51	0.55	.58
LTL	0.98	.45	0.34	.84	3.05	.06
RTL	0.99	.83	2.71	.26	0.51	.61

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Variables	Normality		Homoscedasticity		Parallelism	
	W	*p*	*K-squared*	*p*	*F*	*p*
LTPJ	0.97	.24	1.39	.50	2.52	.09
RTPJ	0.96	.07	1.59	.45	0.54	.58
P3 – mean amplitude						
FL	0.86	<.01	2.62	.27	1.60	.21
FM	0.80	<.01	8.65	.01	1.36	.26
CL	0.86	<.01	15.49	<.01	3.52	.04
CM	0.76	<.01	25.77	<.01	0.34	.72
PL	0.87	<.01	1.38	.50	1.72	.19
PM	0.58	<.01	32.18	<.01	4.17	.02
OL	0.73	<.01	19.43	<.01	5.30	<.01
OM	0.96	.03	0.34	.85	1.74	.19
LTL	0.75	<.01	25.64	<.01	5.36	<.01
RTL	0.73	<.01	16.27	<.01	1.69	.19
LTPJ	0.77	<.01	0.09	.96	1.26	.29
RTPJ	0.79	<.01	5.20	.07	0.63	.54
P3 – peak amplitude						
FL	0.81	<.01	5.45	.07	1.31	.28
FM	0.80	<.01	6.03	.05	0.76	.47
CL	0.85	<.01	13.00	<.01	2.89	.06
CM	0.88	<.01	15.66	<.01	0.33	.72
PL	0.73	<.01	3.77	.15	0.51	.61
PM	0.51	<.01	37.63	<.01	2.24	.12
OL	0.83	<.01	10.12	<.01	5.72	<.01
OM	0.93	<.01	1.33	.51	2.36	.10
LTL	0.74	<.01	29.07	<.01	5.78	<.01
RTL	0.72	<.01	12.13	<.01	1.76	.18
LTPJ	0.73	<.01	0.35	.84	0.34	.71
RTPJ	0.76	<.01	6.90	.03	0.82	.44
P3 – peak latency						
FL	0.97	.24	1.22	.54	0.07	.93
FM	0.95	.01	0.23	.89	0.34	.71
CL	0.98	.36	1.11	.58	0.31	.74
CM	0.94	.01	1.23	.54	0.69	.51
PL	0.98	.34	0.30	.86	0.97	.38
PM	0.96	.06	0.34	.84	0.39	.68
OL	0.98	.35	0.76	.69	1.08	.35
OM	0.93	<.01	1.18	.55	0.73	.49
LTL	0.99	.95	4.89	.09	0.30	.74
RTL	0.96	.07	1.22	.54	0.34	.72
LTPJ	0.99	.71	1.25	.53	0.14	.87
RTPJ	0.96	.04	1.68	.43	1.65	.20
the choice reaction time task						
P3 – mean amplitude						
FL	0.85	<.01	13.62	<.01	2.87	.06
FM	0.54	<.01	28.01	<.01	0.25	.78
CL	0.92	<.01	0.64	.73	0.37	.69
CM	0.95	.01	6.25	.04	0.04	.96
PL	0.92	<.01	4.88	.09	1.82	.17
PM	0.86	<.01	3.41	.18	0.06	.94
OL	0.71	<.01	29.08	<.01	1.04	.36

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Variables	Normality		Homoscedasticity		Parallelism	
	W	*p*	*K-squared*	*p*	*F*	*p*
OM	0.68	<.01	25.10	<.01	1.70	.19
LTL	0.82	<.01	11.94	<.01	0.75	.48
RTL	0.94	<.01	5.46	.07	1.26	.29
LTPJ	0.96	.02	6.76	.03	0.55	.58
RTPJ	0.96	.02	2.70	.26	0.35	.70
P3 – peak amplitude						
FL	0.85	<.01	6.04	.05	1.00	.37
FM	0.51	<.01	27.11	<.01	0.43	.65
CL	0.86	<.01	1.21	.55	0.27	.76
CM	0.97	.06	6.48	.04	0.43	.65
PL	0.91	<.01	4.69	.10	2.17	.12
PM	0.85	<.01	3.60	.17	0.18	.83
OL	0.85	<.01	17.05	<.01	0.51	.60
OM	0.92	<.01	15.30	<.01	3.17	.05
LTL	0.75	<.01	18.78	<.01	1.87	.16
RTL	0.90	<.01	7.33	.03	0.75	.48
LTPJ	0.93	<.01	8.51	.01	0.73	.48
RTPJ	0.93	<.01	3.82	.15	0.49	.62
P3 – peak latency						
FL	0.98	.42	5.60	.06	0.35	.70
FM	0.97	.13	0.26	.88	1.06	.35
CL	0.98	.58	1.36	.51	2.18	.12
CM	0.92	<.01	0.57	.75	0.37	.69
PL	0.97	.20	0.75	.69	2.21	.12
PM	0.94	.01	0.45	.80	1.28	.29
OL	0.99	.94	0.14	.93	1.19	.31
OM	0.95	.01	1.04	.60	0.13	.88
LTL	0.98	.34	4.03	.13	0.57	.57
RTL	0.99	.65	0.16	.92	0.45	.64
LTPJ	0.97	.15	2.53	.28	2.68	.08
RTPJ	0.97	.14	0.27	.87	0.09	.91
the sound-induced flash illusion task						
N1 – mean amplitude						
FL	0.78	<.01	26.65	<.01	0.44	.65
FM	0.78	<.01	26.65	<.01	0.44	.65
CL	0.91	<.01	12.20	<.01	4.96	<.01
CM	0.91	<.01	12.20	<.01	4.96	<.01
PL	0.87	<.01	29.42	<.01	2.94	.06
PM	0.87	<.01	29.42	<.01	2.94	.06
OL	0.54	<.01	53.08	<.01	0.18	.83
OM	0.54	<.01	53.08	<.01	0.18	.83
LTL	0.61	<.01	81.21	<.01	2.04	.14
RTL	0.61	<.01	81.21	<.01	2.04	.14
LTPJ	0.51	<.01	77.12	<.01	0.51	.60
RTPJ	0.51	<.01	77.12	<.01	0.51	.60
N1 – peak amplitude						
FL	0.82	<.01	21.18	<.01	0.88	.42
FM	0.82	<.01	21.18	<.01	0.88	.42
CL	0.89	<.01	8.34	.02	4.42	.01
CM	0.89	<.01	8.34	.02	4.42	.01

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Variables	Normality		Homoscedasticity		Parallelism	
	W	*p*	*K-squared*	*p*	*F*	*p*
PL	0.95	<.01	2.48	.29	3.32	.04
PM	0.95	<.01	2.48	.29	3.32	.04
OL	0.45	<.01	72.10	<.01	0.16	.85
OM	0.45	<.01	72.10	<.01	0.16	.85
LTL	0.64	<.01	59.65	<.01	3.02	.05
RTL	0.64	<.01	59.65	<.01	3.02	.05
LTPJ	0.68	<.01	43.90	<.01	1.93	.15
RTPJ	0.68	<.01	43.90	<.01	1.93	.15
N1 – peak latency						
FL	0.98	.22	0.18	.91	0.22	.80
FM	0.98	.22	0.18	.91	0.22	.80
CL	0.94	<.01	0.08	.96	0.12	.89
CM	0.94	<.01	0.08	.96	0.12	.89
PL	0.98	.36	3.00	.22	0.35	.71
PM	0.98	.36	3.00	.22	0.35	.71
OL	0.96	<.01	0.62	.73	1.74	.18
OM	0.96	<.01	0.62	.73	1.74	.18
LTL	0.98	.32	5.18	.08	1.38	.26
RTL	0.98	.32	5.18	.08	1.38	.26
LTPJ	0.94	<.01	0.36	.84	3.22	.04
RTPJ	0.94	<.01	0.36	.84	3.22	.04
P2 – mean amplitude						
FL	0.62	<.01	33.69	<.01	0.69	.50
FM	0.62	<.01	33.69	<.01	0.69	.50
CL	0.94	<.01	6.74	.03	4.09	.02
CM	0.94	<.01	6.74	.03	4.09	.02
PL	0.95	<.01	8.63	.01	1.02	.37
PM	0.95	<.01	8.63	.01	1.02	.37
OL	0.74	<.01	20.36	<.01	0.27	.76
OM	0.74	<.01	20.36	<.01	0.27	.76
LTL	0.46	<.01	121.18	<.01	1.33	.27
RTL	0.46	<.01	121.18	<.01	1.33	.27
LTPJ	0.44	<.01	78.82	<.01	0.47	.62
RTPJ	0.44	<.01	78.82	<.01	0.47	.62
P2 – peak amplitude						
FL	0.59	<.01	37.00	<.01	0.26	.78
FM	0.59	<.01	37.00	<.01	0.26	.78
CL	0.94	<.01	8.16	.02	6.04	<.01
CM	0.94	<.01	8.16	.02	6.04	<.01
PL	0.96	.01	2.23	.33	2.23	.11
PM	0.96	.01	2.23	.33	2.23	.11
OL	0.64	<.01	34.58	<.01	0.33	.72
OM	0.64	<.01	34.58	<.01	0.33	.72
LTL	0.49	<.01	108.18	<.01	1.58	.21
RTL	0.49	<.01	108.18	<.01	1.58	.21
LTPJ	0.49	<.01	66.13	<.01	0.91	.41
RTPJ	0.49	<.01	66.13	<.01	0.91	.41
P2 – peak latency						
FL	0.98	.34	1.99	.37	0.02	.98
FM	0.98	.34	1.99	.37	0.02	.98

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Variables	Normality		Homoscedasticity		Parallelism	
	W	*p*	*K-squared*	*p*	*F*	*p*
CL	0.96	<.01	0.59	.74	0.52	.60
CM	0.96	<.01	0.59	.74	0.52	.60
PL	0.98	.11	2.58	.28	2.46	.09
PM	0.98	.11	2.58	.28	2.46	.09
OL	0.95	<.01	0.68	.71	0.50	.61
OM	0.95	<.01	0.68	.71	0.50	.61
LTL	0.99	.87	3.43	.18	0.80	.45
RTL	0.99	.87	3.43	.18	0.80	.45
LTPJ	0.92	<.01	1.10	.58	0.58	.56
RTPJ	0.92	<.01	1.10	.58	0.58	.56

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APPENDIX B

Regression analyses of EEG and ERP

Table 87 Regression analyses of EEG on resting state and computerized neuropsychological tests

Task and Relative Bands	ROI	Model	Model summary					
			R^2_{adj}	R^2	*RSE*	*df*	*F*	*p*
CBTP								
Delta	OM	MCST	0.44	0.46	0.12	28	23.80	<.01
		CST	0.10	0.13	0.11	29	4.45	.04
		Control	0.09	0.13	0.09	25	3.71	.07
Upper Alpha	OL	MCST	0.45	0.47	0.01	28	24.34	<.01
		CST	0.15	0.18	0.02	29	6.18	.02
		Control	0.20	0.24	0.01	25	7.70	.01
	OM	MCST	0.50	0.52	0.01	28	30.00	<.01
		CST	0.11	0.14	0.01	29	4.84	.04
		Control	0.22	0.25	0.01	25	8.44	.01
Full Alpha	LTPJ	MCST	0.37	0.39	0.04	28	17.68	<.01
		CST	0.31	0.33	0.04	29	14.36	<.01
		Control	-0.03	0.01	0.04	25	0.20	.66
	OM	MCST	0.32	0.35	0.03	28	14.87	<.01
		CST	0.11	0.14	0.03	29	4.66	.04
		Control	0.26	0.29	0.02	25	10.07	<.01
Beta	OL	MCST	0.45	0.47	0.06	28	24.48	<.01
		CST	0.09	0.12	0.06	29	4.13	.05
		Control	0.13	0.16	0.04	25	4.84	.04
	OM	MCST	0.58	0.60	0.06	28	41.58	<.01
		CST	0.07	0.10	0.05	29	3.35	.08
		Control	0.07	0.10	0.05	25	2.87	.10
CRAT								
Delta	OM	MCST	0.40	0.42	0.14	29	21.28	<.01
	OM	CST	0.40	0.42	0.10	29	21.07	<.01
	OM	Control	0.15	0.19	0.12	24	5.53	.03
Upper Alpha	OM	MCST	0.33	0.36	0.02	29	16.10	<.01
	OM	CST	0.54	0.56	0.01	29	36.27	<.01
	OM	Control	0.14	0.18	0.02	24	5.15	.03
Beta	FL	MCST	0.34	0.36	0.07	29	16.56	<.01
	FL	CST	0.47	0.48	0.07	29	27.10	<.01
	FL	Control	0.04	0.08	0.09	24	1.95	.18
	FM	MCST	0.04	0.07	0.09	29	2.33	.14
	FM	CST	0.44	0.46	0.07	29	25.00	<.01
	FM	Control	-0.02	0.02	0.07	24	0.47	.50
	OM	MCST	0.41	0.43	0.07	29	21.53	<.01
	OM	CST	0.39	0.41	0.04	29	19.78	<.01
	OM	Control	0.26	0.29	0.06	24	9.88	<.01
Eyes closed								

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Task and Relative Bands	ROI	Model	Model summary					
			R^2_{adj}	R^2	*RSE*	*df*	*F*	*p*
Lower Alpha	FL	MCST	0.67	0.68	0.06	29	61.49	<.01
		CST	0.18	0.21	0.07	28	7.23	.01
		Control	0.07	0.11	0.08	26	3.08	.09
	LTL	MCST	0.66	0.67	0.06	29	59.28	<.01
		CST	0.15	0.18	0.07	28	6.12	.02
		Control	0.09	0.13	0.08	26	3.75	.06
	LTPJ	MCST	0.46	0.48	0.09	29	26.43	<.01
		CST	0.13	0.16	0.09	28	5.22	.03
		Control	-0.04	0.00	0.11	26	0.06	.81
	OL	MCST	0.62	0.63	0.11	29	49.57	<.01
		CST	0.24	0.27	0.09	28	10.12	<.01
		Control	-0.01	0.03	0.09	26	0.82	.37
	OM	MCST	0.65	0.66	0.11	29	56.73	<.01
		CST	0.33	0.35	0.09	28	15.03	<.01
		Control	0.04	0.08	0.09	26	2.25	.15
	PL	MCST	0.66	0.67	0.07	29	60.00	<.01
		CST	0.22	0.24	0.07	28	8.94	.01
		Control	-0.01	0.03	0.08	26	0.68	.42
	PM	MCST	0.85	0.85	0.05	29	169.58	<.01
		CST	0.14	0.17	0.08	28	5.89	.02
		Control	0.24	0.27	0.08	26	9.70	<.01
	RTL	MCST	0.39	0.42	0.08	29	20.57	<.01
		CST	0.00	0.03	0.06	28	1.01	.32
		Control	0.03	0.06	0.07	26	1.74	.20
Upper Alpha	OL	MCST	0.31	0.33	0.03	29	14.56	<.01
		CST	0.52	0.54	0.05	28	32.44	<.01
		Control	0.49	0.51	0.03	26	27.32	<.01
	OM	MCST	0.23	0.25	0.03	29	9.88	<.01
		CST	0.51	0.53	0.05	28	31.54	<.01
		Control	0.26	0.29	0.04	26	10.73	<.01
Full Alpha	FL	MCST	0.59	0.60	0.08	29	43.96	<.01
		CST	0.14	0.17	0.11	28	5.78	.02
		Control	0.11	0.14	0.11	26	4.25	.05
	LTPJ	MCST	0.42	0.44	0.12	29	23.03	<.01
		CST	0.17	0.20	0.15	28	7.01	.01
		Control	-0.04	0.00	0.15	26	0.00	.96
	OL	MCST	0.53	0.55	0.13	29	35.08	<.01
		CST	0.31	0.33	0.14	28	13.74	<.01
		Control	0.10	0.13	0.11	26	3.87	.06
	OM	MCST	0.57	0.59	0.13	29	41.58	<.01
		CST	0.36	0.38	0.13	28	17.51	<.01
		Control	0.12	0.15	0.12	26	4.68	.04

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Task and Relative Bands	ROI	Model	Model summary					
			R^2_{adj}	R^2	*RSE*	*df*	*F*	*p*
	PM	MCST	0.61	0.63	0.12	29	48.65	<.01
		CST	0.11	0.15	0.16	28	4.75	.04
		Control	0.38	0.40	0.14	26	17.45	<.01
Beta	RTPJ	MCST	0.16	0.19	0.05	29	6.79	.01
		CST	-0.04	0.00	0.07	28	0.01	.91
		Control	0.43	0.46	0.07	26	21.76	<.01
Eyes open								
Beta	RTPJ	MCST	0.37	0.39	0.07	29	18.61	<.01
		CST	-0.03	0.00	0.09	27	0.06	.81
		Control	0.06	0.1	0.09	26	2.77	.11
MTRT								
Delta	FM	MCST	0.18	0.21	0.18	28	7.51	.01
		CST	-0.02	0.02	0.17	29	0.49	.49
		Control	-0.01	0.03	0.15	25	0.82	.37
Upper Alpha	LTL	MCST	0.46	0.48	0.02	28	25.49	<.01
		CST	0.16	0.19	0.02	29	6.78	.01
		Control	0.25	0.28	0.02	25	9.70	<.01
Beta	FM	MCST	0.34	0.36	0.10	28	15.73	<.01
		CST	-0.03	0.01	0.09	29	0.21	.65
		Control	-0.03	0.01	0.07	25	0.24	.63
OPAL								
Delta	LTPJ	MCST	0.20	0.23	0.15	29	8.54	.01
		CST	0.21	0.24	0.11	28	8.88	.01
		Control	-0.04	0.00	0.13	26	0.08	.78
	PM	MCST	-0.03	0.01	0.16	29	0.25	.62
		CST	0.10	0.13	0.13	28	4.34	.05
		Control	0.54	0.55	0.09	26	32.21	<.01
Theta	FL	MCST	-0.01	0.02	0.02	29	0.61	.44
		CST	0.25	0.27	0.02	28	10.58	<.01
		Control	0.00	0.04	0.02	26	1.03	.32
	LTL	MCST	0.00	0.03	0.02	29	1.03	.32
		CST	0.33	0.35	0.02	28	15.02	<.01
		Control	-0.01	0.03	0.02	26	0.76	.39
	LTPJ	MCST	0.08	0.11	0.04	29	3.66	.07
		CST	0.46	0.48	0.02	28	25.68	<.01
		Control	0.07	0.10	0.03	26	3.02	.09
	OL	MCST	0.17	0.20	0.03	29	7.15	.01
		CST	0.39	0.41	0.03	28	19.34	<.01
		Control	-0.04	0.00	0.03	26	0.06	.81
	OM	MCST	0.02	0.05	0.03	29	1.51	.23
		CST	0.37	0.39	0.03	28	18.20	<.01
		Control	-0.03	0.01	0.03	26	0.31	.58

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Task and Relative Bands	ROI	Model	Model summary					
			R^2_{adj}	R^2	*RSE*	*df*	*F*	*p*
Lower Alpha	CM	MCST	-0.03	0.00	0.02	29	0.02	.90
		CST	0.29	0.31	0.02	28	12.74	<.01
		Control	-0.04	0.00	0.02	26	0.00	.95
Upper Alpha	CM	MCST	-0.03	0.00	0.02	29	0.08	.78
		CST	0.55	0.57	0.01	28	36.87	<.01
		Control	-0.04	0.00	0.02	26	0.04	.83
	LTPJ	MCST	0.24	0.27	0.02	29	10.55	<.01
		CST	0.16	0.19	0.02	28	6.56	.02
		Control	-0.03	0.01	0.02	26	0.16	.69
	PM	MCST	-0.02	0.01	0.03	29	0.41	.52
		CST	0.11	0.14	0.02	28	4.47	.04
		Control	0.62	0.63	0.01	26	44.18	<.01
Full Alpha	CM	MCST	-0.03	0.00	0.04	29	0.04	.84
		CST	0.42	0.44	0.03	28	21.70	<.01
		Control	-0.04	0.00	0.04	26	0.00	.97
	PM	MCST	-0.02	0.02	0.04	29	0.50	.49
		CST	0.06	0.09	0.05	28	2.72	.11
		Control	0.55	0.56	0.02	26	33.67	<.01
Beta	PM	MCST	-0.03	0.00	0.08	29	0.00	.99
		CST	0.10	0.13	0.05	28	4.09	.05
		Control	0.70	0.71	0.03	26	65.12	<.01
SIFI								
Beta	CM	MCST	-0.02	0.01	0.08	29	0.31	.58
		CST	0.02	0.06	0.08	28	1.72	.20
		Control	0.56	0.58	0.06	25	34.62	<.01
VFT								
Theta	LTL	MCST	0.06	0.09	0.02	29	3.03	.09
		CST	0.01	0.04	0.02	29	1.29	.27
		Control	0.05	0.10	0.03	19	2.09	.16
Lower Alpha	PM	MCST	-0.03	0.00	0.02	29	0.02	.89
		CST	0.44	0.46	0.02	29	24.71	<.01
		Control	0.27	0.31	0.01	19	8.35	.01
Upper Alpha	PM	MCST	-0.03	0.00	0.03	29	0.02	.88
		CST	0.57	0.58	0.02	29	40.13	<.01
		Control	0.27	0.31	0.01	19	8.39	.01
Full Alpha	PM	MCST	-0.03	0.00	0.04	29	0.00	.99
		CST	0.52	0.54	0.04	29	33.95	<.01
		Control	0.26	0.30	0.02	19	8.06	.01
VPAL								
Delta	PM	MCST	-0.02	0.02	0.17	28	0.56	.46
		CST	0.25	0.28	0.13	29	11.12	<.01
		Control	0.69	0.70	0.08	24	56.24	<.01

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Task and Relative Bands	ROI	Model	Model summary					
			R^2_{adj}	R^2	*RSE*	*df*	*F*	*p*
Theta	CL	MCST	-0.03	0.01	0.03	28	0.20	.66
		CST	0.21	0.24	0.03	29	9.06	.01
		Control	0.09	0.12	0.02	24	3.42	.08
	FM	MCST	0.06	0.10	0.04	28	3.01	.09
		CST	0.07	0.11	0.04	29	3.42	.07
		Control	0.02	0.06	0.03	24	1.42	.25
	LTPJ	MCST	0.03	0.07	0.04	28	1.96	.17
		CST	0.10	0.13	0.03	29	4.39	.05
		Control	0.04	0.08	0.03	24	2.14	.16
	OL	MCST	0.15	0.18	0.04	28	6.03	.02
		CST	0.32	0.35	0.04	29	15.30	<.01
		Control	0.03	0.07	0.03	24	1.76	.20
Upper Alpha	CL	MCST	-0.04	0.00	0.03	28	0.00	.99
		CST	0.51	0.53	0.02	29	32.11	<.01
		Control	0.32	0.35	0.01	24	12.88	<.01
	CM	MCST	-0.03	0.00	0.03	28	0.03	.87
		CST	0.51	0.53	0.02	29	32.61	<.01
		Control	0.20	0.23	0.02	24	7.28	.01
Beta	OL	MCST	0.08	0.12	0.05	28	3.66	.07
		CST	0.26	0.29	0.04	29	11.73	<.01
		Control	0.38	0.40	0.06	24	16.06	<.01
	PM	MCST	-0.02	0.02	0.07	28	0.57	.46
		CST	0.35	0.37	0.05	29	17.11	<.01
		Control	0.65	0.66	0.04	24	47.18	<.01
WCST								
Delta	OM	MCST	0.10	0.13	0.12	29	4.44	.04
		CST	0.28	0.30	0.09	29	12.42	<.01
		Control	0.45	0.47	0.10	26	23.39	<.01
	PM	MCST	0.21	0.24	0.11	29	9.01	.01
		CST	0.00	0.03	0.13	29	0.96	.34
		Control	0.36	0.39	0.11	26	16.47	<.01
Upper Alpha	OM	MCST	0.05	0.08	0.02	29	2.45	.13
		CST	0.48	0.50	0.01	29	28.63	<.01
		Control	0.47	0.49	0.01	26	25.08	<.01
	PM	MCST	0.41	0.43	0.02	29	21.82	<.01
		CST	0.05	0.08	0.02	29	2.54	.12
		Control	0.26	0.28	0.02	26	10.32	<.01
Full Alpha	PM	MCST	0.30	0.32	0.04	29	13.60	<.01
		CST	-0.02	0.01	0.05	29	0.42	.52
		Control	0.16	0.19	0.04	26	6.04	.02
Beta	OL	MCST	0.08	0.12	0.05	29	3.78	.06
		CST	0.28	0.31	0.03	29	12.92	<.01

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Task and Relative Bands	ROI	Model	Model summary					
			R^2_{adj}	R^2	*RSE*	*df*	*F*	*p*
		Control	0.40	0.42	0.06	26	18.74	<.01
	OM	MCST	0.04	0.07	0.06	29	2.11	.16
		CST	0.27	0.30	0.03	29	12.35	<.01
		Control	0.52	0.54	0.06	26	30.17	<.01
	PM	MCST	0.34	0.36	0.04	29	16.13	<.01
		CST	0.04	0.08	0.05	29	2.40	.13
		Control	0.54	0.55	0.05	26	32.09	<.01

Table 88 Regression analyses of ERP on computerized neuropsychological tests

Task and Parameter	ROI	Model	Model summary					
			R^2_{adj}	R^2	*RSE*	*df*	*F*	*p*
Verbal paired associates learning task								
P3/LPC - Mean								
	LTPJ	MCST	-0.01	0.04	18.42	18	0.81	.38
		CST	-0.04	0.01	7.42	20	0.10	.75
		Control	0.17	0.21	14.86	19	5.04	.04
P300 - Peak Amplitude								
	LTPJ	MCST	-0.02	0.03	17.89	18	0.56	.46
		CST	-0.04	0.01	5.61	20	0.19	.67
		Control	0.34	0.38	10.47	19	11.49	<.01
P3/LPC - Peak Amplitude								
	LTPJ	MCST	-0.01	0.04	22.42	18	0.80	.38
		CST	-0.05	0.00	6.65	20	0.02	.89
		Control	0.30	0.33	14.43	19	9.40	.01
Corsi block-tapping task								
P3/LPC - Peak Latency								
	CM	MCST	0.51	0.54	47.90	19	22.15	<.01
		CST	-0.01	0.04	62.32	20	0.84	.37
		Control	-0.05	0.00	73.43	21	0.00	.96
Mental rotation task								
N200 - Mean Amplitude								
	CM	MCST	0.03	0.06	16.63	26	1.71	.20
		CST	0.44	0.46	29.59	25	21.40	<.01
		Control	-0.03	0.02	13.69	21	0.38	.55
	OL	MCST	0.16	0.19	6.83	26	6.21	.02
		CST	0.04	0.08	15.99	25	2.05	.17
		Control	-0.02	0.02	9.73	21	0.54	.47
P600 - Mean Amplitude								
	FM	MCST	0.65	0.66	13.26	28	54.32	<.01
		CST	0.01	0.05	15.40	25	1.39	.25
		Control	0.01	0.06	7.21	21	1.24	.28
	CM	MCST	-0.02	0.01	17.38	28	0.41	.53

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Task and Parameter	ROI	Model	Model summary					
			R^2_{adj}	R^2	*RSE*	*df*	*F*	*p*
		CST	0.63	0.65	26.40	25	46.05	<.01
		Control	-0.04	0.01	19.15	21	0.13	.72
	RTPJ	MCST	0.22	0.24	13.04	28	9.07	.01
		CST	-0.04	0.00	14.17	25	0.03	.87
		Control	0.08	0.13	8.54	21	3.04	.10
N200 - Peak Amplitude								
	CM	MCST	0.07	0.10	15.08	26	3.02	.09
		CST	0.57	0.58	27.86	25	35.04	<.01
		Control	-0.03	0.01	15.06	21	0.26	.62
	OL	MCST	0.20	0.23	7.27	26	7.85	.01
		CST	0.08	0.12	16.54	25	3.31	.08
		Control	0.00	0.04	9.19	21	0.97	.34
P600 - Peak Amplitude								
	FM	MCST	0.58	0.60	15.05	28	41.20	<.01
		CST	0.00	0.04	16.20	25	0.99	.33
		Control	-0.05	0.00	8.14	21	0.00	.95
	CM	MCST	-0.01	0.02	19.96	28	0.65	.43
		CST	0.51	0.53	33.44	25	28.16	<.01
		Control	-0.04	0.01	20.52	21	0.11	.74
	RTPJ	MCST	0.19	0.22	11.98	28	7.90	.01
		CST	-0.02	0.02	13.48	25	0.49	.49
		Control	0.07	0.11	8.89	21	2.71	.11
N200 - Peak Latency								
	PM	MCST	-0.04	0.00	28.49	26	0.08	.78
		CST	0.22	0.25	29.46	25	8.33	.01
		Control	-0.02	0.02	35.99	21	0.51	.48
P600 - Peak Latency								
	CM	MCST	0.41	0.43	52.23	28	21.48	.00
		CST	-0.03	0.01	67.14	25	0.31	.59
		Control	-0.04	0.01	73.26	21	0.18	.67
	PL	MCST	0.30	0.33	27.03	28	13.67	<.01
		CST	0.06	0.09	37.04	25	2.57	.12
		Control	0.03	0.07	37.16	21	1.61	.22
Wisconsin card sorting test								
P300 - Mean Amplitude								
	CM	MCST	0.00	0.06	15.90	15	0.95	.34
		CST	0.47	0.50	19.15	19	18.93	<.01
		Control	0.22	0.25	21.37	22	7.39	.01
P3/LPC - Mean Amplitude								
	CM	MCST	0.06	0.12	32.43	15	1.96	.18
		CST	0.60	0.62	20.29	19	30.89	<.01
		Control	0.13	0.17	24.19	22	4.41	.05
	LTL	MCST	0.07	0.13	5.65	15	2.25	.15

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Task and Parameter	ROI	Model	Model summary					
			R^2_{adj}	R^2	*RSE*	*df*	*F*	*p*
		CST	-0.05	0.00	5.24	19	0.04	.84
		Control	0.21	0.24	10.82	22	7.02	.01
P300 - Peak Amplitude								
	CM	MCST	-0.06	0.01	16.68	15	0.08	.78
		CST	0.24	0.27	29.14	19	7.20	.01
		Control	0.19	0.22	20.72	22	6.25	.02
P3/LPC - Peak Amplitude								
	CM	MCST	0.03	0.09	21.01	15	1.49	.24
		CST	0.58	0.60	21.73	19	28.12	<.01
		Control	0.12	0.16	23.74	22	4.12	.05
Simple reaction time task								
P300 - Mean Amplitude								
	CL	MCST	-0.05	0.02	8.85	14	0.26	.62
		CST	0.34	0.37	17.51	17	10.18	.01
		Control	0.17	0.20	10.21	22	5.61	.03
	PM	MCST	-0.06	0.01	13.11	14	0.21	.65
		CST	-0.06	0.00	24.34	17	0.03	.87
		Control	0.19	0.22	48.97	22	6.25	.02
	OL	MCST	-0.06	0.01	18.39	14	0.16	.69
		CST	0.24	0.28	21.04	17	6.71	.02
		Control	-0.03	0.01	8.74	22	0.29	.59
	LTL	MCST	-0.05	0.02	3.87	14	0.26	.62
		CST	0.16	0.21	10.68	17	4.52	.05
		Control	0.16	0.19	4.37	22	5.27	.03
N100 - Mean Amplitude								
	CL	MCST	-0.05	0.02	3.49	14	0.35	.56
		CST	0.65	0.67	6.52	17	34.92	<.01
		Control	0.05	0.09	7.83	22	2.10	.16
	OL	MCST	-0.01	0.06	10.11	14	0.92	.35
		CST	0.23	0.27	11.84	17	6.39	.02
		Control	-0.03	0.01	6.69	22	0.25	.62
P300 - Peak Amplitude								
	OL	MCST	0.28	0.32	13.55	14	6.70	.02
		CST	0.13	0.18	22.80	17	3.76	.07
		Control	-0.03	0.01	12.25	22	0.33	.57
	LTL	MCST	-0.07	0.00	5.22	14	0.03	.86
		CST	0.21	0.25	13.71	17	5.66	.03
		Control	0.05	0.09	5.36	22	2.21	.15
N100 - Peak Amplitude								
	OL	MCST	0.37	0.41	10.08	14	9.87	.01
		CST	0.08	0.13	14.68	17	2.47	.13
		Control	-0.04	0.01	10.26	22	0.20	.66
Choice reaction time task								

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Task and Parameter	ROI	Model	Model summary					
			R^2_{adj}	R^2	*RSE*	*df*	*F*	*p*
P300 - Peak Amplitude								
	OM	MCST	0.07	0.12	37.81	21	2.77	.11
		CST	0.36	0.40	28.38	19	12.50	<.01
		Control	-0.04	0.01	16.53	20	0.15	.70
Sound-induced flash illusion task								
N100 - Mean Amplitude								
	FM	MCST	0.09	0.12	2.46	29	3.82	.06
		CST	0.04	0.08	3.20	28	2.33	.14
		Control	0.08	0.11	4.64	28	3.57	.07
P200 - Mean Amplitude								
	FM	MCST	0.00	0.03	4.11	29	1.01	.32
		CST	0.03	0.07	4.34	29	2.05	.16
		Control	0.09	0.12	6.08	28	3.83	.06
N100 - Peak Amplitude								
	FM	MCST	0.09	0.12	2.83	29	4.06	.05
		CST	0.01	0.05	4.17	28	1.35	.26
		Control	0.08	0.11	4.97	28	3.58	.07
P200 - Peak Amplitude								
	FM	MCST	0.00	0.03	3.89	29	0.99	.33
		CST	0.02	0.05	5.00	28	1.60	.22
		Control	0.14	0.17	6.12	28	5.85	.02
	LTPJ	MCST	0.07	0.10	23.15	29	3.09	.09
		CST	-0.03	0.00	20.76	29	0.01	.92
		Control	0.06	0.09	21.58	28	2.87	.10

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APPENDIX C

Ethical Approval and Researcher Qualifications

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Certificate Number IRB4-191/2566

Certificate of Human Research Approval
Burapha University

BUU Ethics Committee for Human Research has considered the following research protocol:

Protocol Code: G-HU 154/2566

Protocol Title: Development of Computerized Multicomponent Cognitive Stimulation for Improving Cognitive Functions in Older Adults with Mild Cognitive Impairment: A Multimodal Investigation Using Neuropsychological and EEG/ERP Assessment

Principal Investigator: Khanitin Jornkokgoud

Affiliation: College of Research Methodology and Cognitive Science

Principal Advisor (Independent Study/ Thesis/ Dissertation):

Assistant. Professor Dr.Pattrawadee Makmee

Associate Professor Dr.Peera Wongupparaj

Affiliation: College of Research Methodology and Cognitive Science

Review Method: ☑ Exemption ☐ Expedited ☐ Full board

BUU Ethics Committee for Human Research has considered the following research protocol according to the ethical principles of human research in which the researchers respect human's right and honor, do not violate right and safety, and do no harms to the research participants.

Therefore, the research protocol is approved (See attached)

1. Form of Human Research Protocol Submission	Version 3: 27 July 2023
2. Research Protocol	Version 1: 18 May 2023
3. Participant Information Sheet	Version 2: 24 July 2023
4. Informed Consent Form	Version 1: 1 May 2023
5. Research Instruments	Version 1: 18 May 2023
6. Others (if any)	Version -: -

Approval Date: 11 August 2023

Valid Date: 11 August 2024

Sign

(Pimonpan Lertlam)

Chair of The Burapha University Institutional Review Board

Panel 4 (Humanities and Social Sciences)

****Remark: This approval has the following details****

NECAST

Certificate of Completion

National Research Council of Thailand (NRCT)

certify that

คณิติน จรโคกกรวด

has completed the

Human Subject Protection (HSP)

Date approved

(13/5/2023)

(Dr.Wiparat De-ong)

Executive Director
National Research Council of Thailand

Date expired

(13/5/2025)

GRADUATE SCHOOL BURAPHA UNIVERSITY

THIS IS TO CERTIFY THAT

Khanitin Jornkokgoud

63810094

College of Research Methodology and

Cognitive Science

HAS SUCCESSFULLY COMPLETED THE ONLINE RESEARCH ETHICS

FOR GRADUATE STUDENTS

ON 10/9/2020

ASSOCIATE PROFESSOR DR.NUJJAREE CHAIMONGKOL
DEAN OF GRADUATE SCHOOL

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MoCA
COGNITIVE ASSESSMENT

CERTIFICATE OF COMPLETION

This certificate acknowledges that

Khanitin Jornkokgoud

has successfully completed a one hour training and certification to administer and score the Montreal Cognitive Assessment, MoCA. Only health professionals with expertise in cognition can interpret test results.

Completion date: 2022/03/16

Student Id: 63810094

Suggested recertification date: 2024/03/16

THJORKH7101857-01

Dr Nasreddine, Ziad

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Z.Nasreddine MD FRCP(C)

Certificate of Attendance

This is to certify that

Khanitin Jornkokgoud

attended the **Cognitive Stimulation Therapy (CST)**

for dementia training day

Signed: Aimée Spector Date: 04.05.2023

Professor Aimee Spector

University College London, UK

UCL

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CERTIFICATE

Of

CONTINUING PROFESSIONAL DEVELOPMENT

This to certify

Khanitin Jornkokgoud

attended

Individual Cognitive Stimulation Therapy (iCST)

One-day online education course delivered by

Dr Phuong Leung

Learning outcomes

- Understand the theories of mental stimulation and carers' involvement in cognition-based interventions.
- Understand how iCST was designed, developed and evaluated.
- Understand how to apply the iCST key principles and communication techniques.
- Be able to deliver iCST to the person with dementia and train the family carer individually at an iCST setup visit.

Date of CPD Activity: 10th May 2022

No. CPD Hours/Points: 5.30

Dr Phuong Leung

Founder of iCST Dementia Education Training and Consultancy

CPD CERTIFIED

The CPD Certification Service

Certificate numbers: A 1092179

https://www.icstdementiatraining.co.uk

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APPENDIX D

Program Manual and Assessment Material

Program Manual

The program manual is available online at manual.cmcs.app, or you can access it by scanning the QR code below.

Assessment Material

All assessment materials, including the computer-based neuropsychological test manual,screening tests, and questionnaires related to the inclusion criteria and key variables in this study, are available in the folder accessible via the QR code below.

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BIOGRAPHY

NAME Khanitin Jornkokgoud

DATE OF BIRTH 7 October 1988

PLACE OF BIRTH Phen District, Udonthani Province

PRESENT ADDRESS 23/1 moo 13, Tumbol Khamthaophatthana, Amphoe Kantharawichai, Maha Sarakham 44150

EDUCATION

2012 Bachelor of Science (B.Sc.)
Information Technology,
Udon Thani Rajabhat University

2014 Master of Science (M.S.)
Computer Science and Information Systems,
National Institute of Development Administration

2020 Bachelor of Arts (B.A.) with First Class Honors
Psychology, Valaya Alongkorn
Rajabhat University under the Royal Patronage

2022 Master of Education (M.Ed.)
Psychology, Mahasarakham University

2025 Doctor of Philosophy (Ph.D.)
Research and Statistics in Cognitive Science
Burapha University, Thailand

2025 Doctor of Philosophy (Ph.D.)
Cognitive Science
University of Trento, Italy

AWARDS OR GRANTS

2021 The Best Research Paper Award from IRD
Suan Sunandha Rajabhat University
Conference 9th, June 2021.

2022 Erasmus+ International Credit Mobility
to study and research for 6 months, from January
to June 2022, at the University of Trento, Italy

2023 Thesis Research Funding
National Research Council of Thailand (NRCT)

2023 TED Youth Startup - IDEA Program Funding
Technology and Innovation-based
Enterprise Development Fund, Thailand

2023 The Outstanding Student Award, College of
Research Methodology and Cognitive Science,
Burapha University, Thailand

2024 Student Mobility Grant
Burapha University Internationalization Fund
to research for 6 months, from January
to July 2024, at the University of Trento, Italy

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