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Toward more context-sensitive clinical measures for assessing executive attention in autistic children

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"Se quanto hai già trovato è fatto di materia pura,
non potrà mai marcire. E tu, un giorno, potrai tornare.
Se è stato soltanto un attimo di luce, come l'esplosione
di una stella, allora non troverai più nulla quando tornerai.
Ma avrai visto un'esplosione di luce.
E anche solo per questo ne sarà valsa la pena."
(Paulo Coelho, *L'Alchimista)*

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Abstract

Executive functions (EFs) are higher-order cognitive skills that enable individuals to control impulses, manage and update information, ignore distractions, and shift attention as needed, supporting effective adaptation to new or complex situations. EF challenges are frequently reported in neurodivergent children, particularly in autistic children, although existing research yields mixed and contradictory findings. These inconsistencies arise not only from differences in participant samples and assessment tools but also from the dominant reliance on reductionist evaluation methods. Given that multiple EFs and broader cognitive abilities are inherently interrelated, single-task paradigms that attempt to isolate specific EF components fail to fully reflect their complexity. This thesis aimed to identify context-sensitive tools for assessing EFs in neurodivergent children, particularly those with autism, that account for individual cognitive profiles and real-world functioning. Neuropsychological tasks from the Measures of Executive Attention, designed within the Executive Attention theoretical framework, were administered to neurodiverse children aged 5-16, including autistic children, those with specific learning disorders, and neurotypical peers. The multidimensional battery of tasks demonstrated good ecological validity and usability across neurodivergent populations. Moreover, in-depth analyses of group performance, task successes and failures, latent factors, and cluster patterns provided valuable insights into executive functioning, shedding light on developmental trajectories, intergroup similarities and differences, and the interplay between executive attention and broader cognitive abilities, such as linguistic, fine-motor skills and fluid intelligence. Finally, considerable variability in performance further underscored the individuality of cognitive profiles, emphasizing that diagnostic labels alone offer an overly simplistic representation of a person. Overall, adopting a multidimensional and contextually grounded approach to assessing executive functioning enables a deeper understanding of neurodivergent children's cognitive profiles and supports the implementation of personalized intervention and educational strategies.

Keywords: executive attention; executive functioning; cognitive abilities; intelligence quotient; neurodiversity; autistic children; autistic traits; specific learning disorders; neurotypical children; clinical assessment

Chapter 1

Theoretical background and state of art[1]

1.1 Executive functions

The term Executive Functions (EFs) was first used by the American neuropsychologist Muriel Lezak in 1983 to refer to the cognitive abilities that enable an individual to act in a goal-directed, independent, and adaptive manner. Historically, the literature highlights the famous case of Phineas Gage, a foreman working for a construction company on a railway line. On 13 September 1848, Gage suffered a serious accident: an explosion caused a metal rod to pierce his left cheek, pass through the base of his skull, traverse the frontal region of his brain, and exit through the top of his head, landing approximately thirty meters away (Damasio, 1995; Harlow, 1868). Although he survived the incident, Gage experienced a profound personality change. His case became highly significant in the study of EFs, as he was the first patient in the medical literature to be described with damage to the prefrontal cortex. This allowed researchers to investigate more deeply the relationship between this brain region and the behavioral changes that emerged following the injury.

Currently, EFs refer to sophisticated cognitive abilities that allow individuals to regulate impulses, retain and manipulate relevant information, filter out distractions, and flexibly shift attention across

[1] This chapter is an extended version of:

Anderle, F., & Venuti, P. (under review). Neuropsychological assessment of executive-attention functions in autistic children and adolescents: Challenges, future directions, and clinical recommendations. *Research in Autism*

My contribution in this work: conceptualization, curation and preparation, formal and data analysis, manuscript first draft writing, and editing

tasks or demands. These skills enable individuals to regulate their behavior and emotions according to the specific context and situation, adapting their actions effectively to novel and complex situations in everyday life (Diamond, 2013; Friedman & Miyake, 2017; Hendry et al., 2016; Miyake & Friedman, 2012). Thus, EFs are a multidimensional construct encompassing various self-regulatory processes that are distinct yet interconnected. Importantly, EFs extend beyond cognitive control to also include the regulation of emotional responses and behavioral actions (Baddeley, 2013; Zelazo et al., 2007).

1.1.1 Neuroanatomical substrates of executive functions

From a neurobiological perspective, the frontal cortex is the anatomical locus of EFs; however, these functions are mainly located in the prefrontal cortex (PFC; Alvarez & Emory, 2006; Stauss & Knight, 2002). This is the brain region that matures later compared to other areas in development. Indeed, the slow maturation of these functions aligns with the development of their anatomical substrate, and thus, the full maturation of EFs, although present from the first months of life, is only reached in early adulthood (Vicari & Di Vara, 2022). From a neurobiological perspective, the PFC is a region of the neocortex, highly developed in primates, and is responsible for coordinating a wide range of neural processes. It consists of a network of interconnected areas that send and receive projections from cortical sensory systems, motor areas, and other subcortical layers (Miller & Cohen, 2001). The PFC is divided into the orbitofrontal, dorsolateral, and ventromedial prefrontal cortex. Traditionally, a distinction is made between the top-down processes that operate in more affectively neutral contexts, referred to as *cool EFs*, and those that operate in motivationally and emotionally significant situations, referred to as *hot EFs* (Zelazo & Carlson, 2012). Cool EFs typically include abilities such as working memory, inhibitory control, cognitive flexibility, and problem-solving, while hot EF processes involve affective decision-making, delay of gratification, and delay discounting (Kouklari et al., 2024; Reynolds et al., 2002). Specifically, the orbitofrontal cortex is engaged during decision-making processes, allowing for the evaluation of various situations encountered in daily life, considering the present context and past experiences. In consequence, the hot EFs are located in this region (Demetriou et al., 2019). In contrast, cool EFs are based in the dorsolateral prefrontal cortex (Demetriou et al., 2019). It becomes active when complex, flexible, and goal-directed behaviors are required, adapting behavior according to environmental demands (Purves et al., 2019). Finally, the ventrolateral prefrontal cortex integrates both cognitive and motivational information and interacts with the dorsolateral cortex, facilitating a conscious and goal-oriented decision regarding the behaviors to adopt (Corbetta & Shulman, 2002; Sakagami & Pan, 2007; Stuss, 2011). Although cool

and hot processes are perceived as distinct, they cooperate and interact in the execution of the demands of each task (Zelazo, 2020).

1.2 Executive functions and autistic children

Autism Spectrum Disorders (ASD) are neurodevelopmental conditions defined by two core domains: differences in social communication and interaction and the presence of restricted, repetitive patterns of behaviors, interests, or activities (American Psychiatric Association, 2022). Specifically, the social communication and interaction area, also referred to as Social Affect (SA), encompasses different modalities compared to neurotypical peers in interpreting nonverbal cues, engaging in reciprocal social interactions, and regulating emotional expression and relationships (American Psychiatric Association, 2022). In contrast, the second core domain, the Restricted and Repetitive Behaviors (RRBs), involves a strong preference for sameness, including adherence to routines, rituals, and intense interests, as well as repetitive sensory-motor behaviors such as stereotypies and sensory fixations (Faja & Nelson Darling, 2019). These characteristics typically emerge during early development and may lead to clinically significant difficulties in social, academic, occupational, and other important domains of functioning.

In recent decades, research has consistently recognized that autism involves not only social challenges but also cognitive differences, particularly in EFs, observable as early as the preschool years (Christoforou et al., 2023; Garon et al., 2018). However, there is ongoing debate about the specificity and universality of these difficulties, given the heterogeneity in autism's clinical presentation (Brunsdon & Happé, 2014; Frith, 2012; Valeri, 2010). Various neuropsychological models have been developed to explain autism-related features, generally following two methodological perspectives: *domain-specific approaches*, which propose that cognitive challenges are specific to social functioning (e.g., Theory of Mind impairments), and *domain-general approaches*, which examine broader cognitive processes affecting both social and non-social domains, such as EF difficulties and the Weak Central Coherence theory.

With a particular focus on executive functioning, various authors have proposed differing perspectives, and an ongoing debate continues regarding the nature of individual differences in this domain. The Executive Dysfunction Model suggested that alterations in EFs are a core characteristic of autism, significantly influencing differences in social cognition and other key domains (Hill, 2004; Pennington & Ozonoff, 1996). Conversely, other researchers argued that differences in executive

functioning are secondary, arising from fundamental socio-communicative difficulties. From this perspective, difficulties in social skills negatively impact broader cognitive domains, including executive processes (Narzisi et al., 2013; Lai et al., 2017). Supporting this view, studies on preschool-aged children have often found no significant differences in EF performance between autistic and neurotypical groups when matched on mental age (Dawson et al., 2002; Griffith et al., 1999; Yerys et al., 2007). However, more recent research indicates that autistic preschoolers and school-aged children tend to perform lower on key EF tasks, specifically those measuring working memory, inhibition, and cognitive flexibility, compared to their neurotypical counterparts (Demetriou et al., 2018; Gentil-Gutiérrez et al., 2022; Tschida & Yerys, 2022; Valeri et al., 2020; Van Eylen et al., 2015). Examining the cognitive differences observed in autistic children through a broader interpretive lens, such as the neurodiversity paradigm, may offer a more appropriate framework for understanding individual variation. Rather than following a uniform pattern, these differences often manifest in diverse ways within the same population and across the lifespan (Pellicano & de Houting, 2021). Specifically, this thesis will use the term *neurodivergent* to refer to individuals whose neurological functioning differs from what is considered typical (e.g., individuals with autism, ADHD, or dyslexia), while *neurodiverse* will be used to describe groups that include both neurodivergent and neurotypical individuals, reflecting a range of neurological variations.

1.2.1 Neurobiological evidence in autism

In autistic children, differences in EF have been described both at behavioral and neurobiological levels. Particularly, a different activity in the prefrontal cortex is present compared to neurotypical individuals (Alexandropoulou, 2021; Carotenuto et al., 2019; Demetriou et al., 2019). Functional imaging studies reveal that autistic individuals show altered brain activity during executive and attentional tasks, particularly a reduced activation has been observed in the frontoparietal networks, brain systems underlying cognitive control and flexibility (Blume et al., 2024; May & Kana, 2020; Yerys et al., 2019). These patterns suggest that executive attention differences in autism may stem, at least in part, from atypical development or functioning of these neural substrates. Moreover, neurotransmitters play a key role in regulating inhibition and shifting skills (Alexandropoulou, 2021; Demetriou et al., 2019). In autism, abnormal dopamine levels have been linked to motor difficulties, repetitive and stereotyped behaviors, seizures, attention deficits, and broader executive dysfunction, reflecting the widespread impact of dopamine on brain regions implicated in ASD, including the prefrontal cortex, amygdala, cerebellum, and parietal lobe (Alexandropoulou, 2021; Kriete & Noelle, 2015). Additionally, serotonin influences response inhibition through its action in the orbitofrontal

cortex, while noradrenaline is involved in modulating arousal and attentional processes (Demetriou et al., 2019; Hill, 2004).

1.2.2 The importance of studying executive functions in autism

Investigating EFs, particularly in autistic children, is especially important given the challenges they face in behavioral and emotional regulation, as well as the role EFs may play in understanding the heterogeneity of autistic traits. Indeed, executive dysfunction has been shown to account for up to 57% of the variability in autism symptoms (Ko et al., 2024). Moreover, the severity of executive dysfunction is correlated with higher levels of both internalizing symptoms, such as anxiety and depression (Gardiner & Iarocci, 2018; Suen et al., 2024) and externalizing symptoms like aggression and oppositional behaviors (Cristofani et al., 2020), in both neurotypical and neurodivergent children (All et al., 2024). Research also indicates that greater executive difficulties are associated with a stronger presence of specific autistic traits (Terroux et al., 2024). Notably, differences in inhibition and cognitive flexibility are strongly linked to restricted and repetitive behaviors, specialized interests, and sensorimotor challenges (Augé et al., 2024; Faja & Darling, 2019). Furthermore, EFs play a pivotal role in learning, academic achievement, and school participation among autistic children (Kheirollahzadeh et al., 2021; Zelazo & Carlson, 2020). Their influence extends to crystallized and fluid intelligence (Solomon et al., 2021), play skills (Faja et al., 2016), socio-emotional competence (Fong & Iarocci, 2020; Torske et al., 2018), and socio-communication abilities (Freeman et al., 2017; Powell et al., 2022). In consequence, executive attention skills are associated with adaptive functioning in autistic children (Bertollo & Yerys, 2019; Pugliese et al., 2016; Solomon et al., 2021; Udhnani et al., 2020) and with broader outcomes such as quality of life (Chien et al., 2024; de Vries & Geurts, 2015; Frazier et al., 2022; Suen et al., 2024).

1.3 Models of executive functions: unitary versus diverse

Various models attempt to understand the structure and nature of executive functioning. They can be conceptualized as either unitary or diverse. The diversity models propose that EFs are distinct and separable, like inhibition, shifting, and updating. In contrast, the unitary model suggests that EFs are a single, general-purpose cognitive control system.

Some authors, such as Lezak (1982) and Roberts and Pennington (1996), have proposed a conceptualization of EFs as distinct and separable components. Lezak (1982) suggests that four types of EFs are essential for appropriate and socially acceptable behavior. They include the ability to set goals, which is closely linked to motivation and self-awareness, and an understanding of how the environment influences an individual; planning, which requires a set of additional abilities, such as observing oneself in relation to the surrounding environment, considering alternative actions, evaluating them, and making choices that direct behavior toward a particular goal. Next, there is the implementation of behaviors necessary to achieve a goal, which requires the ability to initiate, maintain, change, and stop complex behavioral sequences in an organized and integrated manner. Finally, there is the effective performance, which depends on the individual's capacity to monitor the rhythm, intensity, and other qualitative aspects of execution. On the other hand, Roberts and Pennington (1996) propose a model based on two functions: working memory, which is the ability to generate and execute correct responses, and inhibition, which is essential for suppressing inappropriate actions. These components often work synergistically.

In contrast to these diversity models, unitary perspectives have been suggested. They considered that a common underlying factor, such as general executive control or attention regulation, drives performance across various EF tasks. Following this approach, Norman and Shallice's (1986) Supervisory Attentional System (SAS) and Baddeley and Hitch's (1974; 1994) Working Memory model were proposed. Specifically, Norman and Shallice (1986) suggested two complementary processes involved in action selection and control of daily tasks and behaviors: a basic mechanism and the Supervisory Attentional System. The basic mechanism, known as contention scheduling, enables the automatic activation and inhibition of conflicting behaviors in response to a specific stimulus. Thus, this system is responsible for handling and prioritizing routine actions. However, when the stimulus is novel or complex, the Supervisory Attentional System is engaged. It assigns a hierarchy of priorities to different response schemas and selects the most appropriate one to execute (Alexandropoulou, 2021; Carotenuto et al., 2019; Chan et al., 2008). Conversely, Baddeley and Hitch's (1974) model of Working Memory proposes three distinct components: two short-term stores for the manipulation and storage of information, the phonological loop, which handles verbal stimuli, and the visuospatial sketchpad, which processes visual and spatial data, and the central executive, which serves as an attentional control system coordinating these sub-systems and other cognitive processes (Baddeley & Hitch, 1994). Later, Baddeley (2000) introduced a third sub-system, the episodic buffer, which facilitates the temporary storage and integration of various information.

1.3.1 An integrated approach: the Working Memory Capacity or the Executive Attention

Recent approaches adopt a hybrid conceptualization, recognizing a common EF factor alongside specific subcomponents (Engle, 2002; Miyake et al., 2000; Kane et al., 2001; Salthouse et al., 2003). Indeed, both unitary and diversity perspectives contribute valuable insights due to the specific but integrated involvement of these functions during the execution of the tasks.

Miyake et al. (2000) identified three core components: updating, inhibitory control, and cognitive flexibility. *Updating* refers to the process of monitoring and revising information held in working memory; *inhibitory control* involves suppressing dominant or automatic responses in favor of more appropriate ones; and *cognitive flexibility* enables shifting between tasks, mental sets, or strategies in response to changing circumstances (Miyake et al., 2000; Lage et al., 2024). These foundational EFs are critical for the development of higher-order (or second-order) cognitive abilities, such as problem-solving, planning, organization, reasoning, and decision-making, which involves strategizing, executing, and revising plans to achieve specific goals (Best & Miller, 2010; Diamond, 2013; Olde Dubbelink & Geurts, 2017). The identification of these three components as core EFs is based on several key factors. First, these functions can be operationalized more precisely through relatively simple cognitive tasks compared to more complex abilities like planning. Additionally, they are particularly engaged during the execution of complex cognitive tasks. However, to investigate the separability and commonality between these functions, Miyake et al. (2000) conducted a confirmatory factor analysis, showing that a three-factor model provided the best fit: the functions are partially independent but also share common variance. This conclusion is supported by other studies (Baddeley & Hitch, 1974; Friedman et al., 2006; Karr et al., 2018), which provided the foundation for models of EFs that considered them as multidimensional constructs, including lower and higher order abilities which are moderately to strongly correlated with each other (Diamond, 2013; Friedman & Miyake, 2017). Additionally, bifactor models emphasized the importance of a general EF factor alongside domain-specific processes, underscoring the multifaceted and interrelated nature of executive control (Yangüez et al., 2025). When considering the common underlying basis of these EFs (known as *"Common EF"*), Miyake et al. (2000) proposed two primary hypotheses. The first suggests that inhibition serves as the foundational EF. However, this view appears overly reductive, as effective task execution requires the integration of multiple functions (Benso, 2018). The second, and more widely accepted, explanation posits that Working Memory Capacity (WMC) is the core mechanism that underpins EFs (Engle, 2002; Kane et al., 2001). The model proposed by Engle and Kane (2004) was developed based on the Baddeley and Hitch proposal (1974). Engle and Kane (2004) integrated Baddeley and Hitch's (1974) central executive system into their multi-

component model, referred to as WMC or Executive Attention (EA). The WMC and the EA are often considered equivalent or tightly overlapping constructs (McCabe et al., 2010; Engle, 2002; Kane et al., 2007). WMC is a mechanism that allows for maintaining goals, resolving conflicts, monitoring task execution, and retrieving relevant information from memory while resisting distractions from irrelevant internal or external stimuli (Engle, 2018; Engle & Kane, 2004). Executive attention, in turn, supports the manipulation of information and the maintenance of representations that have temporarily fallen outside the focus of attention but remain relevant for achieving current or future goals (Morra & Camba, 2009; Benso, 2018).

The WMC model is composed of three integrated systems, each tailored to different types of tasks. The first system involves short-term memory, which holds information traces that are activated above a certain threshold. These traces can be maintained actively by a second system, which includes retrieval processes and strategies, such as domain-specific rehearsal, to keep the information accessible. Finally, the WMC system maintains attentional focus and supports the retrieval of relevant information that has become inactive (Kane et al., 2007). It influences self-regulatory behavior and plays a critical role in complex learning processes, including both cognitive and motor domains. Importantly, WMC is not the same as the "updating" component of EFs (Miyake et al., 2000). Although it is often mistakenly equated with updating, this is an oversimplification (Kovacs et al., 2016; Pasqualotto et al., 2024). Defining WMC solely as an EF risks circular reasoning, as working memory is a system supported by multiple executive and attentional components (Engle, 2002; Engle et al., 1999; Morra et al., 2018; Shipstead et al., 2016). Thus, the WMC seems to be a multicomponent system that expresses itself through diverse executive functions, which appear present but only partially separable (Benso, 2018).

1.3.2 The modularity of mind

The debate concerning the separability and interaction of EF components can be illuminated by broader discussions on the modularity of the human mind. Modularity, the notion that cognitive functions are implemented by distinct, relatively autonomous subsystems, has long been influential in cognitive science and neuropsychology (D'Souza & Karmiloff-Smith, 2011). Early formulations, most notably Fodor's (1983) theory, characterized modules as domain-specific, automatic, and informationally encapsulated. Importantly, however, Fodor restricted modularity to input systems such as perception and language, explicitly excluding central cognitive processes. Subsequent accounts expanded this framework. Carruthers' (2005) theory of massive modularity proposed that cognition is composed of numerous specialized mechanisms, each evolved to solve particular

adaptive problems, thereby extending modularity to central systems. Despite its theoretical appeal, this strong modular stance has been increasingly challenged by findings from cognitive neuroscience, which instead point to a flexible and highly interconnected neural architecture (Anderson, 2010; Barrett & Kurzban, 2006). In line with this perspective, Benso et al. (2025) acknowledge that some claims of massive modularity capture important aspects of cognitive organization, yet they firmly reject the modularization of central, higher-order systems such as executive functions. Rather than being compartmentalized, these systems are better understood as dynamically integrated and context-sensitive. Empirical evidence has further weakened strict modular accounts. Research on mirror neurons (Rizzolatti & Craighero, 2004) and the theory of neural reuse (Anderson, 2010) demonstrate that neural circuits are frequently redeployed across multiple cognitive domains. Similarly, studies of large-scale brain networks, such as the Salience Network, Default Mode Network, and Central Executive Network (CEN; see **Chapter 1, Section 1.4.2** for a description of the attentional networks), support a distinction between modular states, associated with automatic and mandatory processing, and non-modular states, characterized by executive control, attentional regulation, and working memory. Crucially, these findings suggest that central systems are amodal and integrative rather than modular in the classical sense (Benso et al., 2025). Persistent theoretical and methodological difficulties in treating central systems as modular further reinforce this conclusion (Lundie, 2019; Zerilli, 2019).

Building on these critiques, Benso et al. (2025) argue that reductionist attempts to isolate and fractionate executive functions overlook the superordinate and coordinating role of central systems. Such efforts, they contend, often lead to methodological inconsistencies and theoretical fragmentation, a concern echoed across decades of EF research (Benso, 2018; MacLeod et al., 2003; Moscovitch & Umiltà, 1990; Rabbitt, 1997; Hofmann et al., 2011). Although certain executive processes may display limited modular features, their inherent flexibility and reliance on dynamic integration undermine a fully modular interpretation. In response, Benso et al. (2025) propose a reconceptualization of modularity. Their framework distinguishes three layers of modularity: innate modules, predisposed but experience-dependent systems, and highly trained processes shaped through attention and memory. This model reframes modularity as a dynamic state rather than a fixed structural property, thereby clarifying the boundary between modular and non-modular systems. A system is considered modular when its operation is highly automatic and mandatory; however, when regulated by the CEN, the same system may function in a non-modular mode, engaging slower and more deliberate processing. In this view, modularity is determined by state-dependent patterns of network activation rather than by immutable architectural constraints. This perspective accounts for both cognitive stability and adaptability. During learning, central systems such as the CEN provide

scaffolding and resource allocation, gradually disengaging as expertise develops, and re-engaging when novel demands or goal-directed control are required. Consequently, memory systems shaped through hyper-learning may acquire modular characteristics, while the CEN retains its amodal, supervisory role. Beyond its theoretical contributions, this revised account of modularity carries significant practical implications (Benso et al., 2025; Chiorri & Benso, 2022). In rehabilitation contexts, dynamic and integrative models of modularity offer greater clinical utility than rigid, encapsulated frameworks. By recognizing the interdependence of cognitive subsystems, practitioners can more effectively target vulnerable components and promote reorganization within broader neural networks. Conversely, treating cognitive systems as fixed and isolated risks constraining intervention strategies, limiting opportunities for recovery through reintegration and adaptive reconfiguration.

1.4 Toward a new conceptualization of executive functions: the executive attention

From the earliest stages of development, cognitive and emotional processes interact in complex and dynamic ways, influencing behavior and self-regulation (Hughes et al., 2020). While EFs are typically described as intentionally deployed cognitive processes, self-regulation encompasses a wider range of both cognitive and emotional abilities (Blair & Raver, 2015; Toplak et al., 2013). Together, they contribute to self-control, underscoring their interrelatedness. Although the various components are relatively distinct, they interact with each other during task execution (Miyake et al., 2000). Adopting a multidimensional approach, such as the Executive Attention (EA) or the Working Memory Capacity (WMC), allows for the identification of a common cognitive mechanism underlying both dimensions of regulation, behavioral and emotional (Tiego et al., 2020). Thus, EA supports the development of self-regulation, the capacity in children to manage their thoughts, emotions, and behaviors. In consequence, EA acts as a foundational mechanism across a wide range of complex cognitive activities, providing a more holistic view of how attentional, mnemonic, and executive systems interact to support cognition and adaptive behaviors (Baddeley & Hitch, 2007; Engle & Kane, 2004; Hofmann et al., 2011). Indeed, contemporary models of working memory and executive functioning converge in positing executive attention as a shared underlying construct, rendering distinctions between these domains largely theoretical (Cowan, 1999; Conway et al., 2005; Engle, 2002; Engle & Kane, 2004; Oberauer, 2019). In line with these perspectives, the present thesis adopts a heterogeneous, multicomponent view of executive control, conceptualized primarily in terms

of executive attention (and closely aligned with WMC; see **Chapter 1, Section 1.3.1**). Rather than considering executive processes as discrete or specialized subsystems, this approach emphasizes flexible recruitment of multiple functions in response to task demands. Although specific executive operations can be identified, they cannot be meaningfully expressed in isolation, as they rely on continuous interaction within a broader control architecture (Benso, 2018; Duncan, 2001). From this standpoint, executive attention is supported by a limited-capacity system specialized in monitoring, resolving, and regulating competition among concurrent cognitive processes (Engle, 2018; Kane et al., 2001; Petersen et al., 2012; Petersen & Posner, 2012). It encompasses the capacity to maintain focus on goal-relevant information, suppress prepotent or inappropriate responses, and sustain attention to task-relevant stimuli (Tiego, 2020). This conceptualization is further supported by neuroscientific evidence highlighting cognition as an emergent property of interacting neural networks rather than of encapsulated modules. Executive attention is associated with coordinated activity across large-scale functional systems, with neuroanatomically distinct networks being differentially engaged depending on contextual demands (Benso et al., 2025; Posner & Petersen, 1990; Rueda et al., 2011). Within this architecture, the dorsolateral prefrontal cortex plays a central role in sustaining executive attention and regulating goal-directed behavior (Kane & Engle, 2002; see **Chapter 1, Section 1.1.1**).

On these theoretical and empirical grounds, the term *executive attention* is preferred in the present thesis over the more traditional label *executive functions*. While *executive functions* typically denote a heterogeneous collection of higher-order processes, such as inhibition, cognitive flexibility, working memory, and planning, this fractionated taxonomy has been increasingly criticized for its limited explanatory coherence and reduced ecological validity, particularly in clinical contexts. By contrast, *executive attention* refers to a central, amodal control system that allocates attentional resources, coordinates goal-directed activity, and integrates cognitive processes in a context-sensitive and state-dependent manner. Consistent with network-based models of cognition, executive control is thus conceived as emerging from dynamic interactions among large-scale brain networks, notably the Central Executive Network (see **Chapter 1, Section 1.4.2**), rather than from independent modular components. For continuity with existing literature, the term *executive functions* are retained when referring to established assessment frameworks or measurement traditions; however, *executive attention* is adopted as the primary construct to emphasize its integrative, dynamic, and clinically meaningful nature.

1.4.2 Attentional networks

Support for a multicomponent model of executive attention is influenced particularly by studies that focused on brain networks (Benso, 2018; Menon & D'Esposito, 2022). Brain networks refer to interconnected regions of the brain that communicate with one another through specific sites known as "*hubs*"; damage to these hubs can disrupt the entire circuit and reveal underlying brain dysfunction (Chiorri & Benso, 2022). Distinct networks of brain regions are responsible for different attentional functions, including achieving and sustaining an alert state, directing attention and selecting sensory input, and managing thoughts, emotions, and actions (Petersen & Posner, 2012; Posner & Petersen, 1990). Various control networks allow control of these mechanisms. Particularly, in literature, five attentional control networks have been identified. The first control network, the *Central Executive Networks (CEN*), is characterized by the activation of the dorsolateral prefrontal cortex and the posterior parietal cortex, which are connected to the anterior cingulate gyrus. It is involved in cognitive control processes such as flexibility, updating, and online error correction (Corbetta & Shulman, 2002; Petersen & Posner, 2012; Posner & Petersen, 1990). These networks involve the broader executive attention components (Chiorri & Benso, 2022). The second control network, the *Salience Networks (SN)*, is marked by the activation of the lateral frontal cortex, the right anterior insula (part of the frontal opercular system), and the anterior cingulate gyrus. It plays a key role in task maintenance and facilitates the transition between automatic and controlled cognitive states. The anterior cingulate cortex supports the maintenance of cognitive states by reducing conflict between them, while the insula is crucial for switching between states (Sridharan et al., 2008). The third network, *Default Mode Networks (DMN)*, associated with activation of the posterior cingulate gyrus and the ventromedial prefrontal cortex, becomes active during attentional deactivation and resting states. Thus, it is active during automated tasks in which no specific attentional component is required by individuals (Benso, 2018; Corbetta & Shulman, 2002). The fourth network, the *Orienting Networks (ON),* is associated with activation of the fronto-parietal cortex, particularly the intraparietal sulcus (Petersen & Posner, 2012). The frontal eye fields are involved in voluntary attention orientation, while the locus coeruleus is engaged in automatic orientation (Corbetta et al., 2002). This network supports the spatial orientation of attention. The fifth network, the *Alerting Networks (AN)*, involves activation of the right hemisphere and is associated with sustained vigilance. Activation begins in the locus coeruleus, proceeds to the temporoparietal junction, and then to the ventral frontal cortex (Petersen & Posner, 2012).

Although these networks are functionally distinct and specialized units, they interact with one another and are flexibly activated during different tasks to implement EFs (Duncan & Owen, 2000). In order to control the activation of these units, some authors proposed various models, such as Duncan (2001)

identified the Adaptive Coding Model, suggesting that individual neurons in the PFC are highly adaptable depending on the task at hand.

1.5 Typical and atypical development of executive functions

The development of executive functions is likely linked to structural changes in brain regions that form part of the executive attention network, as well as to evolving patterns of connectivity with other brain areas, particularly the increasing functional connectivity between frontal and parietal regions over the course of development (Power et al., 2010). The growth of executive functions begins in infancy, with early skills emerging during the latter half of the first year of life (Hendry et al., 2016). These abilities expand rapidly throughout the first three years, largely due to the advances in attentional processes (Hendry et al., 2016) and effortful control (Putnam et al., 2006). Effortful control (EC) refers to a dimension of temperament linked to individual differences in controlling attention and behavior (Rothbart & Gartstein, 2008). Development of executive functions continue across the lifespan, reaching a peak in early adulthood before gradually declining after the age of 30, in line with neurobiological changes (Ferguson et al., 2021). In adulthood, EFs demonstrate both unity and diversity, as suggested by Miyake and Friedman (2012), individuating three factors: inhibitory control, updating and shifting. In contrast, studies employing performance-based measures show that, in preschoolers, skills such as updating, cognitive flexibility, and inhibition are represented as a singular ability (Hughes et al., 2009; Nelson et al., 2016; Wiebe et al., 2011; Willoughby et al., 2012). Recent research indicates that EFs gradually differentiate throughout development, revealing a three-factor structure that becomes more pronounced with age, yet also showing considerable variability between individuals (Yangüez et al., 2025). Specifically, by the age of four, inhibition and updating start to differentiate into distinct dimensions (Lee et al., 2013; Monette et al., 2015; van der Ven et al., 2013). While the development of cognitive flexibility typically occurs later, around the age of eight (Hughes et al., 2009; Shing et al., 2010). At this point, children also show improvements in emotional regulation, employing voluntary attentional control and planning strategies to achieve their goals more effectively (Vicari & Di Vara, 2022). By the age of ten, the three core components of executive functioning (inhibition, updating, and cognitive flexibility) are fully differentiated, reflecting increasing specialization within these cognitive domains (Brydges et al., 2014; Lehto et al., 2003).

Challenges in executive functioning are frequently observed in neurodiverse populations such as autistic children (Demetriou et al., 2018; Gentil-Gutiérrez et al., 2022; Tschida & Yerys, 2022), Attention Deficit Hyperactivity Disorder (Craig et al., 2016; Crisci et al., 2021; Khaledi et al., 2019), Specific Learning Disorders (Booth et al., 2010; Reiter et al., 2005; Varvara et al., 2014), and Intellectual Disability (Fidler & Lanfranchi, 2021; Spaniol & Danielsson, 2022). Although it is crucial to highlight that weaknesses in EF performances may also be observed in neurotypical populations (Gathercole et al., 2008). Concerning the autistic children, EF challenges may emerge early in development, and they often persist across the lifespan (Luna et al., 2007; Kouklari et al., 2018; Russo et al., 2007). Regards the EF components, inhibition presented age-related improvements in autistic children, while planning and working memory lacked significant developmental gains compared to typical peers (Kouklari et al., 2018; 2024). Although developmental improvements in EFs occur in autistic individuals at a rate comparable to their neurotypical peers, their overall performance tends to remain lower, with certain developmental periods, such as early childhood and adolescence, revealing more pronounced differences (Happé et al., 2006; Pellicano, 2010; Yeung et al., 2024).

1.6 Challenges in assessing executive functioning: implications for autistic children

1.6.1 Ecological validity issues in EF tasks

Due to the invasive involvement of EFs in daily activities (e.g., reading, calculating, driving, social relationships, etc.), various tools have been developed to evaluate these functions in clinical contexts, employing different methodologies, including performance-based tasks and informant-report instruments, completed by parents or teachers. Informant-reports assess how individuals apply higher-order cognitive skills to manage daily life activities in familiar environments like home or school. Designed to capture behavioral patterns across extended periods, such ratings are often considered to offer a more accurate representation of everyday functioning (Doebel & Müller, 2023; Holochwost et al., 2023). Alternatively, EFs can be evaluated using performance-based tasks that focus on metrics such as accuracy and reaction time. These tasks are generally administered individually under standardized conditions, aiming to elicit deliberate cognitive control. Although consistent evidence suggests that autistic individuals face EF challenges in daily activities,

particularly as reported by parents and teachers, contrasting results emerge when using objective, performance-based measures, highlighting concerns about the ability of traditional measures to capture the real-life challenges these children face (Leung et al., 2016; Jones et al., 2018).

1.6.2 Task impurity and interference effects

Variability in research may be aligned not only to the specific tasks administered and the groups involved (Friedman & Sterling, 2019; Van Eylen et al., 2015), but also to the reductionist approach prevalent in many of the tools designed, which tends to fragment complex, integrative systems into discrete modules (Barrett & Kurzban, 2006; Benso et al., 2025; Bernstein & Waber, 2007; Cohen & D'Esposito, 2016; Pietraszewski & Wertz, 2022). This reductionist perspective has led researchers to examine EFs largely as isolated components, resulting in little consensus regarding how many distinct functions exist or what each entail. For instance, working memory is typically assessed through span tasks like the Digit Span (Wechsler, 2003; 2014), while planning abilities are examined using tasks such as the Tower of London (Shallice, 1982). Cognitive flexibility is often measured with shifting tasks like the Wisconsin Card Sorting Test (Grant & Berg, 1948), and sustained attention and inhibitory control are assessed using subtests from batteries such as the NEPSY-II (Korkman et al., 2007). However, during daily life activities and the execution of tasks, they emerge through the interplay of executive, attentional, and memory processes, acting as transversal components that support higher-order cognition. Furthermore, no single EF can be reliably assessed through one task alone (Karr et al., 2018), as the *task impurity issue* poses a major obstacle to isolating unique executive processes (Benso, 2018; Enkavi et al., 2019; Rabbitt, 1997; Snyder et al., 2015; Tiego et al., 2020; Yangüez et al., 2024). Because task performance inevitably involves multiple cognitive and motor components, shaped by both central and peripheral systems, tools intended to measure specific EFs often recruit additional non-target processes, such as language comprehension or fine-motor control (Benso, 2018; Rabbitt, 1997). Thus, confounding the construct under investigation and increasing measurement error (Benso et al., 2019; Enkavi et al., 2019; Miyake & Friedman, 2012; Snyder et al., 2015; Tiego et al., 2020; Yangüez et al., 2024). This challenge is particularly problematic for autistic children, who often show uneven developmental profiles across these areas (Kouklari et al., 2018). Moreover, Garcia-Molina and Clemente-Estevan (2019) found that autistic children's performance improves significantly when instructions are presented using both verbal and visual modalities. Other studies have demonstrated that autistic individuals often perform better when tasks utilize visual rather than purely verbal instructions (Brunsdon et al., 2015; Cardillo et al., 2020). Similarly, socio-communicative skills have been shown to affect EF task outcomes: differences

between autistic and neurotypical children in tasks involving sorting, inhibition, or visual-spatial working memory diminish when controlling for social-communication abilities (Ellis Weismer et al., 2018). Moreover, Yeung et al. (2020) demonstrated that when linguistic demands are accounted for, autistic children perform comparably to neurotypical peers on fluency tasks. Additionally, challenges with fine motor skills, such as coordination and precision, can hinder performance on EF tasks (Esposito et al., 2011; Fulceri et al., 2019; Staples et al., 2012). Although less extensively studied than linguistic domains, available evidence suggests that motor and sensory factors significantly affect EF performance in autistic populations (Gandotra et al., 2022; Hilton et al., 2014; Joseph & Tager-Flusberg, 2004; Sung et al., 2024). For example, autistic children tend to show lower performance on EF tasks that require motor coordination and rapid movement (Odermatt et al., 2022).

1.6.3 The role of intelligence abilities in cognitive performance

Different intelligence profiles may complicate the accurate identification of real-world challenges, particularly when objective EF measures fail to capture these complexities. Particularly, intelligence quotient (IQ) has been shown to correlate strongly with EF performance in autism (Campbell et al., 2017; Gardiner et al., 2017; Larson et al., 2021). IQ was associated with measures of shifting, such as the Wisconsin Card Sorting Test, in autistic children, while for neurotypicals it correlated with the Digit Span as a measure of working memory (Cruz et al., 2022). Additionally, Han and Chan (2017) observed no significant differences in EF performance between autistic and neurotypical children aged 8-17, regardless of intelligence ability. However, IQ levels seem to be associated primarily with cool EF, such as inhibition, working memory and planning, but not with hot EF aspects, both in neurotypical and in neurodivergent populations (Kouklari et al., 2018).

Research in this area has predominantly focused on autistic individuals with IQ scores above 70, while few studies have explored EF in borderline (IQ between 70 and 85) or low-functioning (IQ below 70) autistic populations. When intelligence abilities are evaluated, no significant differences are reported in the execution of the Wisconsin Card Sorting Test in children with an IQ below 85 (Lung & Bertone, 2023). In contrast, parents of autistic preschoolers with intellectual disabilities reported more pronounced working memory difficulties, as measured by the Behavior Rating Inventory of Executive Function, compared to those without average IQ levels (McClain et al., 2022). These findings highlight the crucial role of intelligence in the development of attention and executive functioning, while also revealing the limitations of current assessment approaches.

1.6.4 The influence of age

Assessing the still-maturing and often unstable attentive-executive functioning skills of preschool and school-aged children poses considerable challenges, particularly given the simultaneous development of other critical domains such as social, motor, and language abilities during childhood (Isquith et al., 2005). These challenges are further amplified in neurodivergent populations, where developmental milestones are often delayed (Kouklari et al., 2018). Many studies examining executive functioning performance span broad age ranges and frequently suffer from the underrepresentation of autistic participants and unbalanced comparison groups, limiting the depth of understanding of EF development in autism. For example, research analyzing wide age brackets, typically from around 6 to 18 years, has reported lower visuospatial working memory performance in autistic individuals (Cardillo et al., 2020; Seng et al., 2021). However, studies adopting a more age-specific approach have identified group differences among younger children up to 10 years old, but not among adolescents (Odermatt et al., 2022). Analyses of differences in performance between children and adolescents, parental assessments indicate that difficulties with inhibition are more pronounced in younger children (aged 6 to 8 years), whereas challenges with planning become increasingly evident during early adolescence (aged 12 to 14 years; Van Den Bergh et al., 2014). Similarly, Alsaedi et al. (2020) found that among children aged 6 to 12 years, planning emerges as the most difficult domain, followed by working memory, emotional control, self-monitoring, initiation, shifting, and the overall index of emotional regulation. Other research has highlighted those difficulties with shifting, planning, monitoring, and organizing materials are particularly prevalent in adolescents aged 14 to 18 years (Tschida & Yerys, 2022). Among these, shifting consistently emerges as the most challenging domain for autistic children, according to both parental reports and self-assessment measures (Granader et al., 2014; Kenworthy et al., 2022; Van Eylen et al., 2015).

1.6.5 The influence of emotion-regulation on cognitive task performance

Emotional regulation is a frequently overlooked but crucial factor influencing EF task performance. It refers to the ability to manage emotions, behaviors, and impulses to achieve goals or respond adaptively to challenges (Bausela-Herreras, 2024; Kälin & Roebers, 2021). Some authors suggest that socio-cognitive abilities like emotion regulation, emotional intelligence, or moral judgment could be included in the category of hot EFs (Anderson, 2010; Zimmerman et al., 2016), while others consider these processes closely linked to, but do not belong to hot EFs (Kouklari et al., 2017, 2018,

2019; Yu et al., 2021; Zelazo et al., 2005). Although EFs and self-regulation are distinct, they are closely related-self-regulation depends heavily on EFs, encompassing processes like impulse control and emotional modulation, which are often impaired in autism (Conner et al., 2021; Samson et al., 2015). In novel or demanding situations, autistic individuals commonly experience emotional dysregulation, which can lead to increased anxiety, agitation, and impaired cognitive performance (Bellato et al., 2021; Lory et al., 2020). Also, Kenworthy et al. (2020) argued that performance on traditional flexibility and planning tasks, involving emotional components such as emotion-laden or socially provocative contexts, can better distinguish autistic youth from neurotypicals. The significance of emotional regulation on EF tasks was first highlighted by Damasio (1995), who proposed the somatic marker hypothesis: effective decision-making requires linking cognitive processes to emotionally grounded bodily signals. In populations in which this connection is missing, such as autistic children, behavioral regulation becomes severely challenged (Alexandropoulou, 2021). Therefore, evaluating EF in autism should also account for emotional regulation, offering more ecologically valid insights into autistic individuals' EF profiles.

1.7 Multidimensional approaches to assess executive functions in neurodivergent children

Given these challenges faced in assessing executive attention functions in autism, there is a crucial need for context-sensitive, non-reductionist tools, moving beyond the limitations of traditional neuropsychological measures. To address these theoretical and methodological complexities, broader and more integrative models have been proposed in various neurodevelopmental disorders, yielding promising results and supporting their potential utility in clinical practice. For example, using a multidimensional assessment of EFs in ADHD, it was found that EFs could be represented as consecutive cognitive processes instead of distinct and fractionated domains (Crippa et al., 2015). They suggest that perform a goal-directed behavior requires a child to implement sequential steps that implicate various cognitive processes: regulating impulsive behaviors (inhibition), understanding and internalizing the rules of the task (memory), formulating a strategy (planning), carrying out the sequence of actions (execution), and finally, evaluating whether the goal has been achieved by reviewing the task's guidelines. Other applications of multidimensional approaches to study EFs involved children with specific learning disorders (Pasqualotto et al., 2024; Pasqualotto & Venuti, 2020). Pasqualotto et al. (2024) found that the nature of reading abilities is derived from a complex

interaction between reading speed processes, attentional control, working memory, and verbal fluency, providing distinct clusters of participants. However, multidimensional frameworks have never been applied in autistic populations. Exploring executive attention in autism through a broader perspective is essential for gaining deeper insights into the heterogeneity of cognitive processes and behavioral outcomes, contributing to a more nuanced understanding of executive attention challenges in autism. Additionally, it could help clarify the complex interplay between behavioral and emotional regulation in neurodivergent children, thereby informing more accurate assessments and interventions.

1.8 Exploring executive attention abilities in autism: objectives of the project

The existing literature on EF performance in autistic children remains controversial and inconsistent. These inconsistencies stem not only from variability in how participant groups are characterized but also from the predominant reliance on reductionist approaches to EF assessment. Despite the close interdependence among multiple EFs and broader cognitive abilities, most existing measures employ single-task paradigms intended to isolate specific EF components. Moreover, disentangling discrete executive processes is inherently difficult, as task performance typically engages multiple interacting cognitive domains, including linguistic and fine-motor skills. To address these limitations, there is a need for more context-sensitive clinical measures of executive functions. Thus, this thesis aims to deepen our understanding of EFs assessment in neurodivergent populations, particularly in autistic children, by applying a multidimensional framework, namely Executive Attention (Engle, 2018; Kane et al., 2001; Petersen et al., 2012; Petersen & Posner, 2012).

The *first objective* (*Chapter 2*) is to examine the associations between autistic traits and EF performance using traditional, performance-based tasks, with particular attention to the mediating roles of intelligence and the role of demographic variables in autistic children.

The *second objective* (*Chapter 3*) is to identify the latent constructs underlying a set of novel performance-based tasks selected from the *Measures of Executive Attention (MEA) battery* (Benso et al., 2019), applied to a neurodiverse sample. The MEA battery is specifically designed to minimize task impurity and provide a more functional valid assessment of executive function profiles in children and adolescents.

The *third objective* (*Chapter 4*) is to examine the convergence between performance-based tasks were drawn from the MEA battery and a well-established parent-report measure of executive functioning in neurodiverse school-aged children.

The *fourth objective* (*Chapter 5*) is to assess executive attention in neurodivergent populations, focusing primarily on school-aged autistic children, through a multidimensional battery of tasks not yet used in the autistic population. Similarities and differences in executive attention performance and age-related changes across groups (autistic children, neurotypicals, and children with specific learning disorders) are explored. Additionally, the percentages of successes and failures in the task's completion are analyzed between neurotypical and neurodivergent children.

The *fifth objective* (*Chapter 6*) is to identify specific patterns of performance on executive attention measures in relation to cognitive abilities (intelligence, language, and fine motor skills) within the neurodiverse population.

Finally, a general discussion of the findings, including clinical and research implications of the project (*Chapter 7*), is provided.

Chapter 2

Executive functions and autistic traits: the mediating role of intelligence quotient and developmental trajectories[2]

Summary

Earlier studies have examined how Executive Functions (EFs) relate to autistic traits, such as social skills and restricted and repetitive behaviors (RRBs). Although some consistent findings come from measures in the same settings, especially parent reports, results from studies combining performance-based tasks and parent reports have been mixed. This research explored the

[2] This chapter is an extended version of:

Anderle, F., Barbieri, R., Pasqualotto, A., Bentenuto, A., & Venuti, P. (2025). Linking cognitive flexibility, planning, and autistic traits: The mediating role of cognitive abilities. *Research in Developmental Disabilities*. https://doi.org/10.1016/j.ridd.2025.105136

Anderle, F., Venuti, P., & Bentenuto, A. (under review). From childhood to adolescence: A cross-sectional examination of cognitive profiles and autistic traits in neurodiverse children. *Research in Neurodiversity*

My contribution in these works: conceptualization, study design and methodology, data extraction, curation and preparation, formal and data analysis, manuscript first draft writing, and manuscript review and editing

associations between EFs and autistic traits, with a focus on whether intelligence quotient (IQ) act as a mediator. 110 autistic children aged 4 to 17 (33 with IQ below 85 and 77 with IQ 85 or above) were evaluated using an extensive neuropsychological battery, including the Wechsler Intelligence Scales, EF tasks like the Wisconsin Card Sorting Test and Tower of London, clinician assessments (ADOS-2), and parent questionnaires (SRS-2) for autistic traits. Findings revealed significant positive associations between cognitive flexibility and clinician-rated RRBs, but a negative link between planning abilities and parent-reported autistic traits. Notably, the total IQ score, driven by the Wechsler Scales, mediated the relations between cognitive flexibility, planning, and clinician-rated social-communication skills. Participants with lower IQ scored worse on most EF tasks, except for shifting errors and planning task timing, and clinicians noted higher social-communication challenges. Additionally, age-related analyses in the higher IQ group revealed stable cognitive flexibility functions across ages, while planning skills improved gradually through adolescence. Besides, socio-communication challenges increased during early adolescence as reported by parents, while clinicians observed RRBs declined in late adolescence. These results highlight inconsistencies between performance-based EF tests and autistic traits reported by parents and clinicians. Crucially, IQ substantially impacts clinical evaluations of EF and social communication, emphasizing the need for more sensitive, ecologically valid neuropsychological assessments. However, IQ did not affect clinician-rated RRBs or parent reports, indicating these behaviors may be independent of overall cognitive functioning.

Keywords

Executive functions, cognitive flexibility, planning, autism, social-communicative, restricted and repetitive behaviors, intelligence quotient

Key points

- Cognitive flexibility is positively associated with clinician-rated restricted and repetitive behaviors, while planning abilities are negatively linked to parent-reported autistic traits.
- IQ mediate the relation between executive functions and social-communication difficulties as reported by clinicians.
- Children with lower IQ scores perform worse on most executive function tasks, but no significant IQ-related differences are found in clinician-rated RRBs or parent-reported autistic traits.

- Stability in cognitive flexibility across ages, while improvement in planning occur over time.
- Parents report increasing socio-communication issues, while clinicians observed RRBs declined in adolescence.

2.1 Introduction

2.1.1 The link between executive functions and autistic traits

Autistic children display varied cognitive profiles, with challenges in executive functioning. Studies have documented persistent differences in cognitive flexibility between autistic and neurotypical individuals from early childhood (Gardiner et al., 2017), through school age (Panerai et al., 2014), and into adolescence (Robinson et al., 2009), confirming the lasting nature of these difficulties across development and contexts. Additionally, inhibitory control is notably challenging, especially in childhood (Tschida & Yerys, 2022; Van Den Bergh et al., 2014). Moreover, Robinson et al. (2009) found that autistic children made more perseverative errors on the Wisconsin Card Sorting Test, suggesting difficulties in self-monitoring and adapting behavior based on feedback. Other components of EFs that autistic children often struggle with are planning and problem-solving, particularly in adolescence (Van Den Bergh et al., 2014). They frequently show weaker performance on planning tasks, taking longer to complete them due to co-occurring challenges with flexibility (Craig et al., 2016; Unterrainer et al., 2016). Interestingly, their performance improves when tasks require less advanced planning, pointing to specific difficulties in strategy implementation (Unterrainer et al., 2016). EFs are thought to support not only learning and academic success, but also key behavioral domains in autism, including social communication and restricted, repetitive behaviors (RRBs).

Associations between executive functions and social abilities

Challenges in social communication and interaction, such as interpreting nonverbal signals, managing reciprocal exchanges, and regulating emotional expression, have been consistently linked to EF performance in autistic children (Torske et al., 2018). Among EF domains, cognitive flexibility appears especially critical, as challenges in shifting between perspectives or adapting to changing

social demands may compromise the fluid navigation of social interactions (Panerai et al., 2014; Pugliese et al., 2016). Deficits in this area can heighten interpersonal difficulties by limiting responsiveness to dynamic social cues. Beyond flexibility, behavioral regulation skills, particularly inhibition, emotional control, and shifting, have also been associated with fewer social challenges across both autistic and neurotypical populations (Leung et al., 2016). Metacognitive EF components, including planning, working memory, and self-monitoring, further contribute to social functioning, although the strength and consistency of these relationships vary (Tsermentseli et al., 2018). Such variability may stem in part from differences in how EF and social outcomes are measured, as tools vary in ecological validity and the types of behaviors they capture. Clinician-administered instruments like the Autism Diagnostic Observation Schedule-2 (ADOS-2) assess observable behaviors in controlled environments, whereas parent-report measures such as the Social Responsiveness Scale-2 (SRS-2) offer insight into everyday social functioning. Notably, studies employing ecologically valid, informant-based tools, such as the Behavior Rating Inventory of Executive Function (BRIEF) for EF and the SRS-2 for social behaviors, tend to demonstrate stronger and more consistent associations between EF and social communication (Leung et al., 2016). Conversely, research combining performance-based EF tasks with observational or parent-report measures often yields weaker or inconsistent findings. For instance, BRIEF scores were not significantly correlated with ADOS-2 clinician ratings (Leung et al., 2016), and Jones et al. (2018) found no relationship between EF task performance and parent-reported autistic traits in adolescents. These discrepancies underscore the importance of considering ecological validity when interpreting EF-social behavior links. Tools used in structured settings may not fully capture the complexities of real-world social functioning. Nevertheless, across diverse methodologies, cognitive flexibility and behavioral regulation consistently emerge as core contributors to social-communicative outcomes in autism, more so than metacognitive processes like planning or working memory alone. This suggests that interventions targeting flexibility and self-regulation may be especially effective in enhancing social functioning in autistic individuals.

Associations between executive functions and restricted and repetitive behaviors

RRBs constitute a second major characteristic of autism and encompass a broad spectrum of actions. These are typically categorized into two groups: higher-order behaviors, such as a preference for sameness, adherence to rituals, and intense, narrow interests; and lower-order behaviors, including repetitive motor actions and unusual sensory interests (Faja & Nelson Darling, 2019).

A number of studies have identified associations between RRBs and EF components, especially cognitive flexibility and inhibitory control. For example, difficulties with cognitive flexibility have been linked to insistence on sameness in children and adolescents between the ages of 8 and 18 (Geurts et al., 2009; Van Eylen et al., 2015). Similarly, deficits in inhibition and self-control appear to relate to sensory and motor repetitive behaviors, indicating that challenges in these EF areas may contribute to problems with overriding automatic or habitual responses (Lopez et al., 2005; Mostert-Kerckhoffs et al., 2015). Although the role of planning has been explored less frequently, some research suggests that impairments in planning are also related to heightened levels of RRBs (Bölte et al., 2011). Importantly, Faja and Nelson Darling (2019) and Iversen et al. (2021) observed these EF-RRB relationships across a wide age span, from early childhood to young adulthood (ages 4-29), implying that these connections are developmentally persistent. Nonetheless, findings across studies are not entirely consistent, particularly when comparing outcomes from structured EF tasks to real-world expressions of behavioral inflexibility. This discrepancy may highlight the distinction between EFs in controlled settings versus everyday environments. Gaining a clearer understanding of how specific EF components relate to various RRB types may contribute to more targeted and effective strategies to support flexibility and self-regulation.

2.1.2 The complex interplay between autistic traits, executive functions and cognitive abilities

Intelligence quotient (IQ) is widely recognized as being closely associated with EFs (Campbell et al., 2017; Gardiner et al., 2017; Larson et al., 2021), as well as with socio-communicative abilities and socialization skills in autism (Itskovich et al., 2021; Joseph et al., 2002; Syriopoulou-Delli et al., 2018). For example, Gardiner et al. (2017) found no EF differences between autistic and neurotypical preschoolers when matched on IQ score. Similarly, Zacharov et al. (2021) showed that non-verbal mental age predicted flexibility outcomes. Campbell et al. (2017) further demonstrated that non-verbal, rather than verbal, intelligence was a key predictor of cognitive flexibility in autistic youth aged 5 to 19. However, a meta-analysis by Olde Dubbelink and Geurts (2017) indicated that planning performance was not significantly influenced by IQ, suggesting that not all EF domains depend on intelligence abilities in the same manner. Additionally, lower nonverbal intelligence is associated with greater social challenges (Joseph et al., 2002; Syriopoulou-Delli et al., 2018), while higher IQ supports better generalization of learned social skills into everyday life (Ben-Itzchak et al., 2014). Despite the associations found between IQ, EFs and social constructs, limited research has explored how the IQ index may influence the relationship between EFs and autistic traits. Prior research has

indicated that certain EFs, particularly inhibition and cognitive flexibility, may help explain the link between autistic traits and challenges in behavioral regulation (Faja & Dawson, 2015). However, the potential mediating influence of the broader intellectual level has received relatively little attention, especially in autistic youth. Since both executive functioning and autistic traits have been associated with general intelligence skills, the present study examines whether IQ acts as a mediator in the relationship between EFs and autistic traits. Investigating this possibility can help determine whether the observed links are driven by specific executive deficits or reflect a broader intelligence profile. This mediation framework offers a novel perspective on the cognitive mechanisms underlying EF challenges in autism and their connection to social and behavioral traits.

2.1.3 The development of autistic traits, executive functions and intelligence abilities

Changes across the lifespan are frequently observed in autistic traits, intelligence abilities, and EF domains. Research consistently shows that restricted and repetitive behaviors in autistic children tend to decrease in frequency and severity with age (Berry et al., 2018; Esbensen et al., 2009). Moreover, longitudinal studies provide evidence of substantial developmental shifts in the socio-communication domain, though the pace and extent of progress often depend on individual IQ profiles (Fountain et al., 2023; Smith et al., 2012). For example, autistic individuals diagnosed in childhood with average IQ were later evaluated at age 19 as functioning socially like their neurotypical peers (Lord et al., 2015). Overall, higher IQ score is associated with more pronounced developmental gains, while those with more severe autistic traits tend to show more stable or slower-changing adaptive behaviors (Smith et al., 2012; Szatmari et al., 2015). IQ also tend to improve during adolescence for many autistic individuals. However, such intelligence gains do not always correspond with reductions in autistic traits, especially across the age range of 12 to 23 years (Simonoff et al., 2020). A broader review of longitudinal research, from childhood to late adolescence, similarly suggests mixed outcomes: while some studies indicate stability in social functioning, intelligence abilities, and language skills, others report improvements in adaptive functioning and a decline in the severity of autism-related behaviors over time (Magiati et al., 2014).

Regarding EFs, studies report significant differences primarily in younger groups, with fewer distinctions observed among adolescents (see **Chapter 1, Section 1.6.4** for further details). Some changes across development are reported in EF for autistic children; however, inconsistency in results emerged due to the study design, participants' demographic characteristics, methodologies, and measurement tools. For example, parent reports underscore that planning differences become more

apparent during adolescence (ages 12-14) (Tschida & Yerys, 2022; Van Den Bergh et al., 2014). In contrast, a study using performance-based tasks suggests improvement in planning skills with age (Kouklari et al., 2018). While results on planning remain mixed, cognitive flexibility appears to be the most impaired ability among autistic children and adolescents, according to various contextual measures (Granader et al., 2014; Kenworthy et al., 2022; Van Eylen et al., 2015).

2.1.4 Aims and hypotheses

This study aims to analyze the associations between EFs and autistic traits as reported by parent and clinician ratings, encompassing both social-communicative skills and restricted and repetitive behaviors, and whether these relations and performances differ among autistic children with higher and lower IQ levels. Moreover, it investigates the mediating role of IQ in these associations. Finally, it explores the developmental changes within autistic children with average IQ across intelligence skills, executive functions, and autistic traits, using consistent tools.

Stronger associations for EFs with IQ, as reported consistently in the literature (Campbell et al., 2017; Gardiner et al., 2017; Larson et al., 2021), as well as between socio-communication and intelligence skills (Itskovich et al., 2021; Joseph et al., 2002; Syriopoulou-Delli et al., 2018), are hypothesized. In contrast, it is anticipated to find weaker and generally non-significant correlations between EF measures and autistic traits, assessed primarily by parent measures (Leung et al., 2016; Jones et al., 2018). Moreover, it is expected to observe a mediating role of IQ in these associations with different associations based on participants' IQ levels, with stronger links in children with above-average IQ scores. In consequence, higher EF performance, intelligence abilities, and lower autistic traits in children with above-average IQ scores are anticipated. Finally, distinct age-related changes across intelligence, executive, and behavioral domains are expected. Specifically, relative stability in intelligence profiles over time (Magiati et al., 2014), alongside improvements in autistic traits (Esbensen et al., 2009; Berry et al., 2018; Lord et al., 2015), are anticipated. Enhancements in social and communication abilities are expected, aligning with earlier findings (Fountain et al., 2023; Smith et al., 2012), along with a decrease in RRBs (Chowdhury et al., 2010; Esbensen et al., 2009). Moreover, higher performance in planning tasks (Kouklari et al., 2018), but relative stability in shifting tests (Granader et al., 2014; Kenworthy et al., 2022; Van Eylen et al., 2015) is anticipated.

2.2 Methods

2.2.1 Participants

The study involved 110 autistic participants aged 4 to 17. Autistic children were recruited at the ODFLab (Laboratory of Observation, Diagnosis, and Education), part of the Department of Psychology and Cognitive Science at the University of Trento in Rovereto, Italy. ODFLab is a research and clinical center, offering families and individuals functional assessments as well as access to therapeutic programs. Specifically, the study included analyses drawn on neuropsychological assessments carried out during routine clinical evaluations at the specialized center. Notably, it relied exclusively on existing clinical data and did not conduct any additional testing specifically for research purposes. However, only children who had completed a Wechsler Intelligence Scale assessment were included in the study (Fancello & Cianchetti, 2008; Orsini et al., 2013; Orsini et al., 2015; Saggino et al., 2019).

The diagnosis of Autism Spectrum Disorders (ASD) was confirmed through clinical judgment by an independent clinician based on the DSM-5 criteria for autism spectrum disorder as well as through the administration of the Autism Diagnostic Observation Schedule (ADOS-2; Lord et al., 2012). Following the diagnostic assessment, children diagnosed with ASD are assigned a severity level based on their adaptive functioning in various contexts (e.g., school, clinical setting, home) and the level of support they require. The DSM-5 defines three levels of severity: level 1 (requiring support), level 2 (requiring substantial support), and level 3 (requiring very substantial support). In the present sample, no one received a level 3 of severity (see **Tables 2.1** and **2.2**). At the time of diagnosis, clinicians also indicate whether the child presents intellectual impairment, typically identified through significantly below-average scores on standardized intelligence assessments, and/or language impairment, characterized by difficulties in articulation, comprehension, or expressive language, relative to neurotypical peers (see **Tables 2.1** and **2.2** for the distribution of the sample).

Additional analyses were conducted by dividing the sample based on IQ score. Given that the Wechsler Scales (Fancello & Cianchetti, 2008; Orsini et al., 2013; Orsini et al., 2015; Saggino et al., 2019) are the standard tool for assessing intellectual functioning in children in Italy, these measures were used to stratify our sample. Moreover, scores are calculated using age-specific norms, enabling comparisons across the different instruments. In consequence, the sample was divided into children with *lower-IQ*, which means with borderline intellectual functioning or below (IQ < 85, $n = 33$) and

with *higher-IQ*, which means average or upper IQ score (IQ ≥ 85, n = 77). No age differences were found between subgroups (p = .33).

Finally, due to the significant changes in cognitive profiles during development, the evolutionary trajectories across intelligence, EFs, and behavioral domains were explored. These developmental trajectories were examined only in the *higher-IQ subgroup* (n = 77) because of the strong associations observed between IQ with EFs and autistic traits and the low numerosity of participants in the group with *lower IQ* that may influence results.

Table 2.1 *Samples' demographic characteristics*

Characteristics	***n***	**M**	**SD**	**min**	**max**
Age (in years)	110	9.85	3.06	4	17
Intelligence abilities					
Total IQ	110	95.3	19.82	53	146
Visual-spatial	110	105.36	18.56	67	148
Verbal comprehension	110	100.59	18.97	54	146
	n	**%**			
Sex					
Males	95	86.4			
Females	15	13.6			
Severity level					
1	86	78.2			
2	24	21.8			
Intellectual level					
Without Intellectual Deficits	94	85.5			
With Intellectual Deficits	16	14.5			
Linguistic level					
Without Linguistic Deficits	108	98.2			
With Linguistic Deficits	2	1.8			
Comorbidity					
Without comorbidity	96	87.3			
With comorbidity	14	12.7			
ADHD	2	14.3			
Motor tic	1	7.1			
Stammering	1	7.1			
Coordination	2	14.3			

Depression	1	7.1
SLD	7	50

Note. ***IQ*** *= Intelligence Quotient.* ***n*** *= subjects;* ***M*** *= mean;* ***SD*** *= standard deviation;* ***min*** *= minimum score;* ***max*** *= maximum score.* ***ADHD*** *= Attention Deficit Hyperactivity Disorder,* ***SLD*** *= Specific Learning Disorders.*

Table 2.2 *Samples' demographic characteristics based on IQ level groups*

Characteristics	**Lower IQ**					**Higher IQ**				
	n	**M**	**SD**	**min**	**max**	***n***	**M**	**SD**	**min**	**max**
Age (in years)	33	9.52	2.72	5	16	77	10	3.2	4	17
Intelligence abilities										
Total IQ	33	71.67	9.15	53	84	77	105.43	13.48	86	146
Visual-spatial	33	87.06	12.03	67	113	77	113.21	15	82	148
Verbal comprehension	33	80.91	10.82	54	98	77	109.03	15.05	82	146
	n	**%**				***n***	**%**			
Sex										
Males	31	94				64	83			
Females	2	6				13	17			
Severity level										
1	15	45				71	92			
2	18	55				6	8			
Intellectual level										
Without Intellectual Deficits	17	52				77	100			
With Intellectual Deficits	16	48				0	0			
Linguistic level										
Without Linguistic Deficits	32	97				76	99			
With Linguistic Deficits	1	3				1	1			
Comorbidity										

Without comorbidity	31	94	65	84
With comorbidity	2	6	12	16
ADHD	0	0	2	16.7
Motor tic	0	0	1	8.3
Stammering	1	50	0	0
Coordination	1	50	1	8.3
Depression	0	0	1	8.3
SLD	0	0	7	58.4

***Note. IQ** = Intelligence Quotient. **n** = subjects; **M** = mean; **SD** = standard deviation; **min** = minimum score; **max** = maximum score. **ADHD** = Attention Deficit Hyperactivity Disorder, **SLD** = Specific Learning Disorders.*

2.2.2 Procedure

This study was conducted in accordance with the ethical guidelines of the Italian Association of Psychology (AIP), the Declaration of Helsinki (World Medical Association, 2013) and was approved by both the Ethics Committee of the University of Trento and the Trento Health Authority (APSS, Prot. A924). It involved the analysis of clinical reports from individuals who underwent psychodiagnostic evaluations at the ODFLab in Rovereto (Italy) between 2014 and 2025. Inclusion criteria required that the assessment comprise a standardized battery of neuropsychological instruments: the Wechsler Intelligence Scale, the Wisconsin Card Sorting Test (WCST), the Tower of London (ToL), the Autism Diagnostic Observation Schedule-Second Edition (ADOS-2), and the Social Responsiveness Scale-Second Edition (SRS-2).

2.2.3 Materials

Intelligence abilities

The *Wechsler Intelligence Scales* are clinical tools for assessing cognitive abilities suitable for individuals aged 2 to 90. The Wechsler Scales are standardized scales with satisfactory validity and reliability (Fancello & Cianchetti, 2008; Orsini et al., 2013; Orsini et al., 2015; Saggino et al., 2019). Different versions of the Wechsler Scales were administered according to participants' age. Specifically, 8 children completed the WPPSI-III for Preschoolers (Fancello & Cianchetti, 2008), 4

completed the WPPSI-IV for Preschoolers (Saggino et al., 2019), 95 completed the WISC-IV for Children (Orsini et al., 2015), and 3 completed the WAIS-IV for Adults (Orsini et al., 2013).
The batteries yield a total IQ index derived from the administration of multiple tests that assess four broad cognitive domains: Verbal Comprehension, Visual-Spatial ability, Working Memory, and Processing Speed. The total IQ score (refers as IQ or total IQ in the text) was used in the present study as the mediator in the relations between EFs and behavioral domains, as well as the index to divide the sample into subgroups (*lower vs higher-IQ*). The Verbal Comprehension (VC) index gives information about the child's ability to access and apply acquired word knowledge, while the Visual-Spatial (VS) domain provides the child's ability to nonverbal reasoning and concept formation, visual perception and organization, analyze and synthesize abstract information, visual-motor coordination. Additionally, the Working Memory (WM) index assesses the ability to retain and manipulate new information while maintaining sustained attention during task execution. In contrast, the Processing Speed (PS) domain evaluates the capacity to maintain focused attention and to flexibly shift attention across visual stimuli. These two indices were included solely to examine developmental changes in cognitive profiles in autistic children. They were excluded from earlier analyses due to their strong overlap with broader executive functioning, which could confound the interpretation of the results. The batteries provide standard scores (*M=100, SD=15*) for the total IQ score as well as for the four dimensions of intelligence.

Autistic traits

The *Autism Diagnostic Observation Schedule-Second Edition* (ADOS-2; Lord et al., 2012) is a semi-structured observational assessment designed to evaluate behaviors associated with autism spectrum disorder. It focuses on two main domains aligned with the Diagnostic and Statistical Manual of Mental Disorders-Fifth Edition (DSM-5, American Psychiatric Association, 2013) criteria: Social Affect (Social), which includes nonverbal communication skills such as eye contact, gestures, and social engagement, and Restricted and Repetitive Behaviors (RRBs), such as stereotyped movements and fixated interests. The assessment provides scores that classify individuals as falling within the Autism, Autism Spectrum, or non-spectrum range, along with a severity metric. Higher scores reflect a greater presence of autism-related traits. The ADOS-2 comprises five modules, each selected according to the child's age and expressive language abilities.

The *Social Responsiveness Scale-Second Edition* (SRS-2; Constantino & Gruber, 2005; Constantino, 2012) is a parent-report questionnaire with good psychometric properties, designed to assess social

functioning and autism-related behaviors in children aged 4 to 18. It includes 65 items divided into five subscales: social awareness, social cognition, social communication, social motivation, and autistic mannerisms. A total raw score of 65 or above indicates a positive screening for ASD. For this study, raw scores were converted into standardized *T-scores (M = 50, SD = 10)* using the SRS-Second Edition. This allowed to calculate the Social Communication Index (Social), which combines the social awareness, cognition, communication, and motivation subscales, and the Restricted and Repetitive Behaviors (RRBs) domain, reflecting the autistic mannerisms component, in line with DSM-5 criteria (American Psychiatric Association, 2013). Notably, not all parents completed the questionnaires (SRS-2), resulting in 23 missing data.

Executive functions

The *Wisconsin Card Sorting Test* (WCST; Hardoy et al., 2000) is a well-established neuropsychological tool used to assess EFs, especially cognitive flexibility, abstract reasoning, and the capacity to develop and adapt problem-solving strategies in response to changing environmental demands. It is suitable for individuals aged 6 to 70. The *Modified Card Sorting Test* (MCST; Fancello & Cianchetti, 2003) is the adapted version suitable for younger children (aged 4 to 13). Both versions include four target cards and multiple response cards to be matched. The main distinction between the two versions lies in the number of cards to be sorted: 128 in the WCST and 48 in the MCST. The examiner provides feedback on whether the sorting strategy used (based on color, shape, or number) is correct or incorrect. Participants must correctly sort six cards for the MCST or ten for the WCST using the same rule before the rule changes. Several indices were calculated, including the number of categories completed, the number of cards used, total correct responses, total errors, perseverative errors (repeated application of an outdated rule), non-perseverative errors (incorrect attempts at new rules). These measures provide standardized *z-scores* (*M = 0, SD = 1*). Both versions are standardized and exhibit good reliability and validity (Fancello & Cianchetti, 2003; Hardoy et al., 2000).

The *Tower of London* (ToL; Fancello et al., 2006; Gugliotta, 2009) is a standardized neuropsychological task designed to evaluate EFs, particularly planning and problem-solving abilities, in children aged 4 to 17. Depending on the participant's age, one of two versions was used to align scoring with Italian normative data (Fancello et al., 2006; Gugliotta, 2009). Both versions have demonstrated solid reliability and validity. The test consists of a board with three pegs of varying heights and three colored beads. The child is required to rearrange the beads from an initial setup to match a target configuration, increasing in complexity, while adhering to specific movement rules.

Performance is measured using several indicators: decision time (the interval between viewing the target configuration and initiating the first move), execution time (the time taken to complete the task), total time, number of rule violations, and points (number of moves needed to reach the solution). Most scores are expressed as standardized *T-scores* (*M = 50, SD = 10*), while total points were converted into standardized *z-scores* (*M = 0, SD = 1*) to have a comparable value between versions due to the task suitable for older participants provided only this parameter (Gugliotta, 2009).

2.2.4 Analytic plan

Descriptive statistics for all variables included in the study are presented in **Table 2.3** (full sample), while **Table 2.4** provides corresponding data for the subgroups.

Table 2.3 *Sample's descriptive analysis*

Variables	*n*	M	SD	min	max
Autism Diagnostic Observation Schedule					
Social Affect	110	8.8	2.81	2	16
RRBs	110	1.99	1.42	0	6
Total score	110	10.8	3.34	2	21
Social Responsiveness Scale					
Social domain	87	74.9	17.08	44	119
RRBs	87	77.3	18.45	44	121
Total score	87	76.47	17.6	44	122
Wisconsin Card Sorting Test					
Categories	108	-0.4	1.3	-4.88	1.83
Cards	101	-0.11	0.96	-1.82	2.61
Correct Responses	109	-0.51	1.39	-5.66	2.13
Errors	109	-0.42	1.24	-3.99	1.69
Perseverative errors	109	-0.79	2	-10.48	1.55
Other errors	109	0.1	0.94	-3.06	2.38

Tower of London					
Decision time	89	51.22	9.42	40	100
Execution time	82	55.95	13.43	36	100
Total time	89	55.47	12.65	36	100
Rules violation	89	83.62	20.33	32	100
Points	102	-1.04	1.51	-5.01	1.57

***Note. n** = subjects; **M** = mean; **SD** = standard deviation; **min** = minimum score; **max** = maximum score. **RRBs** = Restricted and repetitive behaviors.*

***Table 2.4** Subgroups' descriptive analyses*

		Lower IQ					**Higher IQ**			
Variables	***n***	**M**	**SD**	**min**	**max**	***n***	**M**	**SD**	**min**	**max**
Autism Diagnostic Observation Schedule										
Social Affect	33	10.27	2.81	5	16	77	8.17	2.59	2	15
RRBs	33	2.27	1.33	0	6	77	1.87	1.45	0	6
Total score	33	12.58	3.19	6	21	77	10.04	3.12	2	19
Social Responsiveness Scale										
Social domain	26	73.88	17.49	44	106	61	75.33	17.03	44	119
RRBs	26	78.46	19.78	44	108	61	76.8	18	47	121
Total score	26	75.92	18.2	44	107	61	76.7	17.49	46	122
Wisconsin Card Sorting Test										
Categories	32	-0.98	1.26	-4.46	1.12	76	-0.16	1.24	-4.88	1.83
Cards	31	-0.44	0.68	-1.82	2.61	70	0.04	1.04	-1.59	2.51
Correct Responses	32	-1.37	1.58	-5.66	1.61	77	-0.15	1.14	-3.44	2.13
Errors	32	-1.22	1.22	-3.99	1.39	77	-0.09	1.09	-3.32	1.69
Perseverative errors	32	-2.13	2.61	-10.48	1.27	77	-0.23	1.36	-4.33	1.55
Other errors	32	-0.04	0.88	-2.15	1.29	77	0.15	0.97	-3.06	2.38
Tower of London										
Decision time	25	49.32	5.79	40	63	64	51.97	10.45	40	100

Execution time	24	58.42	13.66	39	100	58	54.93	13.32	36	86
Total time	25	57.28	11.99	39	95	64	54.77	12.92	36	100
Rules violation	25	93.36	14.29	45	100	64	79.81	21.15	32	100
Points	28	-1.98	1.38	-4.02	0.94	74	-0.69	1.41	-5.01	1.57

***Note. IQ** = Intelligence Quotient. **n** = subjects; **M** = mean; **SD** = standard deviation; **min** = minimum score; **max** = maximum score. **RRBs** = Restricted and repetitive behaviors.*

Data distributions were examined using Shapiro-Wilk tests for homogeneity and Levene's test for homoscedasticity across executive functions (ToL and WCST scores), autistic traits (social affect, restricted and repetitive behaviors, total score as calculated by ADOS-2 and SRS-2), intelligence abilities (verbal comprehension, visual-spatial skills, and total IQ driven by Wechsler Intelligence Scales), and demographic variables (age and sex). Because the data violated normality and homogeneity of variance assumptions, non-parametric statistical methods were applied to reduce the influence of outliers and address the unbalance group sizes between lower and higher-IQ participants. To investigate associations among the various measures, the non-parametric Spearman correlation analyses were employed across the full sample, followed by subgroup analyses. Additionally, multiple regression analyses were performed using Generalized Linear Models (GLMs) with Gaussian distribution to assess the influence of covariates (sex, age, verbal comprehension, and visual-spatial skills) on the relation between EF outcomes and autistic traits (social affect and RRBs as predictors), again across the full sample, followed by subgroup analyses. The syntax used was:

```
model <- glm(outcome ~ predictor + sex + age + verbal comprehension index + visual-spatial index, family = gaussian)
```

Multicollinearity was evaluated in each model, with variance inflation factors (VIFs) remaining below the threshold of 10, indicating no multicollinearity concerns. Given the significant associations observed between EFs and autistic traits with intelligence abilities, mediation analyses using GLMs to explore the potential mediating role of the total IQ score (controlling for sex and age) were conducted. Additionally, bootstrapping with 1000 resamples were applied to account for non-normality and sample size limitations. The syntax used was:

```
med_model <- glm(IQ ~ predictor + sex + age, family = gaussian)
out_model <- glm(outcome ~ predictor + IQ + sex + age, family = gaussian)
med <- mediate(med_model, out_model, treat = "predictor", mediator = "QIT", boot = TRUE, sims = 1000)
```

Moreover, Wilcoxon signed-rank tests were used to compare EF performance, autistic traits, and intelligence abilities between the lower and higher IQ groups.

Additionally, considering the strong associations between age and most key variables, developmental changes were explored only within the higher IQ subgroup to account for intelligence influence. Firstly, GLMs between various measures and age were conducted, using the following syntax:

```
model <- glm(outcome ~ predictor, family = gaussian)
```

Then, this subgroup was divided into four age bands (4-7, 8-10, 11-13, and 14-17 years), corresponding to major developmental milestones in neurotypical children (Gioia et al., 2015), to examine age-related variations in executive functions, intelligence indices, and autistic traits among neurodivergent children. The decision to use these age bands was motivated by the aim of better understanding potential increases or decreases in challenges and resources associated with changing cognitive and social demands across development. To investigate specific age-related differences, Kruskal-Wallis rank sum tests were applied, with Bonferroni per-family task corrections used to account for multiple comparisons.

Statistical analyses were performed using RStudio software with *stats* for descriptive, correlations, and Generalized linear models, *graphics* packages for correlations' visualization (R Core Team, 2024), *mediation* for mediation analyses (Tingley et al., 2014), *car* for multicollinearity (Fox & Weisberg, 2019), *boot* for bootstrapping methods (Canty & Ripley, 2024), *dplyr* for data selection and age-related differences (Wickham et al., 2023), *ggplot2* for mediation models' visualization (Wickham, 2016). The threshold for statistical significance was set at $\alpha = 0.05$.

2.3 Results

2.3.1 Associations among executive functions and autistic traits with demographic and intelligence information

Significant associations were found between EF and autistic traits scores with age. Furthermore, intelligence variables (specifically, visuo-spatial index, verbal comprehension index, and total IQ) of the Wechsler Scales showed strong relations with most of the measures. In particular, IQ was correlated with all measures, except for parent-reported autistic traits (SRS-2). Additionally, both visual-spatial and verbal comprehension domains were associated with executive functioning measures. See **Table 2.5** for further details.

Table 2.5 *Associations between executive functions and autistic traits with demographic information and intelligence scores*

Variables	Age	Sex	VS	VC	IQ
Wisconsin Card Sorting Test					
Categories	.13	0	**.44*** **	**0.3** **	**0.38*** **
Cards	-.09	-.03	**.33*** **	**0.31** **	**0.32*** **
Correct responses	.16	.11	**.42*** **	**0.24***	**0.38*** **
Total errors	**.21***	.06	**.56*** **	**0.4*** **	**0.49*** **
Perseverative errors	**.23***	.07	**.52*** **	**0.46*** **	**0.47*** **
Other errors	.01	-.01	**.27** **	0.13	**0.24***
Tower of London					
Decision time	**.25***	.05	0.08	0.07	0.04
Execution time	**.28***	**.23***	**-0.3** **	**-0.35** **	**-0.36** **
Total time	**.36*** **	.17	-0.21	**-0.26***	**-0.3** **
Rules violation	-.08	-.09	**-0.26***	**-0.4*** **	**-0.42*** **

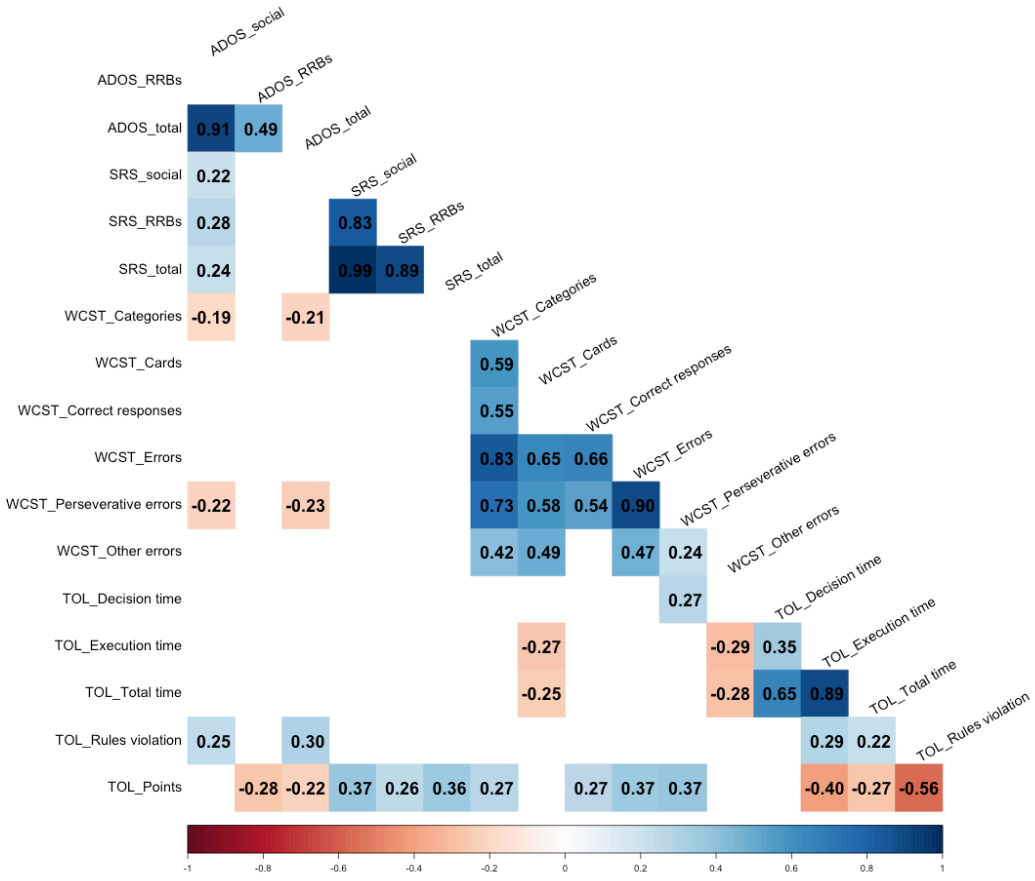
Points	**.40*** **	.17	**0.5*** **	**0.48*** **	**0.51*** **
Autism Diagnostic Observation Schedule-2					
Social affect	**.23***	**-.19***	-0.15	**-0.34*** **	**-0.31****
RRBs	**-.29****	-.05	-0.15	-0.01	-0.12
Total score	.09	-.17	**-0.24***	**-0.33*** **	**-0.35*** **
Social Responsiveness Scale-2					
Social affect	**.3****	0	0.17	0.03	0.02
RRBs	**.22***	-.03	0.08	-0.04	-0.06
Total score	**.28****	-.02	0.15	0.02	0.01

***Note. VC** = Verbal Comprehension, **VS** = Visual-Spatial, **IQ** = Intelligence Quotient, **RRB** = Restricted and repetitive behaviors. [a] Test significance * p < .05, ** p < .01, *** p < .001. Spearman correlation coefficient: weak (0.1-0.3), moderate (0.3-0.5) and strong (>0.5).*

2.3.2 Associations among key measures

Small negative correlations between WCST categories and perseverative errors, and both the social affect and total scores of the ADOS-2 were observed. Additionally, there was a small positive association between rule violations on the ToL and ADOS-2 social affect and total scores. A small negative correlation was also found between ToL points and both the RRBs and total scores on the ADOS-2. In contrast, ToL points showed a moderate positive correlation with the social and total scores on the SRS-2, and a small positive correlation with RRBs scores. See **Figure 2.1** for details and **Appendix A**, **Table A.1**.

Figure 2.1 *Correlations between executive functions and autistic traits measures*



Note. WISC *= Wechsler Intelligence Scale,* ***ADOS*** *= Autism Diagnostic Observation Schedule,* ***SRS*** *= Social Responsiveness Scale,* ***RRBs*** *= Restricted and repetitive behaviors,* ***WCST*** *= Wisconsin Card Sorting Test,* ***TOL*** *= Tower of London. Spearman correlation coefficient: weak (0.1-0.3), moderate (0.3-0.5) and strong (>0.5).*

GLMs revealed that the number of cards used in the WCST was associated with RRBs score on the ADOS-2, while perseverative errors were linked to social affect scores, after controlling for demographic variables (sex and age) and intelligence abilities of the Wechsler Scales (verbal comprehension and visual-spatial skills). See **Table 2.6** for further details. Additionally, ToL points were associated with both social and RRBs scores on the SRS-2 (see **Table 2.7**).

Table 2.6 *Generalized linear models between Wisconsin Card Sorting Test scores and autistic traits, controlling for sex, age and intelligence abilities (verbal comprehension and visual-spatial skills)*

Outcome	Predictor	β	SE	*t*	p^a	CI_lower	CI_upper
Categories	**ADOS_Social**	-.09	.05	-2.02	.05	-.19	.02
	ADOS_RRBs	.06	.09	.68	.50	-.10	.22
	SRS_Social	.003	.008	.42	.68	-.01	.02
	SRS_RRBs	.001	.007	.17	.86	-.01	.02
Cards	**ADOS_Social**	-.02	.04	-.44	.66	-.09	.06
	ADOS_RRBs	.19	.06	3.21	**.002****	.06	.31
	SRS_Social	.002	.006	.38	.71	-.008	.01
	SRS_RRBs	.001	.005	.18	.86	-.01	.01
Correct responses	**ADOS_Social**	-.06	.05	-1.30	.20	-.15	.03
	ADOS_RRBs	-.07	.09	-.73	.47	-.22	.12
	SRS_Social	.003	.009	.30	.77	-.02	.02
	SRS_RRBs	0	.008	.06	.95	-.02	.02
Errors	**ADOS_Social**	-.06	.04	-1.44	.15	-.14	.02
	ADOS_RRBs	.10	.07	1.40	.16	-.03	.23
	SRS_Social	.005	.007	.76	.45	-.01	.02

	SRS_RRBs	.002	.006	.35	.73	-.01	.02
Perseverative errors	**ADOS_Social**	-.17	.07	-2.52	**.01***	-.30	-.03
	ADOS_RRBs	.06	.12	.49	.63	-.16	.28
	SRS_Social	.01	.01	1.10	.28	-.01	.04
	SRS_RRBs	.009	.01	.84	.40	-.02	.03
Other errors	**ADOS_Social**	.04	.04	1.00	.32	-.04	.10
	ADOS_RRBs	.06	.07	.97	.33	-.07	.18
	SRS_Social	-.003	.006	-.45	.65	-.02	.01
	SRS_RRBs	-.004	.005	-.69	.49	-.02	.008

Note. ADOS *= Autism Diagnostic Observation Schedule,* ***SRS*** *= Social Responsiveness Scale,* ***RRBs*** *= Restricted and repetitive behaviors,* ***VC*** *= Verbal Comprehension,* ***VS*** *= Visual-Spatial. [a] Test significance * p < .05, ** p < .01, *** p < .001.*

Table 2.7 *Generalized linear models between Tower of London scores and autistic traits, controlling for sex, age and intelligence abilities (verbal comprehension and visual-spatial skills)*

Outcome	**Predictor**	**β**	**SE**	***t***	***p*[a]**	**CI_lower**	**CI_upper**
Decision time	**ADOS_Social**	-.32	.40	-.81	.42	-.92	.28
	ADOS_RRBs	.01	.74	.02	.99	-1.71	1.86
	SRS_Social	-.03	.08	-.45	.66	-.17	.11

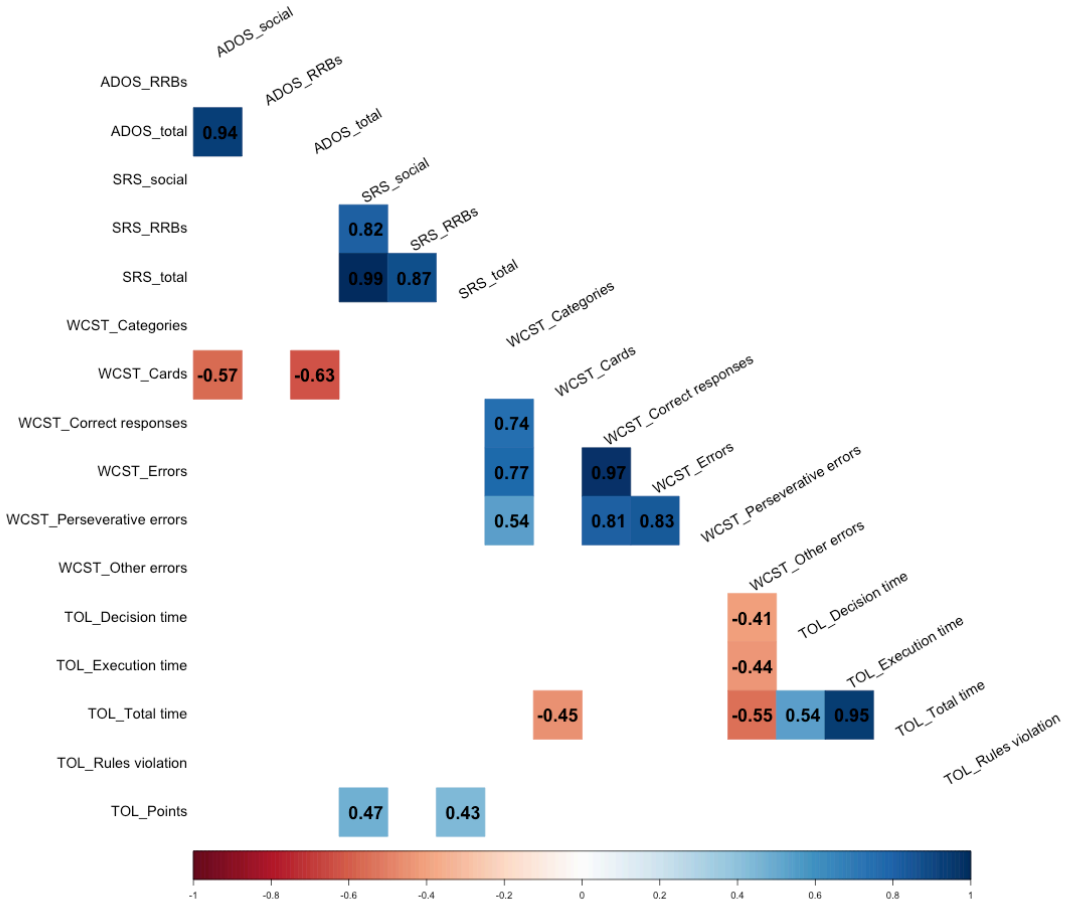
	SRS_RRBs	-.09	.07	-1.31	.20	-.22	.03
Execution time	**ADOS_Social**	-.35	.53	-.65	.52	-1.63	.88
	ADOS_RRBs	-.30	.97	-.30	.76	-2.47	1.69
	SRS_Social	-.05	.10	-.50	.62	-.24	.13
	SRS_RRBs	-.08	.09	-.98	.33	-.24	.05
Total time	**ADOS_Social**	-.76	.48	-1.57	.12	-1.71	.15
	ADOS_RRBs	-.68	.90	-.76	.45	-2.59	1.05
	SRS_Social	-.08	.10	-.87	.39	-.23	.09
	SRS_RRBs	-.12	.08	-1.54	.13	-.29	.008
Rules violation	**ADOS_Social**	1.05	.81	1.30	.20	-.76	3.07
	ADOS_RRBs	1.18	1.49	.79	.43	-2.48	5.37
	SRS_Social	.05	.14	.36	.72	-.23	.36
	SRS_RRBs	-.05	.13	-.39	.70	-.31	.21
Points	**ADOS_Social**	-.04	.05	-.76	.45	-.12	.05
	ADOS_RRBs	-.15	.09	-1.69	.09	-.29	.008
	SRS_Social	.02	.009	2.31	**.02***	.001	.04
	SRS_RRBs	.02	.008	2.31	**.02***	.002	.03

Note. ADOS *= Autism Diagnostic Observation Schedule,* ***SRS*** *= Social Responsiveness Scale,* ***RRBs*** *= Restricted and repetitive behaviors,* ***VC*** *= Verbal Comprehension,* ***VS*** *= Visual-Spatial. ª Test significance * p < .05, ** p < .01, *** p < .001.*

Within IQ-based subgroup analyses

Among children with lower IQ scores, moderate to strong negative correlations between the number of cards used in the WCST and both the social affect and total scores on the ADOS-2 were observed. While moderate positive associations between the execution time of ToL and the social and total score of ADOS-2 were found. No significant associations were found with RRBs. Additionally, social affect and total scores on the SRS-2 showed moderate positive correlations only with ToL points. Full details are available in **Figure 2.2** and **Appendix A**, **Table A.2**.

Figure 2.2 *Correlations between executive functions and autistic traits for the lower IQ group*

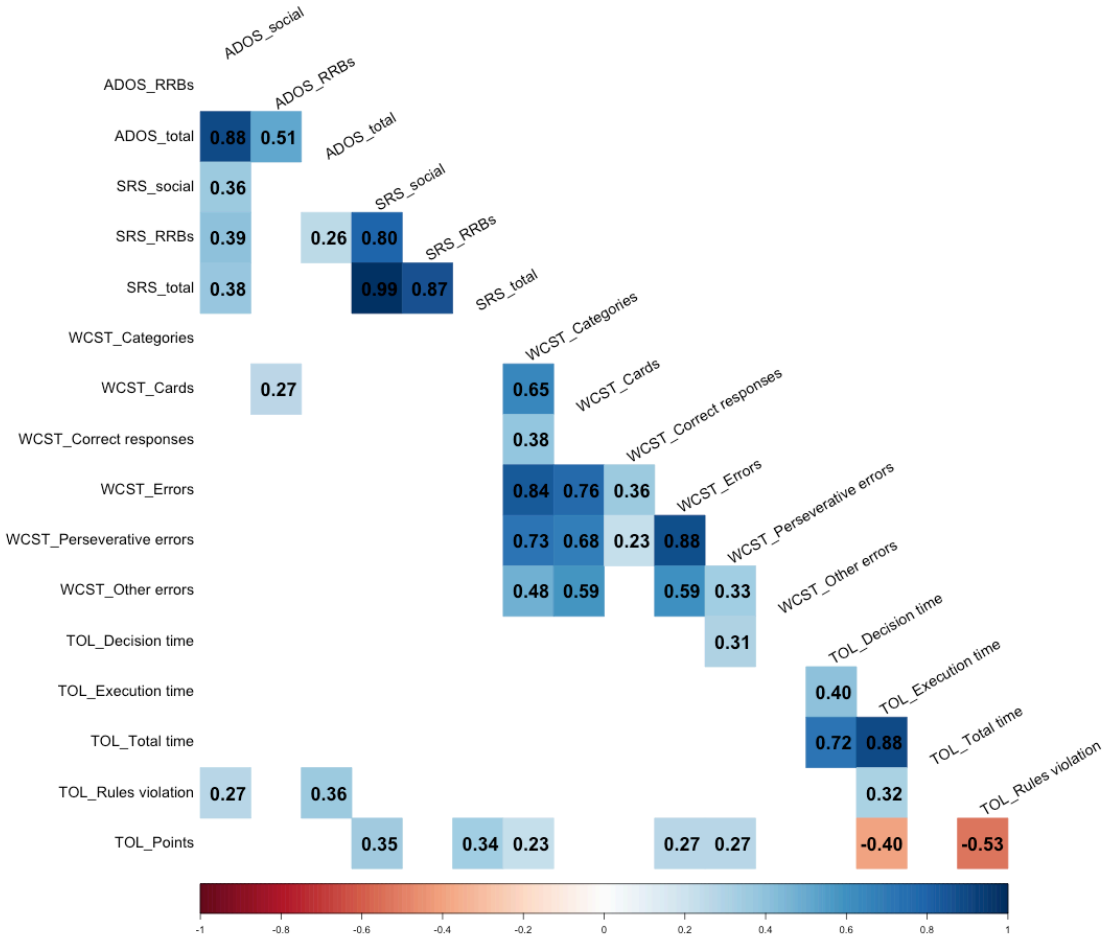


Note. WISC *= Wechsler Intelligence Scale,* ***ADOS*** *= Autism Diagnostic Observation Schedule,* ***SRS*** *= Social Responsiveness Scale,* ***RRBs*** *= Restricted and repetitive behaviors,* ***WCST*** *= Wisconsin Card Sorting Test,* ***TOL*** *= Tower of London. Spearman correlation coefficient: weak (0.1-0.3), moderate (0.3-0.5) and strong (>0.5).*

GLMs indicated that, among children with lower IQ levels, and after controlling for intelligence (verbal comprehension, and visual-spatial skills of the Wechsler Scales) and demographic variables (sex, and age), significant associations emerged between WCST card used and ToL rule violations with social affect scores on the ADOS-2. Full results are presented in **Appendix A, Table A.4** for WCST and **Table A.5** for ToL.

In contrast, among children with higher IQ scores, small positive associations between ToL rule violations and both the social affect and total scores on the ADOS-2 were found. Additionally, the number of cards used in the WCST showed a small positive correlation with RRBs score of ADOS-2. ToL points were moderately positively associated with the social affect score on the SRS-2. For more information, refer to **Figure 2.3** and **Appendix A**, **Table A.3**.

Figure 2.3 *Correlations between executive functions and autistic traits for the higher IQ group*



Note. WISC *= Wechsler Intelligence Scale,* ***ADOS*** *= Autism Diagnostic Observation Schedule,* ***SRS*** *= Social Responsiveness Scale,* ***RRBs*** *= Restricted and repetitive behaviors,* ***WCST*** *= Wisconsin Card Sorting Test,* ***TOL*** *= Tower of London. Spearman correlation coefficient: weak (0.1-0.3), moderate (0.3-0.5) and strong (>0.5).*

In the higher IQ group, GLMs revealed significant relations between number of categories achieved and perseverative errors on the WCST and rule violations on the ToL with ADOS-2 social affect score. Additionally, the number of cards used on the WCST was significantly associated with RRBs of ADOS-2. See **Appendix A**, **Table A.6** for WCST and **Table A.7** for ToL for further details.

2.3.3 The mediating role of IQ in the relations between executive functions and autistic traits

Mediation analyses showed that IQ mediated the relation between WCST performance and the social affect domain of the ADOS-2. Additionally, a direct association was found between the number of cards used and the RRBs score on the ADOS-2 (see **Table 2.8**).

IQ also mediated the relations between execution time, total time, rule violations, and points on the ToL with the ADOS-2 social domain. Moreover, direct associations were observed between ToL points and the social and RRBs domain of the SRS-2 (see **Table 2.9**).

2.3.4 Group differences by IQ level

Significant group differences were found across most domains (see **Table 2.10**). Children in the higher IQ group demonstrated stronger intelligence abilities (visual-spatial and verbal comprehension indexes), as well as higher scores in the social affect and total domains of the ADOS-2. However, no significant differences were observed between groups for the ADOS-2 RRBs domain or for SRS-2 scores. In terms of EFs, the higher IQ group showed generally better performance, though no differences were found in the number of cards used or other WCST error types, nor in the timing measures of the ToL.

Table 2.8 *Mediation analysis of IQ between Wisconsin Card Sorting Test scores and autistic traits*

Outcome	Predictor	ACME_Estimate	ACME_p[a]	ADE_Estimate	ADE_p[a]	Total_Effect	Total_p[a]
Categories	**ADOS_Social**	-.05	**.002****	-.08	.12	-.13	**.01***
	ADOS_RRBs	-.03	.48	.07	.41	.03	.68
	SRS_Social	.001	.78	.01	.55	.01	.51
	SRS_RRBs	-.002	.61	.004	.67	.002	.88
Cards	**ADOS_Social**	-.05	**<.001*****	-.01	.79	-.06	.14
	ADOS_RRBs	-.02	.49	.20	**.008****	.17	**.03***
	SRS_Social	.001	.71	.004	.42	.01	.39
	SRS_RRBs	-.001	.80	.003	.62	.002	.72
Correct responses	**ADOS_Social**	-.06	**<.001*****	-.05	.37	-.10	.06
	ADOS_RRBs	-.04	.33	-.06	.47	-.09	.25
	SRS_Social	.001	.82	.01	.54	.007	.52
	SRS_RRBs	-.001	.66	.003	.72	.002	.81
Errors	**ADOS_Social**	-.07	**<.001*****	-.05	.30	-.12	.02
	ADOS_RRBs	-.04	.34	.12	.10	.07	.43
	SRS_Social	.001	.79	.01	.25	.01	.29
	SRS_RRBs	-.002	.65	.01	.47	.003	.73

Perseverative errors	**ADOS_Social**	-.09	**<.001*** **	-.16	.02	-.25	**<.001*** **
	ADOS_RRBs	-.06	.40	.09	.46	.03	.82
	SRS_Social	.002	.74	.02	.16	.02	.20
	SRS_RRBs	-.003	.67	.01	.31	.01	.50
Other errors	**ADOS_Social**	-.03	**.03***	.05	.16	.02	.48
	ADOS_RRBs	-.01	.39	.06	.33	.05	.48
	SRS_Social	.0003	.88	-.001	.99	-.0004	1.00
	SRS_RRBs	-.001	.64	-.002	.77	-.003	.71

Note. ***ACME_Estimate*** *= Average Causal Mediation Effect estimate (indirect effect),* ***ADE_Estimate*** *= Average Direct Effect estimate (direct effect),* ***Total_Effect*** *= Total effect estimate (direct + indirect effects combined).* ***ADOS*** *= Autism Diagnostic Observation Schedule,* ***SRS*** *= Social Responsiveness Scale,* ***RRB*** *= Restrictive and repetitive behaviors.* [a] *Test significance * p < .05, ** p < .01, *** p < .001.*

Table 2.9 *Mediation analysis of IQ between Tower of London scores and autistic traits*

Outcome	Predictor	ACME_Estimate	ACME_p[a]	ADE_Estimate	ADE_p[a]	Total_Effect	Total_p[a]
Decision time	**ADOS_Social**	-.13	.43	-.28	.32	-.41	.11
	ADOS_RRBs	.01	.77	.03	.92	.04	.96
	SRS_Social	.01	.74	-.03	.72	-.02	.8
	SRS_RRBs	.001	.96	-.08	.15	-.08	.18

Execution time	**ADOS_Social**	.53	**.008****	-.42	.56	.12	.79
	ADOS_RRBs	-.11	.80	-.17	.90	-.29	.79
	SRS_Social	-.03	.52	-.09	.21	-.12	.14
	SRS_RRBs	-.002	.94	-.12	.14	-.12	.14
Total time	**ADOS_Social**	.37	**.02***	-.80	.12	-.43	.38
	ADOS_RRBs	-.03	.928	-.59	.53	-.62	.52
	SRS_Social	-.01	.47	-.10	.20	-.12	.12
	SRS_RRBs	-.002	.87	-.14	.05	-.14	**.04***
Rules violation	**ADOS_Social**	.76	**.004****	1.07	.21	1.83	.05
	ADOS_RRBs	-.08	.91	.83	.60	.76	.64
	SRS_Social	-.04	.48	.08	.52	.04	.69
	SRS_RRBs	-.005	.92	-.03	.81	-.03	.80
Points	**ADOS_Social**	-.08	**<.001*****	-.03	.43	-.11	**.01***
	ADOS_RRBs	-.02	.82	-.13	.14	-.14	.23
	SRS_Social	.003	.44	.02	**.01***	.03	**.02***
	SRS_RRBs	-.001	.90	.02	**.014***	.02	**.04***

Note. ***ACME_Estimate*** *= Average Causal Mediation Effect estimate (indirect effect),* ***ADE_Estimate*** *= Average Direct Effect estimate (direct effect),* ***Total_Effect*** *= Total effect estimate (direct + indirect effects combined).* ***ADOS*** *= Autism Diagnostic Observation Schedule,* ***SRS*** *= Social Responsiveness Scale,* ***RRB*** *= Restrictive and repetitive behaviors.* [a] *Test significance * $p < .05$, ** $p < .01$, *** $p < .001$.*

Table 2.10 *Differences in intelligence, executive functions and autistic traits between subgroups*

Variables	Lower IQ group M (SD)	Higher IQ group M (SD)	χ^2	p^a
Wechsler Intelligence Scale				
Visual-spatial	87.06 (12.03)	113.21 (15)	224	**<.001*** **
Verbal comprehension	80.91 (10.82)	109.03 (15.05)	130.5	**<.001*** **
Autism Diagnostic Observation Schedule-2				
Social affect	10.27 (2.81)	8.17 (2.59)	1795.5	**.001** **
RRBs	2.27 (1.33)	1.87 (1.45)	1470.5	.18
Total score	12.58 (3.19)	10.04 (3.12)	1852.5	**<.001*** **
Social Responsiveness Scale-2				
Social affect	73.88 (17.49)	75.33 (17.03)	766	.81
RRBs	78.46 (19.78)	76.8 (18)	818.5	.82
Total score	75.92 (18.2)	76.7 (17.49)	779.5	.90
Wisconsin Card Sorting Test				
Categories	-0.98 (1.26)	-0.16 (1.24)	766.5	**.003** **
Cards	-0.44 (0.68)	0.04 (1.04)	849	.08
Correct responses	-1.37 (1.58)	-0.15 (1.14)	633	**<.001*** **
Errors	-1.22 (1.22)	-0.09 (1.09)	601.5	**<.001*** **
Perseverative errors	-2.13 (2.61)	-0.23 (1.36)	603	**<.001*** **
Other errors	-0.04 (0.88)	0.15 (0.97)	1049.5	.23
Tower Of London				
Decision time	49.32 (5.79)	51.97 (10.45)	708.5	.41
Execution time	58.42 (13.66)	54.93 (13.32)	826	.19
Time	57.28 (11.99)	54.77 (12.92)	930.5	.24

Rules violation	93.36 (14.29)	79.81 (21.15)	1104	**.003****
Points	-1.98 (1.38)	-0.69 (1.41)	515	**<.001*****

Note. ***RRBs*** *= Restricted and repetitive behaviors. [a] Test significance * p < .05, ** p < .01, *** p < .001.*

2.3.5 Developmental changes in autistic children with higher IQ

Age-related predictors in autistic children

Generalized linear regression analysis (referring to **Table 2.11**) within autistic children with higher IQ revealed several significant age-related associations. Specifically, age was a significant predictor of performance in the visual-spatial domain, the RRBs domain of the ADOS-2, and both the social domain and total score of the SRS-2. In terms of EFs, age was significantly associated with total and perseverative errors on the WCST, as well as total time and points achieved on the ToL.

Table 2.11 *Age-related predictors with intelligence skills, autistic traits and executive functioning*

Variables	β (age)	SE	*t*	*p*[a]
Wechsler Intelligence Scale				
Visual-spatial	1.33	.52	2.56	**.01***
Verbal comprehension	.07	.54	.13	.90
Working memory	-.41	.67	-.60	.55
Processing speed	-.04	.52	-.07	.94
Intelligence quotient	.10	.49	.21	.84
Autism Diagnostic Observation Schedule-2				
Social Affect	.18	.09	1.96	.05
RRBs	-.13	.05	-2.64	**.01***
Total score	.05	.11	.41	.68
Social Responsiveness Scale-2				
Social domain	1.60	.65	2.48	**.02***
RRBs	1.16	.70	1.65	.11
Total score	1.57	.67	2.36	**.02***
Wisconsin Card Sorting Test				
Categories	.02	.05	.34	.73
Cards	.05	.04	1.28	.21

Correct Responses	.01	.04	.19	.85
Errors	.04	.04	1.07	.29
Perseverative errors	.06	.05	1.21	.23
Other errors	-.01	.04	-.35	.73
Tower of London				
Decision time	.87	.54	1.63	.11
Execution time	1.35	.74	1.82	.07
Total time	1.62	.64	2.52	**.01***
Rules violation	-1.29	1.09	-1.18	.24
Points	.17	.05	3.49	**.001****

Note. ***β*** *= regression coefficient,* ***SE*** *= standard error,* ***R²*** *= coefficient of determination.* ***RRBs*** *= Restricted and repetitive behaviors. [a] Test significance * p < .05, ** p < .01, *** p < .001.*

Developmental differences across age range

Kruskal-Wallis rank sum tests (**Table 2.12**) revealed some significant differences across age groups. After applying Bonferroni correction, children aged 14-17 showed significantly lower levels of RRBs, as reported by clinicians through the ADOS-2, compared to those aged 11-13 ($p = .01$) and 4-7 ($p = .001$). Moreover, adolescents aged 11-13 exhibited higher visual-spatial performance ($p = .04$) but also higher autistic traits in the social domain ($p = .003$) and total score ($p = .01$) of SRS-2 compared to those aged 4-7.

Significant differences were also observed in the TOL task regarding EF. Children aged 4-7 completed the test more quickly than those aged 8-10 ($p = .02$) and 11-13 ($p = .01$); however, they achieved significantly fewer points than children aged 11-13 ($p = .02$) and 14-17 ($p = .004$).

Table 2.12 *Differences in intelligence, executive functions and autistic traits measures between age groups*

Variables	**Group, age in years (*n*)**							
	Total (77) **M (SD)**	**4-7 (19)** **M (SD)**	**8-10 (25)** **M (SD)**	**11-13 (24)** **M (SD)**	**14-17 (9)** **M (SD)**	χ^2	p^a	**Posthoc[a]**
Wechsler Intelligence Scale								
Visual-spatial	113.21 (15.00)	106.74 (12.47)	111.12 (16.31)	118.62 (13.78)	118.22 (14.68)	8.39	**.04***	**11-13 > 4-7 (.04*)**
Verbal comprehension	109.03 (15.05)	110.37 (12.25)	105.72 (13.60)	110.00 (16.98)	112.78 (19.34)	2.31	.51	-
Working memory	94.99 (16.46)	99.58 (13.79)	91.50 (18.14)	94.67 (17.31)	99.00 (12.09)	3.85	.28	-
Processing speed	90.82 (14.28)	93.89 (14.39)	88.88 (14.52)	87.33 (13.68)	98.78 (12.65)	5.61	.13	-
Total IQ	105.43 (13.48)	106.89 (8.58)	101.68 (14.00)	106.12 (15.39)	110.89 (14.43)	5.41	.14	-
Autism Diagnostic Observation Schedule-2								
Social Affect	8.17 (2.59)	7.32 (2.21)	7.72 (2.48)	9.17 (2.87)	8.56 (2.24)	4.78	.19	-
RRBs	1.87 (1.45)	2.58 (1.12)	1.60 (1.35)	2.17 (1.58)	.33 (.50)	18.91	**<.001*** **	**14-17 < 4-7 (.001**), 11-13 (.01*)**

Total score	10.04 (3.12)	9.89 (2.47)	9.32 (3.22)	11.33 (3.50)	8.89 (2.09)	4.34	.23	-
Social Responsiveness Scale-2								
Social domain	75.33 (17.03)	65.57 (11.20)	71.33 (16.98)	85.40 (16.19)	76.11 (16.70)	13.27	**.004****	**11-13 > 4-7 (.003**)**
RRBs	76.80 (18.00)	70.14 (16.37)	72.83 (16.35)	85.75 (18.79)	75.22 (16.50)	7.55	.06	-
Total score	76.70 (17.49)	67.21 (11.79)	72.44 (16.92)	87.15 (17.23)	76.78 (16.85)	11.53	**.01***	**11-13 > 4-7 (.01**)**
Wisconsin Card Sorting Test								
Categories	-.16 (1.24)	-.17 (1.11)	-.35 (1.55)	.03 (1.12)	-.12 (.93)	1.51	.68	-
Cards	.04 (1.04)	-.23 (.45)	-.19 (.89)	.54 (1.23)	-.31 (1.03)	3.45	.33	-
Correct Responses	-.15 (1.14)	-.21 (1.08)	-.22 (1.29)	-.18 (1.02)	.26 (1.20)	.81	.85	-
Errors	-.09 (1.09)	-.29 (.96)	-.27 (1.26)	.25 (1.09)	-.12 (.75)	3.49	.32	-
Perseverative errors	-.23 (1.36)	-.32 (.94)	-.65 (1.87)	.31 (.91)	-.30 (1.12)	5.49	.14	-
Other errors	.15	-.01	.35	.14	-.03	2.92	.40	-

	(.97)	(.97)	(.96)	(1.07)	(.07)			
Tower of London								
Decision time	51.97 (10.45)	48.56 (7.23)	52.04 (11.00)	54.26 (11.46)	-	5.08	.08	**4-7 < 11-13 (.04*)**
Execution time	54.93 (13.32)	48.42 (5.95)	56.17 (15.89)	57.09 (12.65)	-	3.26	.20	-
Total time	54.77 (12.92)	46.44 (5.81)	57.60 (13.84)	57.48 (13.39)	-	10.32	**.01***	**4-7 < 8-10 (.02*), 11-13 (.01*)**
Rules violation	79.81 (21.15)	83.38 (19.98)	82.60 (18.00)	74.30 (24.62)	-	1.48	.48	-
Points	-.69 (1.41)	-1.50 (1.21)	-.93 (1.25)	-.30 (1.52)	.39 (.94)	15.91	**.001****	**4-7 < 11-13 (.02*), 14-17 (.004**)**

***Note. IQ** = Intelligence Quotient; **RRBs** = Restricted and repetitive behaviors. χ^2 = Chi-squared. [a] Test significance * p < .05, ** p < .01, *** p < .001*

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2.4 Discussion

2.4.1 Executive functions and autistic traits

This study emphasizes a crucial but frequently overlooked issue in clinical evaluations: the inconsistency between performance-based assessments conducted by clinicians and parent-reported evaluations in autistic children. It was found that distinct patterns depended on the type of EFs measured, the source of information (clinician versus parent), and the measurement context (structured testing versus everyday environments).

Consistent with previous research (Augé et al., 2024; Bednarz et al., 2020; Faja & Nelson Darling, 2019; Lopez et al., 2005), performance on the Wisconsin Card Sorting Test (WCST), specifically the number of perseverative errors and cards used, was negatively correlated with clinician-observed restrictive and repetitive behaviors on the ADOS-2. This suggests that increased RRBs are linked to inhibition and cognitive flexibility, as evidenced by the greater number of attempts required to complete the task.

In contrast, performance on the Tower of London (ToL) task showed associations with parent-reported autistic traits on both SRS-2 subscales, which indicates that better performance in ToL is aligned with higher autistic traits. Although this may appear counterintuitive, it is consistent with prior findings showing limited correspondence between lab-based EF tasks and informant-based reports (Jones et al., 2018; Leung et al., 2016). One possibility is that strong planning abilities in structured tasks may not translate to flexible behavior in real-world settings. Supporting this interpretation, Leung et al. (2016) found significant correlations between parent-reported EF and autistic traits, but not between EF parent-report scores and clinician-rated measures of autistic traits.

An additional consideration concerns the divergence between clinician-based assessments and parent-reported evaluations. While this discrepancy may partly reflect differences in measurement context, structured clinical settings versus everyday environments, it may also arise from observer bias, differences in expectations, or the nature of the parent-child relationship. Parents who observe their children over long periods and across varied situations might be more attuned to subtle or cumulative behaviors that are not evident in a short clinical session. Alternatively, stress, worry, or familiarity with the child's patterns might lead to over-reporting or under-reporting specific traits. Clinicians, on the other hand, operate in a more controlled environment, which may mask certain behaviors or elicit atypical performance due to novelty, structure, or social facilitation. Another plausible interpretation involves the notion of cognitive overregulation. Children who perform well

on structured problem-solving tasks like the ToL may rely on rigid, rule-bound strategies that, while effective in laboratory settings, may manifest in daily life as inflexible or overly controlled behaviors. These traits, although advantageous during formal assessment, may be perceived by parents as hallmarks of autistic rigidity, particularly when they interfere with spontaneity or adaptability in less structured situations. Such findings underscore the importance of distinguishing between efficient performance and flexible, context-sensitive behavior in ecological settings.

Further distinctions emerged when participants were stratified by IQ. In children with higher IQ, associations between WCST and both RRBs and social affect (as measured by the ADOS-2) remained significant. However, among children with lower IQ, the number of cards used in the WCST was linked only to social affect, not to RRBs. This pattern suggests that for autistic individuals with lower IQ, perseveration and inflexibility, difficulty in abstracting and understanding classification rules, and difficulties in finding alternative solutions may more strongly influence social communication than RRBs. Interestingly, rule violations in the WCST were significantly associated with social affect across both groups. Yet, when analyzed within these subgroups, associations were confined to variables assessed within the same context, specifically laboratory-based EF tasks and clinician observations, while links with parent-report measures disappeared. These findings highlight the contextual nature of EF-autistic traits associations.

Additionally, a higher IQ score was associated with better EF performance and fewer clinician-rated autistic traits (ADOS-2), echoing patterns found in both neurodivergent and neurotypical populations (Campbell et al., 2017; Itskovich et al., 2021; Joseph et al., 2002; Syriopoulou-Delli et al., 2018). While clinicians noted social-communication differences between IQ groups, parents reported similar levels of day-to-day functioning, suggesting that intelligence resources more strongly influence performance-based and clinician-rated outcomes than parent-perceived behaviors. Mediation analysis further supports this interpretation: IQ significantly mediated the relationships between both WCST (cognitive flexibility) and ToL (planning) performance and clinician-rated social communication. However, IQ did not mediate associations with RRBs in either clinician- or parent-reported measures, consistent with prior evidence suggesting that RRBs may be relatively independent of general intelligence abilities (Olde Dubbelink & Geurts, 2017).

Overall, these findings indicate that IQ significantly shapes EFs performance and clinician-rated social-communication skills but has a more limited role in RRBs and parent-reported traits observed in everyday settings. The results underscore the need to consider both measurement context and informant perspective when interpreting EF-autistic traits associations and caution against overgeneralizing lab-based cognitive performance to real-world functioning without accounting for these contextual influences. These highlight the necessity for more sensitive and ecologically valid

assessment tools that consider individual cognitive profiles. Equally important is the development of instruments that minimize the impact of intelligence level, to more accurately reflect children's true strengths and weaknesses. Moreover, the results highlight the need for clinicians to carefully interpret EF test outcomes in autistic children with varying intelligence abilities. For those with borderline intellectual functioning, caution is needed when using EF performance to predict everyday functioning, as standardized tests may not fully represent real-life skills. To address this gap, adapting assessment methods, especially for children with borderline IQ, could be beneficial. Additionally, for all groups, but particularly those with average or above-average IQ, improving cognitive flexibility and rule-following may strengthen social skills, aiding interaction initiation, turn-taking, and conversational adjustments with peers (Kenworthy et al., 2022). For children with average IQs, enhancing inhibitory control could help reduce RRBs, improve persistence on cognitive tasks, and positively affect learning.

2.4.2 Developmental trajectories in autistic children

In contrast to earlier research that typically examined limited age groups or relied on varied assessment methods, this study offers a more comprehensive developmental overview across a wide age range using standardized and consistent measures. This enables a clearer understanding of how EFs and autistic traits do not develop concurrently but follow distinct trajectories over time. In the average IQ group, age-related analyses showed relatively stable intelligence abilities, aligning with a previous review (Magiati et al., 2014). Only adolescents aged 11-13 exhibited higher visual-spatial performance. Also, cognitive flexibility was found to remain stable across ages, likely due to the consistent challenges reported in this domain across the lifespan, as noted by both parents and adolescents' self-reports (Granader et al., 2014; Kenworthy et al., 2022; Van Eylen et al., 2015). Conversely, planning skills demonstrated a more gradual improvement through adolescence, particularly between the ages of 14 and 17, as shown by a previous work (Kouklari et al., 2018). However, the results are in contrast with studies suggesting greater challenges in planning in early adolescence (ages 12-14) compared to previous ages as reported by parents (Tschida & Yerys, 2022; Van Den Bergh et al., 2014). One possible explanation for these discrepancies is the familiarity with structured performance-based tasks, such as those used to assess planning, where age-related improvement may be influenced by prior experience with these exercises. Structured testing environments, task familiarity, adult support, and reduced sensory distractions may artificially boost performance, especially in autistic children with higher intelligence abilities. However, these controlled lab settings do not capture the challenges autistic individuals face daily in environments

like school, home, or work, where ambiguity, lack of structure, and distractions are common, and thus these challenges are preserved (Jertberg et al., 2024; Kenworthy et al., 2008). As a result, the ecological validity and practical usefulness of traditional assessments may be limited. Moreover, younger children exhibit faster times in planning tasks, likely due to higher levels of impulsivity, which tend to decrease with age, as indicated by longer times needed to complete the tasks, reflecting the development of stronger self-regulation behaviors (Raffaelli et al., 2005). These findings suggest that while advancements in planning abilities accompany the development of self-regulation, they do not automatically generalize to everyday situations without specific intervention or support.

Interestingly, this cognitive progression was accompanied by a decline in clinician-reported RRBs during late adolescence (14-17 years), consistent with previous studies (Berry et al., 2018; Esbensen et al., 2009), though inconsistencies arose depending on the methodological context. For instance, in the present study, parent ratings indicated an increase in socio-communication difficulties in ecological contexts during early adolescence (ages 11-13). However, from a clinical perspective, social-communication behaviors appeared relatively stable, while RRBs were reported by parents as largely unchanged across ages. The increase in social difficulties observed by caregivers in ecological contexts may reflect the escalating social and academic demands that autistic children face in everyday situations. While during childhood, the expectations involve increasing independence and task management, the adolescent period and specifically in the transition between primary to secondary school, introduces more complex academic and social challenges, especially as peer interactions become more reliant on verbal communication rather than shared activities. These results suggest that EF assessments for autistic individuals should account for developmental stages, especially during the critical transition from childhood to adolescence.

2.4.3 Limitations and future directions

This study has several limitations. Methodologically, it did not include a control group for comparison, focusing solely on the performance of the autistic population. Additionally, the sample was relatively small and heterogeneous. Future research should expand the sample size to confirm these preliminary results and developmental trends more accurately in autistic individuals. Moreover, a verbal assessment, the total IQ index of the Wechsler Scales, divides the sample into lower-IQ and higher-IQ groups. While this tool has faced criticism for developmental limitations and cultural biases, future research could validate and expand on these results by employing non-verbal assessments like the Leiter Scales to achieve a more equitable participant classification. Nonetheless, since this sample included verbal autistic children without severe intellectual disabilities, the IQ

measure was deemed appropriate and effective for distinguishing groups in this context. Clinically, these children could complete the full set of tasks administered in the study. Another potential influence on these findings was the presence of comorbid conditions and/or language impairments in some participants. However, it was chosen to include all participants to offer a more inclusive representation of the relations between EFs and autistic traits within a neurodivergent population. Given autism's high individual variability, both assessment and intervention are complex. Future studies should focus on more homogeneous subgroups to refine our understanding of these associations. Moreover, there is a need to increase female representation in future research to explore potential sex differences in EFs and intelligence scores within the autistic population. Understanding whether these relations vary by sex could provide valuable insights into autism's variability.

Conceptually, the measures used in this study simplify complex phenomena like EFs by isolating specific cognitive processes. Future research should adopt a broader framework, such as the Executive Attention model (Engle, 2018; Kane et al., 2001; Petersen et al., 2012; Petersen & Posner, 2012), to investigate these associations. A notable limitation concerns the misalignment between standardized, laboratory-based executive function tasks and the behavioral traits assessed via informant-based tools such as the SRS-2. While performance-based tasks like the WCST and ToL offer controlled assessments of cognitive flexibility and planning, they may not accurately reflect how these abilities manifest in real-world situations. The weak or inconsistent associations between these measures and parent-reported traits suggest a gap in ecological validity. This discrepancy complicates the interpretation of results and underscores the need for integrating more naturalistic, context-sensitive assessment tools or behavioral observations in classrooms and clinical settings to better capture executive functioning in daily life.

2.5 Conclusion

This study highlights a critical but often overlooked challenge in EF research: the inconsistency between clinician-administered performance measures and parent-reported evaluations in autistic children. However, few links between performance-based EF tasks and autistic traits were identified. Specifically, IQ levels strongly influence EF performances and clinician-rated social-communication traits in structured settings but have less impact on restricted and repetitive behaviors and parent-reported everyday traits. These findings emphasize the critical role of context, structured laboratory versus naturalistic environments, and informant perspective in interpreting EF-autistic traits

associations. Importantly, IQ has a significant influence on laboratory clinical assessments of EFs and social communication, highlighting the necessity for more sensitive and ecologically valid neuropsychological tools. In contrast, IQ does not appear to affect clinician-rated restricted and repetitive behaviors or parent-reported measures, suggesting that these behaviors may operate independently of general intelligence functioning. Moreover, age-related changes differ by intelligence abilities and age, with some EF skills improving through adolescence while social challenges increase in everyday contexts, especially during key transitions such as adolescence. These insights highlight the need for more ecologically valid, sensitive assessment tools that account for individual cognitive profiles and real-world functioning, as well as tailored clinical and educational interventions that address the unique developmental and cognitive needs of autistic children across diverse settings.

Chapter 3

Examining the latent constructs underlying performance across multiple executive attention measures in neurodiverse children

Summary

Understanding the structural organization of executive function constructs across tasks is essential for clarifying their theoretical coherence. While confirmatory factor analysis (CFA) is commonly used to identify latent constructs, it often yields unstable solutions influenced by task selection and executive functions (EFs) operationalization, whereas exploratory factor analysis (EFA) offers a promising but underutilized alternative. The present study investigated the structure of executive attention functions in neurodiverse children aged 8 to 16 years using a comprehensive, multidimensional battery of tasks. Exploratory factor analysis revealed a three-factor structure. The first factor associated with PASOT conditions, accuracy of Graphical fluency and Categorization, was primarily defined by accuracy, incorporating linguistic or fine-motor demands. The second factor corresponded to Cancellation subtasks and was characterized by inverse efficiency indices, reflecting contributions from fine-motor abilities. The third factor linked Color naming with

Enumeration (backward and forward) and was also defined by inverse efficiency indices, but with greater involvement of verbal components. Factor correlations indicated that the second factor was relatively distinct, reflecting primarily inhibitory control, whereas the first and the third factors were more strongly correlated, suggesting shared functional overlap likely driven by common working memory demands, with the first factor also reflecting cognitive flexibility. The pattern of communalities, residuals, and factor reliabilities supports the interpretability and robustness of the three-factor model in school-aged neurodiverse children, consistent with prior literature. However, an innovative reformulation of the factors based on task-specific indices and the non-executive abilities involved suggest useful insights. Specifically, using composite measures, such as inverse efficiency scores, provided clearer differentiation between tasks relying on verbal versus visual-spatial abilities. This perspective addresses methodological limitations in EF research, offering clearer insights into their organization in neurodiverse children and guiding assessment design.

Keywords

Executive attention; exploratory factor analysis; task-derived indices; composite scores; neurodiverse children; school-aged children

Key points

- Executive attention functions in neurodiverse children can be captured by a three-factor structure, with separable and interconnected aspects of executive functioning.
- The second factor reflect primarily inhibitory control, while the first and the third factors overlap through shared working memory demands, with the first factor additionally involving cognitive flexibility.
- Task selection and scoring methods significantly influence the observed factor structure, underscoring the importance of methodological considerations.
- Composite indices like inverse efficiency scores enable the distinction of broader cognitive abilities within EF tasks.

3.1 Introduction

The assessment of executive functions (EFs) remains limited by conceptual and methodological challenges, particularly related to reductionist approaches and task impurity issues (see **Chapter 1, Section 1.6.2** for a deeper analysis). To address these limitations, neuropsychological assessment has increasingly adopted multicomponent models, which integrate multiple tasks per construct. Following this framework, the present study adopts a multidimensional approach to assess EFs, namely the executive attention (see **Chapter 1, Section 1.4** for a theoretical explanation). Thus, a multidimensional battery of tasks, including in the *Measures of Executive Attention (MEA) battery* (Benso et al., 2019), was implemented. This battery was developed to minimize task impurity and to capture functional EF profiles more accurately. Methodological refinements, such as the subtractive method and efficiency indices, further enhance construct validity by isolating executive components from general performance effects. Understanding the structural organization of EF constructs across tasks is crucial for clarifying their theoretical coherence. Yet this issue has not been investigated within the present battery and remains underexplored in the broader literature. Factor-analytic techniques, such as confirmatory factor analysis (CFA), are commonly used to model performance across multiple tasks, enabling the identification of latent constructs and partial mitigation of task impurity. One of the first studies to apply CFA to executive functioning was conducted by Miyake et al. (2000). Starting from the common identification of three core components of EFs (updating, inhibitory control, and cognitive flexibility), they associated three cognitive tasks for each dimension, showing both separability and communalities among factors (see **Chapter 1, Section 1.3.1** for further details). However, CFA models often yield limited fit, with correlations between latent variables only partially explained and considerable task-specific variance persisting (Karr et al., 2018; Miyake et al., 2000; Miyake & Friedman, 2012). Moreover, results are highly sensitive to task selection, which varies substantially across studies (Poldrack, 2006), and differences in EF operationalization can significantly alter the identified factor structure (Yangüez et al., 2024). As a result, factorial solutions often lack stability and generalizability (Draheim et al., 2021; Karr et al., 2018). In contrast, exploratory factor analysis (EFA) provides an opportunity to uncover alternative organizational patterns among EF constructs, yet it remains underutilized.

3.1.1 Concerns regarding factor analysis studies of executive functioning in children

Choice of the tasks to assess executive functions

Structural studies of EFs have employed a wide variety of tasks to measure specific constructs, resulting in heterogeneous findings. For example, Agostino et al. (2010) administered seven tasks, including the Antisaccade, Stroop Number, Stroop Color, Letter-Memory, Visual n-back, Contingency Naming Task, and Trail Making Test, and identified a three-factor model in children aged 8-13, distinguishing inhibitory control, cognitive flexibility, and working memory. In contrast, Cirino et al. (2018), studying children aged 8-12 with tasks such as Verbal fluency, Design Fluency, Trail Making Test, Tower of London, and Corsi Block, found a bifactor model encompassing the three core executive functions, characterized by a Common EF and five specific EF factors (working memory-span/manipulation and planning; working memory-updating; generative fluency, self-regulated learning; metacognition). Similarly, Spencer et al. (2020) reported a two-factor model in children aged 9-15, highlighting cognitive flexibility and working memory using Verbal Card Sorting, Perceptual Sorting, and Sentence Span tasks. In younger children aged 4-6, Masten et al. (2012) supported a unidimensional model reflecting a single Common EF construct. These findings suggest that structural models of EFs are age-dependent: younger children generally fit one- or two-factor models, with inhibitory control typically emerging first, followed by working memory (Brydges et al., 2024; Wiebe et al., 2008; Willoughby et al., 2012; Monette et al., 2025). Similarly, works indicate that EFs differentiate gradually across development, with a three-factor structure emerging around age 8 that resembles the adult model, although substantial interindividual variability persists (Yangüez et al., 2025; Brydges et al., 2014; Lehto et al., 2003).

However, age alone does not fully account for the variability in findings. Differences in task selection across studies also appear to play a significant role. For instance, Karr et al. (2018) reviewed prior CFA studies on EF structure and re-analyzed those with sufficient data using bootstrapping techniques. Across these studies, at least seven different models were reported, including one unidimensional, three two-factor, one three-factor, one nested-factor, and one bifactor model (Yangüez et al., 2024). None of these models consistently converged or provided a satisfactory fit, highlighting methodological challenges in mapping EF structure and further illustrating the influence of task selection. Messer et al. (2018) found a two-factor structure in children aged 6-12, comprising an inhibition factor and a general EF factor encompassing working memory, switching, fluency, and planning. Notably, when a verbal planning task was added, the factor structure shifted, demonstrating how specific tasks can substantially shape the observed organization of EFs.

Choice of the index to provide a measure of executive functions

Most tasks assessing EFs provide measures such as accuracy, capacity, reaction time, and efficiency scores. However, the availability of multiple metrics can complicate efforts to identify consistent structural patterns. For instance, in studies using the Stroop task, researchers have employed different indices, primarily reaction time or accuracy (Arán Filippetti & Richaud, 2017; Brocki & Tillman, 2014). In contrast, some tasks consistently yield reliable measures across studies; for example, the Trail Making Test typically provides a reaction time measure (Agostino et al., 2010; Rose et al., 2012). However, due to the higher involvement of both executive and non-executive processes in the execution of tasks, other approaches have been developed to try to reduce the influence of the task impurity issue. An example is the use of the inverse efficiency score, calculated by dividing the time taken to complete a task by the number of correct responses. This method balances speed and accuracy, providing a single measure of task efficiency (Benso et al., 2019; Murphy & Klein, 1988). In this formulation, higher cognitive efficiency is reflected by lower inverse efficiency scores. Another modality to obtain a score of EF is using the subtractive method as proposed by Donders (1868), which contrasts two task conditions to isolate and quantify the contributions of executive and non-executive processes (Benso et al., 2019). A study employed multiple tasks to assess inhibition, and their comparable task requirements likely contributed to inhibition emerging as a distinct factor (Messer et al., 2018). Using tasks with highly similar demands tends to produce a more coherent and robust latent factor. By contrast, Huizinga et al. (2006) did not identify a common factor from their three inhibition tasks (Stop-signal, Flanker, and Stroop), likely due to greater variability in task requests. These findings suggest that the selection of variables included in a factor analysis may be just as critical as the statistical methods themselves in shaping the resulting factor structure, although establishing best practices in task selection remains challenging. Overall, using various indices as a measure of EF tasks may contribute to variability in structural findings.

3.1.2 Aims and hypotheses

Understanding the structural organization of executive attention constructs across tasks is essential for clarifying their theoretical coherence. While CFA is commonly used to identify latent constructs, it often produces unstable solutions influenced by task selection and EF operationalization. In contrast, EFA provides a promising yet underutilized alternative. The present study addresses this gap by applying EFA to a comprehensive set of executive attention tasks, aiming to delineate shared and distinct latent dimensions while offering methodological recommendations to improve the

robustness and interpretability of executive functioning structural research. Specifically, the study aims to investigate the structure of executive attention functions in neurodiverse children aged 8-16 using a multidimensional battery. Based on current literature, a three-factor structure is expected (Karr et al., 2018; Miyake et al., 2000; Yangüez et al., 2025). However, variation in communalities and separability across measures is anticipated due to inconsistencies in previous findings and the influence of task selection on the EF structure (Draheim et al., 2021; Karr et al., 2018; Messer et al., 2018; Poldrack, 2006).

3.2 Methods

3.2.1 Participants

The study involved 227 children (149 males and 78 females) aged 8 to 16 years (M_{age} = 11.75, SD = 2.24), recruited from schools in the northern region of Italy and from the ODFLab (Laboratory of Observation, Diagnosis, and Education) at the Department of Psychology and Cognitive Science, University of Trento (Italy). The sample was composed of children of the following ages: 8 years (n = 16; 10 males), 9 years (n = 33; 24 males), 10 years (n = 21; 14 males), 11 years (n = 33; 23 males), 12 years (n = 39; 26 males), 13 years (n = 28; 19 males), 14 years (n = 29; 16 males), 15 years (n = 16; 8 males) and 16 years (n = 12; 9 males). School-based participants were recruited from inclusive classrooms comprising both neurotypical students (n = 151) and neurodivergent children (n = 76), including those with Autism Spectrum Disorders (n = 30), Specific Learning Disorders (n = 31), Attention-Deficit/Hyperactivity Disorders (n = 3), and socio-linguistic challenges (n = 12). Children with intellectual disabilities were not included due to the well-documented relation between intelligence and EFs (Campbell et al., 2017; Gardiner et al., 2017; Larson et al., 2021).

3.2.2 Materials

The *Measures of Executive Attention (MEA) battery* (Benso et al., 2019) comprises a range of tasks designed to assess distinct components of executive attention. This battery is sensitive to detecting various forms of executive-attentive weaknesses. While a single test may not reveal impairments in this system, the comprehensive nature of the full battery allows for the identification of subtle or

specific deficits across multiple domains. The battery includes tasks that engage sustained, selective, and spatial attention, as well as abilities related to planning, behavioral organization, inhibitory control, cognitive flexibility, and updating. Collectively, these functions constitute the Executive Attention system. In certain tasks, it is possible to address the issue of interference from peripheral systems by first measuring the contribution of domain-specific modules, such as input (perceptual) and output (motor) processes, in task execution. Subsequently, a separate measure of central executive processes is obtained. Using the *subtractive method*, the influence of non-executive systems can be subtracted from the overall performance, allowing for a more accurate estimation of central executive capacity. Moreover, to address the trade-off between speed and accuracy in task performance, the *inverse efficiency* method is applied. This metric is calculated by dividing the time taken to complete the task by the proportion of correct responses. The lower the inverse efficiency score, the more efficient the underlying cognitive process, as it reflects a balance between rapid execution and accuracy. For the present study, and to provide a quicker assessment of executive attention across its components, six tasks were selected from the battery, and some of them were simplified compared to the original version (Benso et al., 2019). *Raw scores* were provided for each condition. **Table 3.1** provides a brief description of each task used in this study, while **Table 3.2** summarizes the executive and non-executive components along with the indices measured by each task involved.

Table 3.1 *Brief description of the Measures of Executive Attention Tasks*

Task	Description
Color naming	Denominate verbally the name of the colors as quickly as possible. Derived from the studies of Denckla and Rudel (1976), this task represents the final output of a processing stream involving the integration of attentional and mnemonic processes, culminating in a relative automatization of verbal label retrieval.
Graphical fluency	Draw various configurations, using 5 points, in a minute providing different measures (accuracy, errors and perseverations). Adapted and modified from the Five-Point Test by Regard et al. (1982), this task is widely used in clinical settings, particularly in the assessment of frontal lobe syndromes (see also Tucha et al., 2012).
Cancellation and visual search	This task requiring participants to mark only the target items on various sheets (Sheets 7 and 8 assess fine-motor speed; Sheet 10 assess fine-motor speed in combination with visual search speed).

Enumeration forward-backward	Tell the number from 1 to 100 (forward condition) as quickly as possible and then from 100 to 1 (backward condition).
Categorization	Repeat only the words verbally provided by the examiner that belong to a specified category. This task is derived from the studies of Haarmann et al. (2003), who developed a *conceptual span task* in which list recall had to be recognized according to semantic elements. It requires active manipulation within working memory. Conceptual span performance showed higher correlations with reading comprehension and problem-solving abilities.
Paced Auditory Serial Opposites Task (PASOT)	Say the opposite of the word heard just before the last one in two different timing between the stimuli (1200ms and 800ms). This task is adapted and modified from Gow and Deary (2004) and consists of a demanding *n-back-like task*. It assesses working memory updating and manipulation, involving attentional and executive control processes.

Table 3.2 *Executive components, non-executive domains and indices involved in the tasks*

Variables	Executive component	Non-executive domain	Index
Color naming	Processing Speed Inhibitory control Visual Discrimination	Language	Inverse efficiency
Graphical fluency (accuracy)	Generativity thinking	Fine-motor	Accuracy
Graphical fluency (error)	Rule adherence	Fine-motor	Accuracy
Graphical fluency (perseveration)	Cognitive flexibility	Fine-motor	Accuracy
Cancellation (sheet 7)	Processing Speed	Fine-motor	Inverse efficiency
Cancellation (sheet 8)	Processing Speed	Fine-motor	Inverse efficiency
Cancellation (sheet 10)	Visual Discrimination Inhibitory Control	Fine-motor	Inverse efficiency

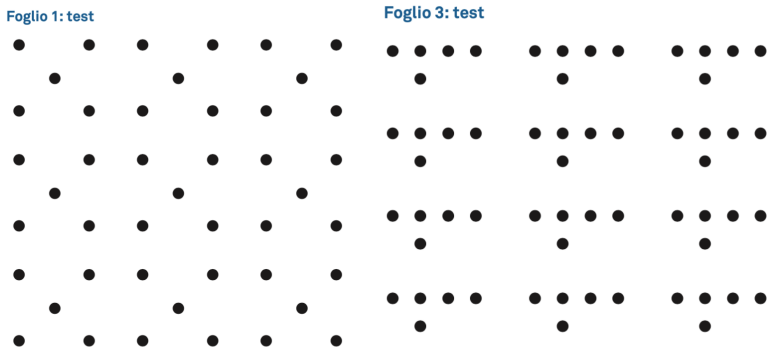
Visual search	Visual Discrimination Inhibitory control		Subtractive method
Enumeration (forward)	Updating	Language	Inverse efficiency
Enumeration (backward)	Updating	Language	Inverse efficiency
Enumeration forward-backward	Updating		Subtractive method
Categorization	Updating	Language	Accuracy
PASOT (1200ms)	Updating	Language	Accuracy
PASOT (800ms)	Updating	Language	Accuracy
PASOT	Updating	Language	Accuracy

The six tasks are the following.

The *Color naming task* assesses processing speed and lexical access abilities. In this task, the child is presented with a sheet displaying blocks of differently colored circles. Their is instructed to name the colors as quickly as possible, moving from left to right like reading. The final score is calculated by dividing the number of correctly named colors by the time taken to complete the task, providing an inverse efficiency score.

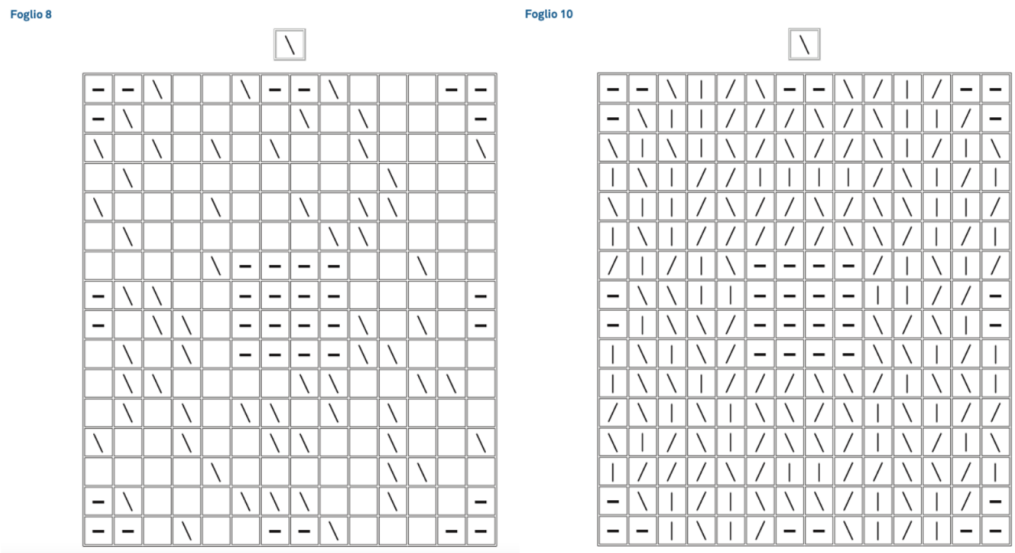
The *Graphical fluency test* assesses cognitive flexibility, generative thinking, and goal maintenance, while also requiring fine motor skills. In this task, the child is asked to create as many different configurations as possible using five dots within one minute, across two separate sheets (see **Figure 3.1**). For each sheet, three parameters are recorded: the number of correct configurations produced (*accuracy parameter of Graphical fluency*), the number of errors made (*error parameter of Graphical fluency*), and the number of repeated drawings (*perseveration parameter of Graphical fluency*). Scores from both sheets are then summed for each parameter, providing three accuracy parameters.

Figure 3.1 *Graphical fluency task*



The *Cancellation and visual search task* evaluate visual scanning ability, selective and sustained attention, spatial orientation, and inhibitory control, while also involving fine motor skills. In this task, the child is required to cross out specific lines on a sheet (see **Figure 3.2**). The main score is calculated by dividing the number of correctly identified items by the time taken to complete the task, providing an inverse efficiency score for each sheet. Additionally, the *Visual search parameter* isolates the visual search ability independent of fine-motor components. This is calculated by subtracting the time taken to complete sheet 8 (*sheet 8 of Cancellation*; representing the time needed to cross out all items without a time limit) from the number of items identified in sheet 10 (*sheet 10 of Cancellation*; assessing visual search within a 45-second limit). Thus, using the subtractive method, the fine-motor component can be removed from the visual search score. Moreover, sheet 7 (*sheet 7 of Cancellation*) requires the child to cross out as many items as possible within 30 seconds.

Figure 3.2 *Cancellation and visual search task*



The *Enumeration forward-backward task* assesses working memory, with a focus on attentive control, sustained attention, and mental representation. In this task, the child is asked to count aloud from 1 to 100 as quickly as possible (*forward condition of Enumeration*) and then count backward from 100 to 1 (*backward condition of Enumeration*). Scores for each condition are calculated by dividing the time taken to complete the task by the number of correct numbers recited, providing an inverse efficiency score for each condition. The total score is derived by subtracting the forward condition score from the backward condition score, providing an index of working memory by accounting for and removing the contribution of speech articulation speed.

The *Categorization task* assesses working memory. In this task, the examiner reads out a list of words of increasing length, and at the end of the list, the child is instructed to recall and repeat only the words belonging to a specific category (such as animals, objects, colors, or cities), providing an accuracy score.

The *PASOT task* measures working memory using an n-back paradigm. In this task, the child hears a sequence of unrelated words (e.g., war-peace, nice-ugly, right-wrong, above-below) and is required to say the opposite of the word presented before the last one. The intertrial interval is 2400ms (*PASOT 2400ms*) in the first condition and 800ms (*PASOT 800ms*) in the second. Each condition yields a score based on the number of correct responses, and the PASOT total score is calculated by summing the results from both conditions, providing an accuracy parameter.

3.2.3 Procedure

All assessments were conducted individually in a quiet setting, either at the ODFLab or in the child's school by trained master's students in Clinical Psychology or psychologists. Each participant completed Color naming, Graphical fluency, Cancellation and visual search, Enumeration, Categorization, and PASOT tasks. To minimize order effects, tasks were presented in a randomized sequence.

3.2.4 Analytic plan

Data were standardized prior to analysis. The data were normalized through *z-score* standardization, in which each variable was centered by its mean and scaled by its standard deviation, yielding zero-mean, unit-variance variables ($M = 0, SD = 1$). Sample adequacy was evaluated with the Kaiser-

Meyer-Olkin (KMO) test and Bartlett's test of sphericity. The latent structure of the dataset was examined using Exploratory Factor Analysis (EFA). The EFA was performed on standardized (*z-scores*) variables, which in this case is preferable because it ensures that all variables contribute equally to the factor solution regardless of their original scales. Only the subtests were included, excluding the composite scores (Visual search, Enumeration, and PASOT) due to their high correlations with the underlying submeasures. Initial extraction was performed with maximum likelihood estimation, and an oblimin rotation was applied to allow for correlated factors, as expected from theory. Factor retention was first explored through visual inspection of the scree plot, followed by two complementary robust procedures: Horn's parallel analysis, comparing observed eigenvalues to those obtained from randomly generated data, and Velicer's Minimum Average Partial (MAP) test, which identifies the dimensionality that minimizes residual common variance. After determining plausible factor solutions, EFAs were estimated and evaluated on multiple indices of fit: the likelihood ratio χ^2 test of model adequacy, the root mean square error of approximation (RMSEA) with 90% confidence intervals, the Tucker-Lewis Index (TLI), the standardized root mean square residual (SRMR), and the Bayesian Information Criterion (BIC). Factors score adequacy was also assessed through the correlation of regression-based scores with the extracted factors, their squared multiple correlations, and the minimum possible correlation estimates. The final model was selected by integrating evidence from factor retention criteria, global and residual fit statistics, parsimony indices, and the theoretical interpretability of the resulting factor structure. Factor internal consistency was evaluated with Cronbach's alpha and McDonald's total ω for single factors. The statistical analysis was performed in RStudio software using the *stats* package for descriptive analysis (R Core Team, 2024) and *psych* for exploratory factor analysis (Revelle, 2023). Descriptive statistics for the raw scores of each task are presented in **Table 3.3**, as they offer greater interpretability than z-scores, which can lose their inherent unit of measurement.

Table 3.3 *Descriptive statistics of the sample*

Variables	*n*	M	SD	min	max
Color naming	227	27.37	8.28	15	81
Graphical fluency (accuracy)	227	23.54	8.1	1	43
Graphical fluency (error)	227	2.33	2.65	0	15
Graphical fluency (perseveration)	227	5.01	7.61	0	50
Cancellation (sheet 7)	227	0.8	0.33	0.33	2.31

Cancellation (sheet 8)	227	0.92	0.4	0.49	3.58
Cancellation (sheet 10)	227	1.84	0.71	0.75	7.5
Visual search	227	0.76	2.38	-34	5.12
Enumeration (forward)	227	65.2	17.79	42	164
Enumeration (backward)	227	97.49	43.55	37	378
Enumeration forward-backward	227	33.12	34.76	-9	236
Categorization	227	14.72	9.51	1	66
PASOT (1200ms)	227	43.37	13.43	1	60
PASOT (800ms)	227	37.93	12.53	2	60
PASOT	227	81.31	24.68	6	120

Note. ***n*** *= subjects;* ***M*** *= mean;* ***SD*** *= standard deviation;* ***min*** *= minimum score;* ***max*** *= maximum score.*

3.3 Results

KMO measure indicated overall good sampling adequacy (MSA = 0.80), with individual item MSAs ranging from 0.71 (sheet 8 of Cancellation) to 0.94 (accuracy parameter of Graphical fluency). Bartlett's test of sphericity confirmed that the correlation matrix was factorable, $\chi^2(45) = 1049.01$, $p < .001$. An exploratory examination of the scree plot suggested the retention of two to three factors. Horn's parallel analysis indicated a three-factor solution, whereas Velicer's Minimum Average Partial (MAP) test supported a two-factor solution (MAP = 0.05). Very Simple Structure (VSS) analysis showed that a single-factor solution performed best under the simplest structure (complexity-1, VSS1 = 0.78), while a two-factor solution performed best at complexity-2 (VSS2 = 0.76), suggesting that multiple-factor solutions were plausible. Information criteria favored the three-factor solution (BIC = -73.44, SABIC = -16.39). Based on these combined retention criteria, only the two- and three-factor solutions were considered for EFA model fitting, as a single-factor solution would be insufficient to capture the multidimensional structure of the data, and solutions with more than three factors did not improve fit or interpretability.

A two-factor EFA explained 51% of the variance (SS loadings = 2.75, 2.34) but demonstrated suboptimal fit: $\chi^2(26) = 124.27$, $p < .001$; RMSEA = 0.129 (90% CI = 0.107-0.153); TLI = 0.83; RMSR = 0.07; BIC = -16.78. Factor intercorrelation was moderate (r = 0.38), and several items

showed cross-loadings, suggesting that the two-factor model lacked clear construct separation. Cancellation tasks loaded coherently, while remaining items clustered ambiguously.

The three-factor EFA accounted for 60% of the variance (SS loadings = 2.21, 2.19, 1.64) and showed markedly improved fit: $\chi^2(18) = 24.21$, $p = 0.15$; RMSEA = 0.039 (90% CI = 0.00-0.076); TLI = 0.98; RMSR = 0.03; BIC = -73.44. Factor correlations were moderate (r = 0.34-0.50), and factor score adequacy was excellent, with regression-based scores correlating 0.95-1.00 with the latent factors and minimum determinacy correlations between 0.81 and 0.99.

Communalities indicated that most items were well represented by the three-factor model: PASOT (1200ms) and PASOT (800ms) exhibited high saturation (>0.75), whereas Color naming, Categorization, and accuracy of Graphical fluency had lower communalities (<0.30). Cancellation (sheet 8) and the backward condition of Enumeration had near-unit communalities (>1.0). Examination of residuals revealed minimal misfit, with RMSR = 0.03, df-corrected RMSR = 0.04, and SRMR = 0.026; higher residuals corresponded to items with lower communalities, consistent with their lower shared variance.

Factor reliability was satisfactory across all factors. Factor 1 (ML3: PASOT 1200ms, PASOT 800ms, accuracy of Graphical fluency, Categorization) had Cronbach's $\alpha = 0.78$ (95% CI: 0.73-0.83) and McDonald's $\omega\_total = 0.80$. Factor 2 (ML2: sheet 8 of Cancellation, sheet 7 of Cancellation, sheet 10 Cancellation) demonstrated Cronbach's $\alpha = 0.85$ (95% CI: 0.81-0.88) and $\omega\_total = 0.86$. Factor 3 (ML1: backward condition of Enumeration, Color naming, forward condition of Enumeration) showed acceptable internal consistency with $\alpha = 0.75$ (95% CI: 0.68-0.80) and $\omega\_total = 0.77$.

3.4 Discussion

This study investigated the structure of executive attention functions in neurodiverse children aged 8-16 using a comprehensive, multidimensional task battery (*Measures of Executive Attention*; Benso et al., 2019). The EFA revealed three main latent factors: the first linked PASOT conditions with accuracy parameter of Graphical fluency and Categorization, the second corresponded to Cancellation subtests, and the third associated Color naming with Enumeration (both backward and forward conditions). The discussion integrates two complementary perspectives: a theoretical interpretation of the latent constructs and a methodological reflection on their measurement.

3.4.1 Latent constructs across executive attention measures

Although it is difficult to isolate entirely unique and clearly separable dimensions of EFs, such as working memory, cognitive flexibility, and inhibition, because any given task simultaneously engages multiple executive and non-executive processes (Benso, 2018; Enkavi et al., 2019; Rabbitt, 1997; Snyder et al., 2015; Tiego et al., 2020), the involvement of these abilities may be more pronounced in certain tasks than in others. This differential engagement allows for the association of specific cognitive functions with each identified factor (Miyake et al., 2000). Therefore, the first factor, given by PASOT conditions with accuracy parameter of Graphical fluency and Categorization tasks, primarily reflects working memory and cognitive flexibility, with additional involvement of linguistic or fine-motor processes. The second factor, providing by Cancellation subtest, is associated with Visual search and inhibitory control, with a stronger contribution from fine-motor skills. While, the third factor, given by Color naming with Enumeration, represents primarily working memory in combination with linguistic abilities. Notably, the other two Graphical fluency parameters (perseveration and error) were not associated with any factor, suggesting their independence from the three latent constructs identified. The three-factor solution reflects both the shared and distinct aspects of executive functioning (Friedman & Miyake, 2017; Miyake et al., 2000). The second factor demonstrated weak to moderate correlations with the other two factors, indicating that it represents a relatively distinct component of executive functioning, primarily reflecting inhibitory control. In contrast, the first and the third factors were more strongly correlated, suggesting shared functional overlap while remaining separable constructs. This overlap is likely driven by common working memory demands, with the first factor also reflecting a unique contribution of cognitive flexibility. Overall, the pattern of communalities, residuals, and factor reliabilities supports the interpretability and robustness of the three-factor model in school-aged neurodiverse children, consistent with previous studies (Karr et al., 2018; Miyake et al., 2000; Yangüez et al., 2025).

3.4.2 Methodological implications: the impact of task choice

Previous research highlighted that results are often highly sensitive to the arbitrary selection of tasks, which vary widely across studies (Messer et al., 2018; Poldrack, 2006). Factorial solutions can therefore be unstable and lack generalizability, providing high variability and inconsistencies in findings (Draheim et al., 2021; Karr et al., 2018). The latent factorial structures that emerged between tests may also depend more on the type of index used than on a shared underlying cognitive construct, highlighting an important reflection on the choice of the index that a task provided (Yangüez et al.,

2024). Attributing a specific construct in this context risks creating a circular argument, as most tasks simultaneously engage multiple executive and non-executive processes, making it difficult to determine which specific process is being measured (Karr et al., 2018). From this perspective, convergence among results likely reflects similarities in task indices rather than shared cognitive mechanisms. Consistent with this view, Messer et al. (2018) showed that using tasks with highly similar demands tends to yield a more coherent and robust latent factor. Accordingly, it may be proposed that a reformulation of the factors based on task-specific indexes and the non-executive abilities involved in task execution: the first factor (PASOT, graphical fluency, and Categorization tasks) is defined by accuracy index and incorporates linguistic or fine-motor demands; the second factor (cancellation tasks) is characterized by inverse efficiency scores, reflecting contributions from fine-motor abilities; and the third factor (color naming and enumeration tasks) is also defined by inverse efficiency scores, but with greater involvement of verbal components. Interestingly, the use of composite measures such as the inverse efficiency score yielded a clearer distinction among executive attention tasks, particularly differentiating those dependent on verbal abilities from those requiring visuospatial processing. This underscores the methodological value of composite indices in delineating broader cognitive domains within EF assessments. Rather than highlighting distinctions strictly between EF components, this approach may reveal a stronger differentiation between these two broader cognitive domains. Both verbal and visual-spatial abilities are closely linked to executive functioning performance, suggesting that general cognitive abilities exert a significant influence on the structure of EFs (Salthouse, 2005; Stephens et al., 2018). Considering the broader cognitive processes involved in task execution may help to better differentiate EF tasks. At the same time, this perspective also suggests that the structured tasks commonly highlighted in the literature may reflect general cognitive abilities more than specific EF skills. Once again, these findings support recent studies recommending that EFs be analyzed from a broader, multidimensional perspective, rather than focusing on discrete domains. A reductionist approach, by contrast, may increase variability in the findings and limit generalizability (Barrett & Kurzban, 2006; Benso et al., 2025; Bernstein & Waber, 2007; Cohen & D'Esposito, 2016; Pietraszewski & Wertz, 2022). Thus, discussing the structure of EFs from a methodological standpoint may help explain the inconsistencies reported in previous studies, where EF tasks are often weakly associated with each other (Karr et al., 2018; Miyake et al., 2000). Moreover, this perspective may help address key limitations related to task selection and scoring methods in studies that used confirmatory factor approaches, offering a more nuanced understanding of the organization of executive functioning in school-aged neurodiverse children and shedding light on important challenges in developing these instruments.

3.4.3 Limitations and future directions

This study has a few methodological limitations. First, the task battery consisted of measures that do not assess discrete functions individually, but rather overall executive attention functioning. While this makes confirmatory factor analysis more challenging, it supports the use of exploratory factor models. Second, the wide age range suggests that increasing the sample size could enable exploratory factor analyses within narrower age groups, which could subsequently be verified through confirmatory factor methods. Collecting additional data would be especially valuable for tasks assessing working memory, such as Categorization, Enumeration (forward and backward), and PASOT. Additionally, the absence of group-specific analyses represents a limitation, as the current EFA outcomes are derived from a mixed sample and therefore lack group specificity. Given that the typically developing cohort constitutes a substantially larger proportion of the total sample (with a ratio exceeding 2:1), the integrated EFA results are likely to predominantly reflect the latent factor structure characteristic of the neurotypical group, potentially obscuring meaningful differences within the neurodivergent subgroup. However, the available data did not permit separate group analyses due to statistical limitations. The collection of additional data would enable a more detailed examination of the structure of executive attention, allowing for differentiation between neurodivergent and neurotypical children. Finally, this EFA was conducted using multiple task-specific indices. Future studies should compare composite task scores (e.g., PASOT, Cancellation tests, Enumeration). Examining convergent or comparable indices may help to confirm or refute the present interpretation by yielding more comparable measures and a broader range of assessment values. This approach would provide stronger support for the current findings and allow for a more refined examination of executive function structural models.

3.5 Conclusion

This study may help overcome key limitations related to task selection and scoring methods in prior research using confirmatory factor approaches, providing a more nuanced understanding of EF organization in school-aged neurodiverse children and highlighting challenges in developing effective assessment tools. In this population, executive attention functions are represented by a three-factor structure, which can be interpreted from both theoretical and methodological perspectives. The first factor, linked to PASOT conditions and the accuracy parameter of Graphical fluency and

Categorization, was mainly defined by accuracy and involved linguistic or fine-motor demands. The second factor, encompassing Cancellation tasks, was characterized by inverse efficiency indices, reflecting fine-motor contributions. The third factor, connecting Color naming with forward and backward conditions of the Enumeration task, was also defined by inverse efficiency indices but relied more heavily on verbal components. Within this framework, inhibitory control (the second factor) emerges as a relatively distinct construct, whereas the first and the third factors were strongly correlated, reflecting shared working memory demands, with the first factor additionally capturing cognitive flexibility, illustrating both separable and interconnected aspects of executive functioning. Importantly, task selection and scoring methods, particularly composite indices such as inverse efficiency scores and accuracy parameters, substantially influence the observed factor structure, enabling clearer differentiation between cognitive domains (verbal versus visuo-spatial). By accounting for task-specific demands and non-executive contributions, researchers can develop a more interpretable model of EF organization, address limitations of previous approaches, and inform the design of more precise assessment instruments for neurodiverse children.

Chapter 4

Convergence between mother-father reports and laboratory-home measures of executive functioning in a sample of neurodiverse children

Summary

Executive function tasks based on performance often lack ecological validity and tend to show weak agreement with parent reports, which are generally viewed as more accurate reflections of children's everyday functioning, both in neurotypical and neurodivergent populations. This study explored how closely mothers' and fathers' ratings of their child's executive functioning align. It also assessed the consistency between parent reports, measured using the widely recognized the Behavior Rating Inventory of Executive Function-2, and six performance-based tasks, from the Measures of Executive Attention Battery, in a neurodiverse sample of 142 children aged 5 to 16. Results showed no significant differences between mother and father ratings and neurodivergent children showed lower performance on both types of measures. Regarding the association between performance-based tasks and parental reports, convergences between these measures were observed only in the full sample, while those disappeared when diagnostic groups were included. This pattern suggests that the observed convergence may be primarily driven by between-group differences in executive functioning

rather than by strong within-group correspondence. Overall, these findings highlight the continued importance of integrating multiple assessment methods to provide a more comprehensive and nuanced understanding of executive functioning across neurodiverse populations.

Keywords

Executive functioning; parent ratings; performance-based assessments; neurotypical children; neurodivergent children; concurrent validity

Key points

- Fathers and mothers report similar perceptions of their children's executive functioning in both neurotypical and neurodivergent children.
- Parent ratings show alignment with performance-based assessments of executive functioning only in the full sample.
- No convergence between contextual measures is observed when diagnostic groups are included.
- Neurotypical children show higher performance on both performance-based measures and parent-reports of executive functions compared to neurodivergent children.

4.1 Introduction

Executive Functions (EFs) can be evaluated using ecologically valid tools, such as questionnaires completed by parents or teachers, as well as using performance-based tasks that focus on metrics such as accuracy and reaction time. Informant reports are designed to capture behavioral patterns across extended periods, offering a more accurate representation of everyday functioning (Doebel & Müller, 2023; Holochwost et al., 2023). In contrast, performance-based tasks are administered under standardized conditions, aiming to elicit deliberate cognitive control. However, the ecological limitations of performance-based tasks have been widely noted in the literature (Krieger & Amador-

Campos, 2018; Mahone et al., 2002; Williams et al., 2022), lacking in the correspondence between different informant ratings (e.g., parent versus teacher reports) and between ratings and laboratory-based measures, particularly within neurodiverse populations (refers to **Chapter 1, Section 1.6.1** for further details).

4.1.1 Perceptions of child's executive functioning by different informants

Mothers have traditionally been regarded as the main caregivers, primarily due to their greater involvement in early caregiving. Nonetheless, recent research emphasizes that both parents contribute significantly to the child's development. Evidence suggests that maternal and paternal influences on the development of EFs are comparable in magnitude, though largely independent of one another (Lucassen et al., 2015; Meuwissen & Englund, 2016; Ribner et al., 2022). Despite this, no studies to date appear to have directly examined the level of agreement between mothers' and fathers' evaluations of their child's executive functioning in everyday contexts, particularly within neurodiverse populations. In many cases, studies use either parent's report interchangeably, with a tendency to prioritize maternal ratings as the primary source of information regarding executive functioning in ecological contexts. Existing research has instead largely focused on discrepancies between parent and teacher reports, given that these informants observe the child in distinct environments, home and school, respectively. For example, Van Tetering and Jolles (2017) reported that, among neurotypical children aged 9 to 12, parents tended to rate their children higher in planning skills, whereas teachers observed stronger self-control and self-monitoring. Similar divergences in ratings have been documented among neurodivergent groups, including autistic children (Tschida & Yerys, 2022). Understanding the perspectives of caregivers remains essential, as they serve as the child's primary social partners throughout development. Their observations offer meaningful insight into real-world executive functioning and can complement clinical assessments, particularly in the context of neurodiversity (Bitsika & Sharpley, 2019).

4.1.2 Associations between contextual measures in neurotypical children

The extent to which different assessment methods converge in evaluating EFs has been addressed in only a limited number of studies. For instance, Morasch and Bell (2011) identified significant correlations between parent-reported measures and laboratory-based tasks assessing inhibitory control in toddlers. Similarly, Kälin and Roebers (2021) observed associations between EF task performance and parental evaluations of self-regulation, while Faridi et al. (2015) reported links between task-based and parent-rated assessments of working memory, inhibition, and emotional regulation. Despite these findings, several studies have highlighted weak or inconsistent relationships between performance-based tasks and rating scales. A meta-analysis by Toplak et al. (2013), which examined 20 studies across a developmental range from preschool to adulthood, found significant correlations between task and rating measures in only 24% of cases. These authors proposed that the two types of assessments may be capturing fundamentally different constructs: while performance-based tasks assess cognitive efficiency under controlled conditions (e.g., inhibition), rating scales reflect how such skills are deployed in real-life, goal-directed contexts. Supporting this distinction, Mareva et al. (2024) suggested that performance tasks primarily measure state-like cognitive functioning under optimal testing conditions, whereas rating scales capture more stable, trait-like patterns of executive control observable in daily behavior. Similarly, Dang et al. (2020) reported low convergent validity between EF assessments targeting the same domains but relying on different methods. Ten Eycke and Dewey (2016) further concluded that task-based and rating-based measures engage distinct neurodevelopmental processes, such as motor coordination and attentional functioning, reinforcing the notion that they reflect separate but complementary aspects of EF.

4.1.3 Associations between contextual measures in neurodiverse populations

The assessment of EFs in neurodiverse populations introduces additional layers of complexity. Some studies have identified positive associations across various EF assessments, including performance-based tasks, observer evaluations, and parental reports, in neurodiverse samples. For example, Anderle et al. (2026) observed such associations in children as young as 20 months. Similarly, Golshan et al. (2019) reported correlations between task-based and parent-reported EF measures in autistic children, though the sample size was limited. Despite a few findings of convergence, particularly those involving toddlers and preschoolers, most studies reveal inconsistencies across

assessment methods, especially with school-aged children. McAuley et al. (2010), for instance, found no significant correlations between parent and teacher ratings and performance-based EF tasks in a neurodiverse cohort aged 6 to 15 years. In a large-scale study of 566 children with various neurodevelopmental conditions aged 8 to 18 years, Mareva et al. (2024) identified three distinct EF profiles: one characterized by impairments across both rating and task-based measures, and two others showing difficulties predominantly in either domain. These findings suggest that the degree of convergence may depend on the specific EF profile of the individual child. Further discrepancies emerge when focusing on specific neurodivergent groups. Autistic individuals, for instance, are often reported by parents and teachers to experience EF difficulties in daily life, yet such challenges are frequently not detected by performance-based assessments, raising concerns about the ecological validity of these tools (Leung et al., 2016; Jones et al., 2018). Gomez-Perez et al. (2016) found no significant differences between autistic and neurotypical children (aged 7-12) on most EF tasks, whereas parental ratings indicated stronger executive functioning in neurotypical peers. Similar inconsistencies were noted by Sankalaite et al. (2025) in autistic participants aged 8-18. Parallel patterns are evident in other neurodevelopmental conditions. For example, in children with ADHD, studies have often reported limited overlap between task-based and rating-based EF assessments (Krieger & Amador-Campos, 2018; Mahone et al., 2002). Tan et al. (2018) found no substantial performance-based differences between children with various Attention-Deficit/Hyperactivity Disorder subtypes and neurotypical controls aged 6-15 years, while parent ratings highlighted significant executive difficulties. Likewise, Williams et al. (2022) reported that children with learning difficulties exhibited marked impairments in behavior-based ratings that were not reflected in their performance on EF tasks.

4.1.4 Aims and hypotheses

The present study aims to analyze the convergence between informants' perceptions and between performance-based and parent reports of executive functioning in a neurodiverse sample aged 5 to 16 years, and whether these relationships vary as a function of neurodiversity. Specifically, a multidimensional set of performance-based tasks from the Measures of Executive Attention Battery (MEA; Benso et al., 2019) is employed alongside a well-established parent-report measure of everyday executive functioning: the Behavior Rating Inventory of Executive Function-Second Edition (BRIEF-2; Gioia et al., 2015).

Given the lack of research directly comparing maternal and paternal perspectives, despite their interchangeable use in previous studies, no significant differences are anticipated between the ratings provided by mothers and fathers, regardless of the child's neurodevelopmental status. Additionally, it is hypothesized that performance-based measures would demonstrate moderate correlations with parent ratings across both neurotypical and neurodivergent groups, although previous findings on this topic have been inconsistent within neurodiverse populations, primarily due to the different constructs evaluated (Mareva et al., 2024; McAuley et al., 2010). This expectation is grounded in the ecological validity principles on which the tasks were developed (Benso et al., 2019) and supported by earlier research showing similar associations (Anderle et al., 2026; Toplak et al., 2013). Finally, it is expected that children with neurodevelopmental conditions would exhibit lower scores on both parent-rated and task-based EF measures compared to neurotypical peers (Berenguer et al., 2018; Demetriou et al., 2018; Townes et al., 2023).

4.2 Methods

4.2.1 Participants

The study sample consisted of 142 children aged between 5 and 16 years, representing a neurodiverse population. Among these participants, 39% (n = 55) had received at least one developmental diagnosis. Autism Disorders were the most common diagnosis (n = 37), followed by Specific Learning Disorders (n = 15), with a smaller subset diagnosed with Attention-Deficit/Hyperactivity Disorders (n = 3). Recruitment took place primarily in inclusive Italian schools, where classrooms comprised both neurotypical and neurodivergent students. Additional participants were enrolled through the ODFLab (Laboratory of Observation, Diagnosis, and Education) at the Department of Psychology and Cognitive Science, University of Trento, Italy. No significant differences emerged between neurotypical and neurodivergent children in fluid intelligence index, as assessed by the Matrix reasoning subtest of the Wechsler Intelligence Scale for Children-IV (Orsini et al., 2015; p = .10). Further details regarding sample characteristics are provided in **Table 4.1**.

Table 4.1 *Sample's description*

	Neurotypical					**Neurodivergent**				
Sex	**Male (%)**	**Female (%)**				**Male (%)**	**Female (%)**			
	48 (55%)	39 (45%)				46 (84%)	9 (16%)			
	n	**M**	**SD**	**min**	**max**	***n***	**M**	**SD**	**min**	**max**
Age	87	9.51	2.39	6	15	55	10.98	2.08	7	16
RM	87	-0.25	0.99	-3.08	2.42	55	-0.18	1.40	-7.88	1.56

Note. n *= subjects;* ***M*** *= mean;* ***SD*** *= standard deviation;* ***min*** *= minimum score;* ***max*** *= maximum score.* ***RM*** *= Matrix reasoning of the Wechsler Intelligence Scale for Children-Fourth Edition (Orsini et al., 2015).*

4.2.2 Procedure

All assessments were carried out individually in a quiet room, either at the ODFLab or within the participants' schools by trained master's students in Clinical Psychology or psychologists. Children completed an age-appropriate set of executive attention tasks drawn from the *Measures of Executive Attention* battery (MEA): those aged 5 to 7 years were given the Color naming, Graphical fluency, and Cancellation and visual search tasks, while participants aged 8 to 16 years completed a more extensive battery that included these tasks along with Enumeration, Categorization, and PASOT. The order of task administration was randomized to reduce potential sequence effects. Additionally, parents were asked to complete a questionnaire (the *Behavior Rating Inventory of Executive Function-2*, BRIEF-2) assessing their child's executive functioning in everyday settings. Although both mothers and fathers were invited to respond, not all families returned the completed questionnaires. **Table 4.2** shows the percentage completion rate of each test.

Table 4.2 *List of tasks and n participants that completed each task*

Tasks	***n***	***n* missing**	**% complete rate**
Measures of Executive Attention			
Color naming	142	0	100
Graphical fluency	142	2	98.59
Cancellation and visual search	142	1	99.30

Enumeration	113	2	98.23
Categorization	113	0	100
PASOT	113	20	82.30
Behavior Rating Inventory of Executive Function-2			
Mothers	142	0	100
Fathers	142	23	83.80

Note. ***n*** *= represent the number of participants required to complete each task.*

4.2.3 Materials

Executive attention was assessed through the six performance-based tasks selected from the *Measures of Executive Attention (MEA) battery* (Benso et al., 2019). A brief description of the task is provided in **Table 4.3**, while for detailed information on the tests, the procedure of administration and scoring refer to **Chapter 3** (**Section 3.2.2**). For each measure, standardized *z-scores* (*M = 0, SD = 1*) were calculated, with higher scores reflecting greater abilities, using as a reference the values obtained from a sample of 206 neurotypical children (see **Appendix B** for more details) due to the adaptation of a few tasks compared the original tests.

Table 4.3 *Brief description of the Measures of Executive Attention Tasks*

Task	Description
Color naming	Denominate verbally the name of the colors as quickly as possible. Derived from the studies of Denckla and Rudel (1976), this task represents the final output of a processing stream involving the integration of attentional and mnemonic processes, culminating in a relative automatization of verbal label retrieval.
Graphical fluency	Draw various configurations, using 5 points, in a minute providing different measures (accuracy, errors and perseverations). Adapted and modified from the Five-Point Test by Regard et al. (1982), this task is widely used in clinical settings, particularly in the assessment of frontal lobe syndromes (see also Tucha et al., 2012).
Cancellation and visual search	This task requiring participants to mark only the target items on various sheets (sheets 7 and 8 assess fine-

	motor speed; sheet 10 assess fine-motor speed in combination with visual search speed).
Enumeration forward-backward	Tell the number from 1 to 100 (forward condition) as quickly as possible and then from 100 to 1 (backward condition).
Categorization	Repeat only the words verbally provided by the examiner that belong to a specified category. This task is derived from the studies of Haarmann et al. (2003), who developed a *conceptual span task* in which list recall had to be recognized according to semantic elements. It requires active manipulation within working memory. Conceptual span performance showed higher correlations with reading comprehension and problem-solving abilities.
Paced Auditory Serial Opposites Task (PASOT)	Say the opposite of the word heard just before the last one in two different timing between the stimuli (1200ms and 800ms). This task is adapted and modified from Gow and Deary (2004) and consists of a demanding *n-back-like task*. It assesses working memory updating and manipulation, involving attentional and executive control processes.

The *Behavior Rating Inventory of Executive Function-2* (BRIEF-2; Gioia et al., 2015), is a standardized questionnaire completed by parents to assess everyday executive functioning in children and adolescents aged 5 to 18. Respondents rate behaviors on a three-point scale (never, sometimes, often), providing insights into practical executive challenges. The BRIEF-2 evaluates multiple dimensions of executive functioning, organized into three primary indices as well as an overall composite score. The Behavioral Regulation Index (BRI) includes subscales for Inhibit, which measures impulse control and the ability to appropriately interrupt behaviors, and Self-monitor, which assesses real-time self-awareness and behavior adjustment. The Emotional Regulation Index (ERI) consists of Shift, assessing cognitive flexibility and task-switching capacity, and Emotional regulation, which evaluates control over emotional reactions. The Cognitive Regulation Index (CRI) comprises Initiate, referring to the ability to independently begin tasks and generate ideas; Working memory, involving the maintenance and manipulation of information during task performance; Plan/organize, reflecting the capacity to anticipate and sequence steps toward goals; Task monitor, which measures the ability to evaluate one's performance and detect errors; and Organization of materials, indicating the maintenance of order in personal belongings and spaces. Together, these three indices form the Global Executive Composite (GEC), which provides a comprehensive profile

of executive functioning in daily life. Scores are expressed as *T-scores* (*M = 50, SD = 10*), where higher scores denote greater difficulties in executive functioning.

4.2.4 Analytic plan

Statistical analyses were performed using RStudio (R Core Team, 2024). The significance threshold is set at $\alpha = .05$. For performance-based tasks (MEA, Benso et al., 2019), only composite scores were considered. Thus, the variables included in the following analyses were: Color naming, accuracy, error and perseveration parameters of Graphical fluency task, Visual search, Enumeration forward-backward, Categorization, PASOT. The assumptions of normality and homoscedasticity were assessed through the Shapiro-Wilk test and Levene's test, respectively. Due to violations of these assumptions, non-parametric methods were employed. Comparisons between mothers' and fathers' reports of executive functioning within the neurodiverse sample were conducted using the Wilcoxon rank-sum test, which was also utilized to compare performance between neurotypical and neurodivergent children. Given the absence of significant differences between parent reports in both the overall sample and subgroups, mother reports were selected for further analysis, as a greater number of mothers completed the questionnaires. Relations between mother-reported executive functioning and performance-based executive attention measures were examined using Generalized Linear Models (GLMs), controlling for sex and age. Additionally, an interaction term was included to evaluate whether group status (neurotypical versus neurodivergent) moderated these associations. To account for multiple testing and the increased risk of Type I error, p-values were adjusted using Holm's correction. Descriptive statistics are provided in **Tables 4.4** and **4.5**.

Table 4.4 *Descriptive analysis of mothers' and fathers' executive functioning questionnaires (Behavior Rating Inventory of Executive Function-2)*

	Sample						Neurotypical						Neurodivergent					
Variables	**mother**			**father**			**mother**			**father**			**mother**			**father**		
BRIEF-2	***n***	**M**	**SD**	***n***	**M**	**SD**	***n***	**M**	**SD**	***n***	**M**	**SD**	***n***	**M**	**SD**	***n***	**M**	**SD**
Inhibit	142	54.49	12.01	119	53.03	11.87	87	50.14	9.32	69	50.57	11.12	55	61.38	12.62	50	56.44	12.15
Self-monitor	142	53.23	11.43	119	53	12.54	87	48.21	8.78	69	47.87	10.31	55	61.18	10.63	50	60.08	11.95
BRI	142	54.45	11.83	119	53.31	12.47	87	49.45	9.05	69	49.29	10.91	55	62.36	11.44	50	58.86	12.45
Shift	142	55.06	13.7	119	53.66	12.85	87	48.79	9.26	69	48.78	10.8	55	64.98	13.78	50	60.38	12.5
ER	142	52.12	11.9	119	51.7	12.01	87	48.03	9.31	69	48.55	10.98	55	58.58	12.74	50	56.04	12.13
ERI	142	53.96	13.22	119	52.54	13.54	87	48.23	9.05	69	48.35	11.4	55	63.04	13.74	50	58.32	14.23
Initiate	141	54.14	11.57	118	53.92	12.99	87	49.3	8.72	69	49	10.29	54	61.94	11.4	49	60.84	13.32
WM	141	54.11	12.16	118	52.66	10.85	87	49.7	10.07	69	49.75	9.14	54	61.22	11.93	49	56.76	11.81
Plan	142	52.13	13.91	119	50.61	12.74	87	47.86	11.26	69	48.23	11.05	55	58.89	15.09	50	53.88	14.22
Task monitor	142	54.21	12.1	119	52.14	11.96	87	50.18	10.69	69	48.07	9.79	55	60.58	11.53	50	57.76	12.49
Organization	142	52.62	10.97	119	51.77	10.89	87	50.31	9.52	69	49.97	9.99	55	56.27	12.16	50	54.26	11.68
CRI	142	54.37	11.83	119	53.29	10.76	87	49.55	9.67	69	49.06	9.57	55	62	10.94	50	59.12	9.58
GEC	142	55.14	12.48	119	54.17	11.66	87	49.46	9.26	69	49.16	9.4	55	64.13	11.67	50	61.08	10.98

Note. ***n*** *= subjects;* ***M*** *= mean;* ***SD*** *= standard deviation.* ***BRI*** *= Behavioral Regulation Index,* ***ER*** *= Emotional Regulation,* ***ERI*** *= Emotional Regulation Index,* ***WM*** *= Working memory,* ***Plan*** *= Plan/Organize,* ***Organization*** *= Organization of materials,* ***CRI*** *= Cognitive Regulation Index,* ***GEC*** *= Global Executive Composite.*

Table 4.5 *Descriptive analysis of executive attention measures (Measures of Executive Attention)*

Variables	**Sample**					**Neurotypical**					**Neurodivergent**				
MEA	***n***	**M**	**SD**	**min**	**max**	***n***	**M**	**SD**	**min**	**max**	***n***	**M**	**SD**	**min**	**max**
Color naming	142	-0.95	2.75	-28.03	1.64	87	-0.23	1.08	-4.89	1.64	55	-2.09	3.96	-28.03	1.55
GF (accuracy)	140	-0.58	1.23	-4.62	3.58	86	-0.19	1.05	-2.2	3.58	54	-1.2	1.24	-4.62	1.71
GF (error)	140	-0.85	2.52	-14.25	1.25	86	-0.06	1.33	-5.49	1.25	54	-2.12	3.34	-14.25	1.06
GF (perseveration)	140	-0.62	2.11	-12.89	0.97	86	-0.26	1.4	-6.55	0.97	54	-1.2	2.83	-12.89	0.92
Visual search	141	-0.81	3.85	-39.86	2.63	86	-.30	1.28	-4.94	2.41	55	-.51	5.89	-39.86	2.63
Enumeration	111	-0.92	2.34	-11.54	1.5	66	-0.41	1.7	-10.12	0.98	45	-1.68	2.91	-11.54	1.5
Categorization	113	-0.34	1.08	-1.91	4.7	64	-0.05	1.21	-1.49	4.7	49	-0.71	0.72	-1.91	1.34
PASOT	93	-0.99	1.63	-6.5	1.51	58	-0.36	1.2	-3.8	1.51	35	-2.04	1.73	-6.5	0.99

Note. n *= subjects;* ***M*** *= mean;* ***SD*** *= standard deviation;* ***min*** *= minimum score;* ***max*** *= maximum score.* ***GF*** *= Graphical fluency.*

4.3 Results

4.3.1 Parents comparison

No significant differences were found between mothers' and fathers' ratings of children's executive functioning in everyday life, both in the overall neurodiverse sample and within the neurodivergent and neurotypical subgroups. Further details are provided in **Tables 4.6** and **4.7**.

Table 4.6 *Parents' comparison for the neurodiverse sample*

Variables	**mother**		**father**		
BRIEF-2	**M**	**SD**	**M**	**SD**	***p*[a]**
Inhibit	54.49	12.01	53.03	11.87	.46
Self-monitor	53.23	11.43	53	12.54	.86
BRI	54.45	11.83	53.31	12.47	.52
Shift	55.06	13.7	53.66	12.85	.64
Emotional regulation	52.12	11.9	51.7	12.01	.86
ERI	53.96	13.22	52.54	13.54	.64
Initiate	54.14	11.57	53.92	12.99	1.00
Working memory	54.11	12.16	52.66	10.85	.53
Plan/organize	52.13	13.91	50.61	12.74	.53
Task monitor	54.21	12.1	52.14	11.96	.24
Organization of materials	52.62	10.97	51.77	10.89	.56
CRI	54.37	11.83	53.29	10.76	.59
GEC	55.14	12.48	54.17	11.66	.65

Note. n *= subjects;* ***M*** *= mean;* ***SD*** *= standard deviation.* ***BRI*** *= Behavioral Regulation Index,* ***ERI*** *= Emotional Regulation Index,* ***CRI*** *= Cognitive Regulation Index,* ***GEC*** *= Global Executive Composite. [a] Test significance * p < .05, ** p < .01, *** p < .001.*

Table 4.7 *Parents' comparison within groups*

	Neurotypical					Neurodivergent				
Variables	**mother**		**father**			**mother**		**father**		
BRIEF-2	**M**	**SD**	**M**	**SD**	***p*[a]**	**M**	**SD**	**M**	**SD**	***p*[a]**
Inhibit	50.14	9.32	50.57	11.12	.69	61.38	12.62	56.44	12.15	.06
Self-monitor	48.21	8.78	47.87	10.31	1.00	61.18	10.63	60.08	11.95	.62
BRI	49.45	9.05	49.29	10.91	.90	62.36	11.44	58.86	12.45	.16
Shift	48.79	9.26	48.78	10.8	.93	64.98	13.78	60.38	12.5	.11
ER	48.03	9.31	48.55	10.98	.86	58.58	12.74	56.04	12.13	.39
ERI	48.23	9.05	48.35	11.4	.96	63.04	13.74	58.32	14.23	.18
Initiate	49.3	8.72	49	10.29	.96	61.94	11.4	60.84	13.32	.78
WM	49.7	10.07	49.75	9.14	.81	61.22	11.93	56.76	11.81	.07
Plan/organize	47.86	11.26	48.23	11.05	.82	58.89	15.09	53.88	14.22	.08
Task monitor	50.18	10.69	48.07	9.79	.23	60.58	11.53	57.76	12.49	.28
Organization	50.31	9.52	49.97	9.99	.81	56.27	12.16	54.26	11.68	.46
CRI	49.55	9.67	49.06	9.57	.82	62	10.94	59.12	9.58	.16
GEC	49.46	9.26	49.16	9.4	.91	64.13	11.67	61.08	10.98	.17

Note. n *= subjects;* ***M*** *= mean;* ***SD*** *= standard deviation.* ***BRI*** *= Behavioral Regulation Index,* ***ER*** *= Emotional regulation,* ***WM*** *= Working memory,* ***ERI*** *= Emotional Regulation Index,* ***Organization*** *= Organization of materials,* ***CRI*** *= Cognitive Regulation Index,* ***GEC*** *= Global Executive Composite.* [a] *Test sign. * p <.05, ** p <.01, *** p <.001.*

Convergence between executive functioning measures

After Holm's correction, GLMs revealed significant associations between various context-based measures (see **Table 4.8**). Most of the performance-based task scores correlated with the parent-reported GEC, except for perseverative errors in Graphical fluency and Enumeration. These associations varied across different BRIEF subdomains. Importantly, when group (neurotypical vs neurodivergent) was considered as a factor in the model, the previously observed convergence was no longer significant, except for working memory associate with the accuracy parameter of Graphical Fluency and Categorization task. Moreover, the relations between the Visual search and both shifting and task-monitoring were moderated by group status.

Table 4.8 *Associations between parent reports and performance-based measures of executive functioning*

Predictor (BRIEF-2)		Outcome (MEA)															
		Color		GF (accuracy)		GF (error)		GF (pers)		Visual		Enum		Cat		PASOT	
		CE	p^a (p^H)	CE	p^a (p^H)	CE	p^a (p^H)	CE	p^a (p^H)	CE	p^a (p^H)	CE	p^a (p^H)	CE	p^a (p^H)	CE	p^a (p^H)
Inhibit	**M1**	-.09	**<.001*** (<.001***)**	-.02	**.01* (.02*)**	-.06	**.002** (.008**)**	-.02	.12 (.35)	-.07	**.01* (.02*)**	-.03	.16 (.65)	-.02	**.04*** (.16)	-.04	**.007** (.03*)**
	M2	-.02	.40 (.57)	0.01	.68 (1.00)	-.01	.66 (1.00)	-.02	.45 (1.00)	-.005	.91 (.91)	-.02	.62 (1.00)	.01	.76 (1.00)	.001	.96 (1.00)
		-.09	**.03*** (.18)	-.03	.16 (.82)	-.03	.45 (1.00)	.01	.79 (1.00)	-.11	.05 (.25)	.01	.77 (1.00)	-.02	.35 (1.00)	-.04	.18 (1.00)
Self-monitor	**M1**	-.03	.16 (.32)	-.03	**.004** (.008**)**	-.05	**.02*** (.05)	-.01	.47 (1.00)	-.02	.55 (.55)	-.01	.53 (1.00)	-.02	.06 (.22)	-.04	**.01*** (.05)
	M2	.004	.90 (1.00)	-.002	.88 (1.00)	.01	.83 (1.00)	-.01	.83 (1.00)	.001	.98 (1.00)	.01	.72 (1.00)	.001	.96 (1.00)	-.01	.80 (1.00)
		.02	.68 (1.00)	-.02	.44 (1.00)	-.03	.52 (1.00)	.02	.56 (1.00)	-.02	.81 (1.00)	.01	.82 (1.00)	-.003	.87 (1.00)	-.02	.60 (1.00)
BRI	**M1**	-.07	**<.001*** (.001**)**	-.03	**.003** (.007**)**	-.06	**.003** (.01*)**	-.02	.13 (.40)	-.06	**.04*** (.07)	-.02	.26 (1.00)	-.02	.05 (.21)	-.05	**.004** (.01*)**
	M2	-.01	.65 (1.00)	.002	.88 (1.00)	-.01	.84 (1.00)	-.02	.46 (1.00)	-.004	.93 (.93)	-.004	.90 (1.00)	.01	.57 (1.00)	-.003	.89 (1.00)
		-.07	.12 (.85)	-.02	.21 (1.00)	-.03	.42 (1.00)	.01	.69 (1.00)	-.09	.17 (.69)	.01	.81 (1.00)	-.02	.35 (1.00)	-.03	.26 (1.00)
Shift	**M1**	-.09	**<.001*** (<.001***)**	-.03	**<.001*** (<.001***)**	-.05	**.003** (.01*)**	-.02	.13 (.39)	-.07	**.002** (.006**)**	-.05	**.006** (.02*)**	-.03	**.001** (.004**)**	-.05	**.001** (.005**)**
	M2	-.04	.22 (.81)	-.02	.25 (.74)	-.01	.75 (1.00)	-.01	.63 (1.00)	.02	.63 (1.00)	-.05	.12 (.71)	-<.001	.25 (1.00)	-.02	.42 (1.00)
		-.06	.11 (.53)	-.007	.67 (1.00)	-.01	.79 (1.00)	-.01	.89 (1.00)	-.16	**.004** (.02*)**	.02	.56 (1.00)	<.001	1.00 (1.00)	-.01	.77 (1.00)
ER	**M1**	-.06	**.003** (.01*)**	-.02	**.01* (.02*)**	-.02	.32 (.63)	-.02	.23 (.64)	-.07	**.008** (.02*)**	-.02	.24 (.94)	-.02	**.02*** (.09)	-.04	**.003** (.01*)**
	M2	-.003	.93 (1.00)	.004	.76 (1.00)	.02	.47 (1.00)	-.01	.76 (1.00)	-.003	.94 (.94)	-.03	.31 (1.00)	-.002	.88 (1.00)	-.01	.75 (1.00)
		-.13	.18 (.67)	-.02	.19 (.75)	-.01	.82 (1.00)	-.001	.97 (1.00)	-.11	.05 (.26)	.05	.26 (1.00)	-.01	.46 (1.00)	-.03	.25 (1.00)
ERI	**M1**	-.08	**<.001*** (<.001***)**	-.03	**<.001*** (.001***)**	-.03	.05 (.14)	-.02	.15 (.44)	-.08	**.002** (.006**)**	-.04	**.03*** (.12)	-.02	**.002** (.009**)**	-.05	**.001** (.002**)**
	M2	-.02	50 (1.00)	-.01	.70 (1.00)	-.01	.76 (1.00)	-.01	.65 (1.00)	.008	.86 (1.00)	-.05	.13 (.79)	-.01	.48 (1.00)	-.01	.48 (1.00)
		-.06	.14 (.68)	-.02	.35 (1.00)	-.01	.82 (1.00)	.004	.91 (1.00)	-.14	**.01*** (.09)	.04	.28 (1.00)	-.01	.72 (1.00)	-.02	.49 (1.00)
Initiate	**M1**	-.04	**.04*** (.08)	-.04	**<.001*** (<.001***)**	-.03	.08 (.17)	-.02	.21 (.57)	-.05	.07 (.14)	-.03	.12 (.49)	-.03	**.001** (.003**)**	-.03	.06 (.25)
	M2	-.01	.79 (1.00)	-.03	.06 (.22)	-.02	.54 (1.00)	.003	.91 (1.00)	-.03	.49 (1.00)	-.03	.34 (1.00)	-.03	.05 (.33)	-.004	.88 (1.00)
		.01	.92 (1.00)	.002	.91 (.97)	.05	.19 (.93)	-.02	.63 (1.00)	-.009	.89 (1.00)	.05	.31 (1.00)	.02	.40 (.80)	.02	.59 (1.00)

Working memory	**M1**	-.06	**.001** (.005**)**	-.05	**<.001*** (<.001***)**	-.06	**.001** (.004**)**	-.03	**.03*** (.11)	-.08	**.004** (.01*)**	-.07	**.001** (.003**)**	-.04	**<.001*** (<.001***)**	-.06	**<.001*** (<.001***)**
	M2	-.03	.27 (.85)	-.03	**.01*** (.04*)**	-.04	.17 (.97)	-.02	.43 (1.00)	-.03	.48 (.71)	-.07	**.03*** (.15)	-.04	**.01*** (.04*)**	-.04	.14 (.86)
		-.01	.77 (1.00)	-.01	.51 (1.00)	.02	.69 (1.00)	-.01	.67 (1.00)	-.09	.14 (.71)	.03	.47 (1.00)	.02	.37 (.89)	.005	.86 (1.00)
Plan/ organize	**M1**	-.06	**<.001*** (<.001**)**	-.03	**<.001*** (<.001***)**	-.05	**.002** (.01*)**	-.02	.27 (.74)	-.06	**.009** (.03*)**	-.03	.08 (.33)	-.02	**.02*** (.06)	-.03	**.02*** (.08)
	M2	-.03	.32 (.94)	-.02	.03* (.14)	-.02	.42 (1.00)	-.0003	.99 (1.00)	-.02	.48 (.82)	-.03	.30 (1.00)	-.01	.45 (1.00)	-.02	.36 (1.00)
		-.04	.24 (.94)	.01	.67 (.67)	-.02	.54 (1.00)	-.01	.70 (1.00)	-.05	.27 (.82)	.02	.58 (1.00)	-.01	.77 (1.00)	.01	.73 (1.00)
Task monitor	**M1**	-.09	**<.001*** (.001**)**	-.03	**<.001*** (.001**)**	-.07	**<.001*** (<.001***)**	-.02	.15 (.43)	-.09	**<.001*** (.002**)**	-.03	.12 (.47)	-.02	**.01*** (.06)	-.04	**.005** (.02*)**
	M2	-.03	.29 (.82)	-.01	.38 (.81)	-.02	.51 (1.00)	-.004	.85 (1.00)	-.02	.63 (.68)	-.005	.86 (1.00)	-.01	.40 (1.00)	-.02	.38 (1.00)
		-.10	**.01*** (.05)	-.02	.20 (.81)	-.07	**.04*** (.24)	-.02	.55 (1.00)	-.17	**.003** (.02*)**	-.02	.68 (1.00)	.003	.88 (1.00)	-.01	.83 (1.00)
Org	**M1**	-.07	**.001** (.004**)**	-.02	.06 (.12)	-.05	**.006** (.02*)**	-.002	.92 (1.00)	-.05	.10 (.20)	-.03	.19 (.76)	-.01	.37 (1.00)	-.01	.68 (1.00)
	M2	-.03	.27 (.81)	-.01	.55 (1.00)	-.04	.12 (.62)	-<.001	1.00 (1.00)	-.02	.69 (1.00)	-.02	.58 (1.00)	.003	.85 (1.00)	-.02	.31 (1.00)
		-.04	.34 (.81)	-.01	.97 (1.00)	-.02	.69 (1.00)	.02	.56 (1.00)	-.04	.48 (1.00)	.002	.97 (1.00)	-.01	.77 (1.00)	.05	.15 (.76)
CRI	**M1**	-.09	**<.001*** (<.001***)**	-.04	**<.001*** (<.001***)**	-.07	**<.001*** (.002**)**	-.02	.13 (.40)	-.08	**.002** (.007**)**	-.05	**.03*** (.11)	-.03	**.001** (.002**)**	-.04	**.005** (.02*)**
	M2	-.03	.23 (.37)	-.02	.07 (.27)	-.03	.21 (1.00)	-.01	.78 (1.00)	-.03	.50 (.50)	-.04	.19 (1.00)	-.02	.10 (.62)	-.02	.34 (1.00)
		-.08	.07 (.30)	-.01	.52 (1.00)	-.002	.95 (1.00)	-.01	.74 (1.00)	-.12	.05 (.27)	.03	.49 (1.00)	.01	.75 (1.00)	.01	.71 (1.00)
GEC	**M1**	-.09	**<.001*** (<.001***)**	-.03	**<.001*** (<.001***)**	-.06	**.001** (.003**)**	-.02	.13 (.44)	-.09	**.001** (.003**)**	-.04	**.04*** (.14)	-.03	**.002** (.008**)**	-.05	**.001** (.002**)**
	M2	-.03	.27 (.87)	-.01	.38 (1.00)	-.03	.37 (1.00)	-.01	.80 (1.00)	-.03	.52 (.52)	-.04	.21 (1.00)	-.01	.48 (1.00)	-.02	.25 (1.00)
		-.07	.08 (.87)	-.02	.29 (1.00)	-.003	.95 (1.00)	-.01	.81 (1.00)	-.12	**.04*** (.21)	.04	.40 (1.00)	-.01	.67 (1.00)	-.002	.95 (1.00)

Note. ***Color*** *= Color naming,* ***GF*** *= Graphical fluency,* ***GF (pers)*** *= perseverative errors of Graphical fluency,* ***Visual*** *= Visual search.* ***Enum*** *= Enumeration,* ***Cat*** *= Categorization.* ***BRI*** *= Behavioral Regulation Index,* ***ER*** *= Emotional regulation,* ***ERI*** *= Emotional Regulation Index,* ***Org*** *= Organization of materials,* ***CRI*** *= Cognitive Regulation Index,* ***GEC*** *= Global Executive Composite.* ***CE*** *= coefficient estimate,* ***p*** *= p-value,* p^H *= p-value with Holm's correction.* ***M1*** *= model with covariates (MEA ~ BRIEF + sex + age),* ***M2*** *= model with covariates and interaction term (MEA ~ BRIEF * groups + sex + age).* [a] *Test significance * p < .05, ** p < .01, *** p < .001.*

Group differences in executive functioning measures

Significant group differences were found on several measures (see **Table 4.9**), with neurotypical children generally showed higher performance compared to neurodivergent peers in EF tasks (MEA battery, Benso et al., 2019) and parent-reported ratings (BRIEF-2, Gioia et al., 2015). However, no significant group differences were observed in Visual search performance (p = .47).

Table 4.9 *Differences between groups in parent reports and performance-based measures of executive functioning*

	Neurotypical		Neurodivergent		
Variables	**M**	**SD**	**M**	**SD**	p^a
Performance-based measures (MEA)					
Color naming	-0.23	1.08	-2.09	3.96	**<.001*** **
Graphical fluency (accuracy)	-0.19	1.05	-1.2	1.24	**<.001*** **
Graphical fluency (error)	-0.06	1.33	-2.12	3.34	**<.001*** **
Graphical fluency (perseveration)	-0.26	1.4	-1.2	2.83	**.03***
Visual search	-0.30	1.28	-1.62	5.89	.24
Enumeration forward-backward	-0.41	1.7	-1.68	2.91	**.004****
Categorization	-0.05	1.21	-0.71	0.72	**.001****
PASOT	-0.36	1.2	-2.04	1.73	**<.001*** **
Parent-reported measures (BRIEF-2)					
Inhibit	50.14	9.32	61.38	12.62	**<.001*** **
Self-monitor	48.21	8.78	61.18	10.63	**<.001*** **
BRI	49.45	9.05	62.36	11.44	**<.001*** **
Shift	48.79	9.26	64.98	13.78	**<.001*** **
Emotional regulation	48.03	9.31	58.58	12.74	**<.001*** **
ERI	48.23	9.05	63.04	13.74	**<.001*** **
Initiate	49.3	8.72	61.94	11.4	**<.001*** **
Working memory	49.7	10.07	61.22	11.93	**<.001*** **
Plan/organize	47.86	11.26	58.89	15.09	**.002****

Task monitor	50.18	10.69	60.58	11.53	**<.001*** **
Organization of materials	50.31	9.52	56.27	12.16	**.002** **
CRI	49.55	9.67	62	10.94	**<.001*** **
GEC	49.46	9.26	64.13	11.67	**<.001*** **

Note. ***n*** *= subjects;* ***M*** *= mean;* ***SD*** *= standard deviation.* ***BRI*** *= Behavioral Regulation Index,* ***ERI*** *= Emotional Regulation Index,* ***CRI*** *= Cognitive Regulation Index,* ***GEC*** *= Global Executive Composite. [a] Test significance * p < .05, ** p < .01, *** p < .001.*

4.4 Discussion

4.4.1 Convergence between parent reports and performance-based tasks

This study found convergence between a well-established parent questionnaire and a novel set of performance-based EF tasks in a neurodiverse sample of children aged 5 to 16. This result suggests that different EF assessment methods, applied in varied contexts, may capture overlapping dimensions of executive functioning. These findings are consistent with prior studies showing positive correlations between performance tasks and rating scales in both neurotypical (Faridi et al., 2015; Kälin & Roebers, 2021) and neurodivergent populations (Anderle et al., 2026). While some research has noted discrepancies, especially within neurodiverse groups (Gomez-Perez et al., 2016; Mareva et al., 2024; McAuley et al., 2010), these results indicate that the performance-based tasks reflect children's daily life executive functioning and align well with parent perceptions. Further evidence for convergence between various context measures comes from observed group differences, where neurodivergent children showed lower executive functioning on both parent-reported and task-based tests (Berenguer et al., 2018; Demetriou et al., 2018; Townes et al., 2023). However, in the present study, convergence between parent reports and the novel performance-based EF tasks emerged only when neurotypical and neurodivergent children were considered together. When group membership was included as a factor in the model, this convergence was no longer observed, indicating that the relation between parent-reported and performance-based EFs may not be consistent within each group. These findings suggest that the convergence observed at the level of the full sample may be largely driven by between-group differences in EF functioning, rather than by strong

within-group correspondence among parent reports and task-based measures. This pattern is consistent with prior work highlighting the limited overlap between informant-based and performance-based assessments of executive functioning in school-aged children (Dang et al., 2020; Leung et al., 2016; Jones et al., 2018; Ten Eycke & Dewey, 2016; Toplak et al., 2013). These results suggest that parent reports and performance-based measures tend to assess different aspects of a child's functioning, highlighting the importance of continue to use multiple assessment methods when evaluating EFs across developmental populations.

Additionally, mothers' and fathers' assessments of their neurodiverse children's EF were highly consistent, showing no significant differences (Gioia et al., 2015), suggesting that both caregivers hold similar views regarding their child's EF. This finding supports the interchangeable use of either parent's report in research and clinical settings and aligns with evidence underscoring that mothers and fathers contribute equally to the EF's development (Meuwissen & Englund, 2016; Ribner et al., 2022). Using this information may help minimize the time required for experimental procedures, although both sources of information remain important for obtaining a broader picture of the child's functioning, especially in the clinical contexts.

4.4.2 Task associations with parent ratings dimensions

Considering the overall sample, while most of the performance-based tasks correlated significantly with parent ratings of general executive functioning, individual tasks differed in their relations with specific EF subdomains, demonstrating their capacity to distinct facets of EF in daily life. The major consistency into associations were found with tasks measuring processing speed and lexical access (Color naming), accuracy of Graphical fluency, Visual search, and working memory skills (PASOT). Some tasks, such as Enumeration and Categorization (both working memory measures), did not significantly relate to behavioral regulation scores, possibly because parent reports primarily capture motor-related regulation behaviors (e.g., restlessness, impulsivity), not directly assessed by cognitive tasks. In contrast, the absence of an association between perseverative errors and parent-reported dimensions, as well as the lack of a relation between Enumeration and the overall executive functioning parameter reported by parents, suggests that these tasks may capture distinct aspects of EFs, primarily related to updating and other cognitive domains. Taken together, these findings indicate that performance-based tasks predominantly assess cognitive regulation, whereas parent-report measures more effectively capture behavioral and emotional regulation. Furthermore, emotional and behavioral regulation may rely on contextual and relational factors that are not directly assessed through performance-based measures (Balart et al., 2021; Chen & Liao, 2021). However,

these relations were no longer significant when diagnostic group were included in the analysis. The only exception is related to working memory, as reported by parents, which remained associated with the accuracy parameter of the graphical fluency and categorization child EF tasks. Importantly, a significant interaction effect was observed only for the relations between the Visual search parameter and both the shifting and task monitoring subdomains of the BRIEF-2. Thus, incorporating multiple contextual measures may be necessary to obtain a more comprehensive picture of the child's functioning.

4.4.3 Limitations and future directions

This study has several limitations that should be addressed in future investigations. First, while the sample included a range of neurodivergent children, certain conditions, such as ADHD and specific learning disorders, were relatively underrepresented. Future research would benefit from larger and more diagnostically diverse neurodivergent samples to enable more detailed comparisons of performance patterns and the alignment of assessment methods within specific clinical groups.

Moreover, the neurodivergent sample had an imbalanced sex distribution, with fewer females represented. This imbalance restricts the ability to thoroughly examine sex-related differences within this population. Future studies should aim for a more equal representation of sexes to better explore potential sex-specific variations in executive functioning. Such research should investigate these differences both independent of diagnosis and within neurotypical and neurodivergent groups, as identifying sex-related patterns could enhance understanding of EF development and assessment. Additionally, the present study lacks a measure of executive functioning in ecological settings beyond the home, such as the school environment. Future research should incorporate teacher reports of children's executive functioning to enable convergence across school, home, and laboratory contexts, thereby strengthening the consistency of the findings. Lastly, this study did not collect information on socioeconomic status, parental occupation, educational background, or the presence of neurotypical or neurodiverse siblings. Incorporating these contextual factors in future research could clarify whether and how they influence the convergence of parental perceptions regarding EF.

4.5 Conclusion

This study provides some evidence between convergence of performance-based and parent-report questionnaires that assess executive functioning in a neurodiverse sample of children aged 5 to 16. However, these associations were found only in the full sample, while they disappeared when diagnostic groups were considered separately, suggesting that the observed convergence may be primarily driven by between-group differences in executive functioning rather than by strong within-group correspondence among parent-reported and task-based measures. Therefore, the findings indicate that integrating multiple assessment methods provides a more comprehensive and nuanced understanding of executive functioning across diverse populations, tapping different dimension of child's cognitive profiles. Additionally, the interchangeable use of mother and father reports further supports practical applications in clinical and research settings by minimizing the time demands of experimental procedures. Future research should expand on these findings by including larger, more diverse samples and considering additional contextual factors to deepen insights into executive functioning development and assessment.

Chapter 5

Executive attention performance in neurotypical and neurodiverse children: a focus on autism and specific learning disorders[3]

Summary

Executive functioning (EF) challenges are well-documented across neurodiverse populations, yet most research has focused on isolated cognitive components. Emerging evidence underscores the interrelated nature of these functions, highlighting the need for more comprehensive and context-sensitive approaches in clinical assessment. In this study, 292 children aged 5 to 16, including both neurotypical and neurodivergent groups, completed a multidimensional battery of executive attention tasks. These tasks were carefully designed to minimize the task impurity issue and provide a more

[3] This chapter is an extended version of:

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accurate reflection of functional EF profiles in developmental populations. Results revealed that neurodivergent children generally exhibited lower performance compared to their neurotypical peers, except in visual discrimination tasks. The age-group analyses revealed that disparities between neurodivergent and neurotypical children emerge early in development, although neurodivergent children demonstrate some improvements in their abilities starting in adolescence. Analyzing specific clinical subgroups, autistic children showed particularly difficulties in tasks that implicate processing speed and linguistic demands relative to those with specific learning disorders. Crucially, working memory tasks with higher emotional regulation demands (such as Enumeration and n-back tests) helped to detect executive attention weaknesses within neurodivergent populations. These findings emphasize the necessity of adopting a broader framework, which integrates cognitive and emotional regulation aspects in the assessment. This approach holds promise for more precise diagnostics and tailored interventions in rehabilitation and educational settings.

Keywords

Executive attention, working memory capacity, neurodiversity, autism, specific learning disorders

Key points

- Neurodivergent children generally exhibit lower performance compared to their neurotypical peers in executive attention tasks**,** but no differences emerge between groups in visual discrimination abilities.
- Autistic children perform lower compared to children with specific learning disorders in tasks that involve processing speed and linguistic demands, while both groups show similar performance in tasks that require fine-motor skills and number manipulation.
- Differences between neurodivergent and neurotypical children emerge early, but neurodivergent children show some improvement from adolescence.
- Working memory tasks are particularly useful in detecting executive attention weaknesses within neurodivergent populations.

5.1 Introduction

Challenges in executive functioning (EF) have been frequently reported in neurodiverse populations (Benallie et al., 2021; Hughes, 2011; McClain et al., 2022), including children with Autism Spectrum Disorders (ASD; Kenworthy et al., 2008; Yerys et al., 2007; Valeri et al., 2020) and those with Specific Learning Disorders (SLD; Booth et al., 2010; Reiter et al., 2005; Varvara et al., 2014). However, various studies have reported contrasting findings, partly due to differences in tasks and methodologies used, as well as the specific parameters considered to measure EF performance (Yangüez et al., 2024). Analyzing these functions within a multidimensional framework may provide crucial insights for capturing the heterogeneity of cognitive processes and behavioral outcomes. The *Measures of Executive Attention (MEA) battery* (Benso et al., 2019; see **Chapter 3, Section 3.2.2,** for a detailed description) was chosen to comprehensively assess executive attention in school-aged neurodiverse children, thereby avoiding overly reductionist methods.

5.1.1 Executive functions in children with autism and specific learning disorders

Autistic children commonly exhibit lower performance in EF, including working memory, cognitive flexibility, inhibition, planning, and attention, compared to neurotypical peers since preschool age (Demetriou et al., 2018; Valeri et al., 2020). Working memory is challenging across both verbal and spatial domains, with difficulties becoming more apparent as memory load increases; although verbal rehearsal is possible, it is not used spontaneously, limiting behavioral self-regulation (Demetriou et al., 2019; Geurts et al., 2014; Lai et al., 2017; Joseph et al., 2005). Cognitive flexibility is also frequently impaired, with increased perseverative errors and repetitive responses in tasks such as the Wisconsin Card Sorting Test (Bölte et al., 2011; Goldstein et al., 2001; Hill, 2004; Iversen & Lewis, 2021; Memari et al., 2013). Inhibition is another area of weakness, particularly under distracting conditions (Adams & Jarrold, 2012; Lemon et al., 2011; Luna et al., 2007). Planning difficulties arise when managing sequences of actions, especially in complex tasks, and performance is similar to that of children with Attention-Deficit/Hyperactivity Disorders (Happé et al., 2006; Hill, 2004). Attentional control varies by age and cognitive ability, with challenges in spatial focus and shifting, particularly when social cues are involved (Allen & Courchesne, 2001; Ames & Fletcher-Watson, 2010; Sanders et al., 2008). Also, parent reports highlight challenges, especially in flexibility, though

not in organization (Blijd-Hoogewys et al., 2014; White et al., 2017). However, significant heterogeneity in the results exists due to task differences and sample variability (Faja & Dawson, 2015; Friedman & Sterling, 2019). Moreover, changes in certain aspects of executive functioning performance, such as planning, have been observed with age among neurodiverse samples (Albert & Steinberg, 2011; Korkman et al., 2001; Kouklari et al., 2018). Overall, executive functioning tends to improve in adulthood, likely due to compensatory strategies; nevertheless, EF abilities remain below typical levels across ages (Demetriou et al., 2018; 2019).

Challenges in EFs are also shown in children with Specific Learning Disorders. EFs have a significant impact on academic achievement and success, especially in literacy and mathematics (Blair & Razza, 2007; Cirino et al., 2019; Viterbori et al., 2015). Parents consistently report more EF-related difficulties in children with SLD in everyday functioning (Mousavi et al., 2025). Most research using performance-based tasks has focused on children with developmental dyslexia, whose challenges are observed in working memory, inhibition, and cognitive flexibility (Reiter et al., 2005; Varvara et al., 2014). Working memory is crucial for phoneme sequencing and reading comprehension; children with dyslexia or dyscalculia exhibit difficulties in the phonological and visuospatial components, respectively, which influence their performance in transparent orthographic systems (e.g., Italian) (Crisci et al., 2021; Mammarella et al., 2018). Cognitive flexibility, particularly the ability to shift between linguistic levels such as phonology and semantics, is often challenging, though findings vary with age and task type (Locascio et al., 2010; Lonergan et al., 2019). Finally, inhibitory control performance is also lower compared to neurotypicals, affecting the suppression of automatic or irrelevant responses and hindering attention to task-relevant cues (Altani et al., 2017).

In clinical assessments, it is crucial to differentiate children with specific diagnoses in order to identify distinct patterns of executive functioning performance. However, only a few studies have compared the performance of autistic children and those with SLD. Aita et al. (2022) found that autistic children tend to show greater difficulties in parent-rated EF compared to children with SLD. Another study (Lievore et al., 2025) reported that autistic children performed worse than both neurotypical children and those with SLD on a computerized task assessing visual and spatial working memory, while no significant differences were found between the SLD and neurotypical groups. Additionally, no group differences emerged in perseverative errors in a computerized version of the Wisconsin Card Sorting Test, used as an index of shifting, or in a computerized go/no-go task measuring inhibitory control between neurodivergent and neurotypical children. Additionally, Poljac et al. (2010) found that children with dyslexia showed greater difficulties in task-switching performance when task requirements were clearly defined, compared to autistic children aged 12-18, who performed similarly to the neurotypical group. Moreover, children with SLD exhibited more

pronounced difficulties in information processing than both the autistic and neurotypical groups. Although a few promising results have been obtained, further studies are needed to better identify similarities and differences in executive functioning profiles across these two clinical groups.

5.1.2 Aims and hypotheses

This study aims to investigate whether neurodivergent children exhibit lower performance on executive attention tasks compared to their neurotypical peers, and whether autistic children perform more poorly than children with SLD on these tasks. Furthermore, the study aims to evaluate the differences in the percentages of failures and successes in the execution of these tasks across neurodivergent children. Given that this study included neurodivergent children with simple size unbalanced relative to the neurotypical groups, analyzing the percentages of failures and successes in task execution may provide valuable insights into their cognitive profiles. Finally, the work seeks to identify specific age ranges in which performance differences between neurodivergent and neurotypical children become evident.

Based on previous research, it is hypothesized that neurodivergent children would perform more poorly on executive attention tasks (Demetriou et al., 2018; Hughes, 2011; Mousavi et al., 2025; Valeri et al., 2020). Moreover, while some overlap in performance between autistic children and those with SLD, particularly in measures of cognitive flexibility, is anticipated (Lievore et al., 2025), overall lower performance is expected in the autistic group, consistent with prior findings (Aita et al., 2022; Lievore et al., 2025). It is also anticipated that neurodivergent children would consistently perform below their neurotypical peers across the examined age range, in line with existing evidence (Demetriou et al., 2018; 2019). However, group differences on performance-based tasks are expected to become less pronounced with development, particularly beginning in adolescence (Albert & Steinberg, 2011; Korkman et al., 2001; Kouklari et al., 2018).

5.2 Methods

5.2.1 Participants

The study included two groups of children aged between 5 and 16 years, recruited from school settings in Italy and from the ODFLab (Laboratory of Observation, Diagnosis, and Education), part of the Department of Psychology and Cognitive Science at the University of Trento in Rovereto, Italy. School-based participants were drawn from inclusive educational settings, where classrooms comprised both neurotypical children and students with special educational needs and disabilities.
A total of n = 321 participants were initially involved in the study. Given the well-established link between executive functioning and intelligence abilities, participants with a fluid intelligence index, measuring through the Matrix reasoning scores of Weschler Intelligence Scale for Children-IV (Orsini et al., 2015), below -2 SD were excluded to reduce confounding effects: 6 from the neurotypical group, 3 from the autistic group, 1 from the specific learning disorders group. Moreover, 18 participants with psychiatric conditions (such as anxiety or depression) and other neurodiverse situations (such ADHD) were excluded to reduce potential bias. The final evaluated sample comprised n = 292 participants (see **Table 5.1**).

Neurotypical group

A total of 200 neurotypical children were recruited from various primary and lower secondary school classrooms in northern Italy. All participants demonstrated age-appropriate proficiency in Italian and presented no history or diagnosis of psychopathological or neurodevelopmental disorders.

Neurodivergent group

The neurodivergent group included 92 children who could be categorized as autistic children and children with specific learning disorders. Children with comorbid neurological or medical conditions, such as epilepsy, or other medical diagnoses, were excluded to ensure diagnostic specificity.

Autistic children. The study included 59 children diagnosed with Autism Spectrum Disorders (ASD). ASD encompasses a range of neurodevelopmental conditions marked by qualitative differences in social communication and interaction, as well as the presence of restricted and repetitive patterns of behavior, interests, or activities, relative to neurotypical development (American Psychiatric

Association, 2022). Diagnosis was confirmed through clinical judgment by an independent clinician, in accordance with the Diagnostic and Statistical Manual of Mental Disorders-5-TR (DSM-5-TR; American Psychiatric Association, 2022) and was supported by the administration of the Autism Diagnostic Observation Schedule (ADOS-2; Lord et al., 2012).

Children with Specific Learning Disorders (SLD). The group comprises 33 children diagnosed with SLD. Prior to inclusion in the study, each child underwent a comprehensive diagnostic evaluation conducted by a licensed psychologist. All diagnoses were confirmed by institutions accredited by the national health system and were based on the criteria set forth in the DSM-5-TR. Specifically, each child demonstrated persistent learning difficulties lasting at least six months, despite the provision of targeted educational interventions. These difficulties may manifest as slow or inaccurate word reading, poor reading comprehension, deficits in spelling or written expression, or challenges with number sense and calculation. Furthermore, academic performance was significantly below age-level expectations, as documented through standardized assessments and detailed clinical judgment.

No significant group differences were found in fluid intelligence scores ($p = .85$). However, age differences were observed: the neurodivergent group was significantly older on average compared to the neurotypical groups ($p = .01$). To address the fourth aim of the present study, participants' ages were categorized into four developmental ranges: 5-7, 8-10, 11-13, and 14-16 years (see **Table 5.1**).

Table 5.1 *Samples' demographic characteristics*

	Characteristics			**Age range (*n*)**			
Group	***n*** **(M, F)**	**Age (M, SD)**	**RM (M, SD)**	**5-7**	**8-10**	**11-13**	**14-16**
Neurotypical	200 (M = 110, F = 90)	10.36 (3.01)	.05 (.94)	44	55	63	38
Neurodivergent	92 (M = 79, F = 13)	11.39 (2.64)	.01 (1.00)	6	27	38	21
ASD	59 (M = 55, F = 4)	11 (2.88)	-.07 (1)	5	22	20	12
SLD	33 (M = 24, F = 9)	12.09 (2.01)	.15 (1.01)	1	5	18	9

Note. n *= subjects.* ***RM*** *= Matrix reasoning score as an index of fluid intelligence, provided in z-scores from the Wechsler Intelligence Scale for Children-IV (Orsini et al., 2015).*

5.2.2 Materials

Z-scores (*M = 0, SD = 1*) were calculated for each parameter (see **Appendix B** for more details).

Broader cognitive measures

The *Matrix reasoning* subtest from the Wechsler Intelligence Scale for Children-IV (WISC-IV; Orsini et al., 2015) is a standardized clinical tool used to assess cognitive functioning, with demonstrated good reliability and validity. The broader battery evaluates various domains, including Verbal Comprehension, Visual-Spatial abilities, Working Memory, and Processing Speed. For this study, only the Matrix reasoning subtest, part of the Visual-Spatial Index, was used as a measure of fluid intelligence. This construct refers to the capacity to reason and solve novel problems independently of prior learning. During the task, children view an incomplete visual matrix and select the correct item to complete it from several options.

The *Comprehension of instructions* subtest from the NEPSY-II (Korkman et al., 2007) was used to evaluate receptive language skills. Specifically, it assesses the child's ability to understand and follow increasingly complex verbal instructions. After hearing each instruction, the child must select the appropriate image.

The *Verbal fluency* subtest from the NEPSY-II (Korkman et al., 2007) was used to assess expressive language abilities. Specifically, it evaluates the capacity to generate as many words as possible within one minute, under two conditions: semantic fluency (e.g., naming animals and foods) and phonological fluency (e.g., producing words that begin with the letters "S" and "F").

The *Visuo-motor precision* task, another subtest from the NEPSY-II (Korkman et al., 2007), assesses fine-motor control by measuring both execution speed (time) and accuracy (errors). In this task, children are asked to trace a path with a pencil using their dominant hand, with paths becoming progressively more difficult. The time parameter reflects the total time required to complete all paths, while the error parameter represents the total number of errors made by the child during the tasks.

Executive attention measures

Executive attention was evaluated using six tasks drawn from the *Measures of Executive Attention (MEA) battery* (Benso et al., 2019). A summary of the tasks is presented in **Table 5.2**, while detailed descriptions and scoring procedures are outlined in **Chapter 3** (**Section 3.2.2**).

Table 5.2 *Brief description of the Measures of Executive Attention Tasks*

Task	Description
Color naming	Denominate verbally the name of the colors as quickly as possible. Derived from the studies of Denckla and Rudel (1976), this task represents the final output of a processing stream involving the integration of attentional and mnemonic processes, culminating in a relative automatization of verbal label retrieval.
Graphical fluency	Draw various configurations, using 5 points, in a minute providing different measures (accuracy, errors and perseverations). Adapted and modified from the Five-Point Test by Regard et al. (1982), this task is widely used in clinical settings, particularly in the assessment of frontal lobe syndromes (see also Tucha et al., 2012).
Cancellation and visual search	This task requiring participants to mark only the target items on various sheets (sheets 7 and 8 assess fine-motor speed; sheet 10 assess fine-motor speed in combination with visual search speed).
Enumeration forward-backward	Tell the number from 1 to 100 (forward condition) as quickly as possible and then from 100 to 1 (backward condition).
Categorization	Repeat only the words verbally provided by the examiner that belong to a specified category. This task is derived from the studies of Haarmann et al. (2003), who developed a *conceptual span task* in which list recall had to be recognized according to semantic elements. It requires active manipulation within working memory. Conceptual span performance showed higher correlations with reading comprehension and problem-solving abilities.
Paced Auditory Serial Opposites Task (PASOT)	Say the opposite of the word heard just before the last one in two different timing between the stimuli (1200ms and 800ms). This task is adapted and modified from Gow and Deary (2004) and consists of a demanding *n-back-like task*. It assesses working memory updating and manipulation, involving attentional and executive control processes.

5.2.3 Procedure

All measures were administered individually in a quiet room, either at the ODFLab or within the participants' school environment by trained master's students in Clinical Psychology or psychologists. Each child completed a battery of cognitive assessments, including *Matrix reasoning*, *Comprehension of instructions*, *Verbal fluency*, and *Visuo-motor precision*. Executive attention tasks were age-specific: participants aged **5 to 7 years** completed *Color naming*, *Graphical fluency*, *Cancellation and visual search* tasks, while those aged **8 to 16 years** completed an extended set comprising *Color naming*, *Graphical fluency*, *Cancellation and visual search*, *Enumeration*, *Categorization*, and *PASOT*. Task administration followed a randomized order to control for order effects. The assessment lasted 45 minutes for the youngest children and 1 hour for the oldest.

5.2.4 Analytic plan

All analyses were performed using RStudio (R Core Team, 2024), with the threshold for statistical significance set at $\alpha = 0.05$.

Data were normalized into *z-scores* based on normative data derived from the neurotypical subsample (see **Supplementary Materials B** for details of the procedure). Descriptive analyses of the sample are reported in **Tables 5.3** and **5.4**.

Normality and homoscedasticity were assessed using the Shapiro-Wilk test and the Levene's test, respectively. As several variables violated the assumption of normality, non-parametric analyses were employed. Generalized Linear Models (GLMs) were used to examine associations between fluid intelligence, linguistic, and fine motor abilities and executive attention measures across the full sample, controlling for sex and age, and including an interaction term with the diagnostic group.

Group differences between neurotypical and neurodivergent children (including those with ASD and SLD) were evaluated using the Wilcoxon rank-sum test, suitable for comparing independent samples across two groups. Moreover, post hoc pairwise comparisons were conducted with p-values adjusted using the Benjamini-Hochberg per-task family procedure, which controls the false discovery rate while offering greater statistical power than more conservative approaches such as the Bonferroni correction. Additional comparisons between the ASD and SLD subgroups were also performed using the Wilcoxon test with Benjamini-Hochberg correction.

Age-range differences within and between groups (neurotypical versus neurodivergent) were also explored to better understand when group differences emerged and whether developmental changes

occurred over time. The Wilcoxon rank-sum test, appropriate for comparing independent samples between two groups, was used to examine differences between neurotypical and neurodivergent developmental trajectories. While within-group age-related differences were assessed using the Kruskal-Wallis test, a non-parametric method suitable for comparing more than two groups (four age groups). P-values were adjusted using the Benjamini-Hochberg procedure to control for multiple comparisons.

The use of non-parametric methods helped minimize the influence of outliers, which is particularly relevant when studying neurodivergent children, such as those with autism or specific learning disorders, who often exhibit considerable variability in task performance (Sankalaite et al., 2025). To preserve this variability, it was decided not to exclude additional data, except for the initial selection of participants, during which cases with fluid intelligence index (Matrix reasoning, WISC-IV) scores below -2 SD were excluded (see the above **paragraph 5.2.1**). Additional analyses were conducted on failures and successes rates for each specific EF task. Failures were calculated from task incompletion, with assessments occasionally interrupted by the experimenter when necessary or at the request of the participants (Enumeration and PASOT), and from performances scoring below −2 SD. Therefore, failures scores comprised both task incompletion and performance below expected levels. To assess whether task withdrawal differed between groups, task completion status (failures vs. success) was cross-tabulated by diagnostic group (neurotypical vs. neurodivergent) for each task, only for the main composite measure (Color naming, accuracy and perseveration parameters of Graphical fluency, Cancellation and visual search, Categorization, Enumeration forward-backward, PASOT). Moreover, percentages, odds ratios (ORs) with 95% confidence intervals, and χ^2 tests (or Fisher's exact tests where appropriate) were reported. Diagnostic performance indices (e.g., sensitivity and specificity) were deliberately not used, as the aim was to examine group differences in task engagement and persistence rather than classification.

Table 5.3 *Descriptive analysis for neurotypical and neurodivergent children*

	Neurotypical					Neurodivergent				
Variables	***n***	**M**	**SD**	**min**	**max**	***n***	**M**	**SD**	**min**	**max**
Broader cognitive measures										
Matrix reasoning	200	0.05	0.94	-1.96	2.42	92	0.01	1	-1.96	2
Comprehension of instructions	198	-0.03	1.1	-6.2	2.41	90	-1.14	1.64	-5.77	1.95
Verbal fluency (semantic)	200	0.09	1.18	-2.28	7.76	92	-0.55	1.23	-3.48	2.25
Verbal fluency (phonological)	199	0.06	1.07	-2.23	3.81	89	-0.5	0.97	-2.51	2.5
Visuo-motor precision (time)	200	-0.09	1.14	-5.42	2.01	91	-0.06	1.72	-7.16	2.78
Visuo-motor precision (error)	200	-0.25	1.75	-13.85	1.04	91	-4.92	9.92	-63.32	0.75
Executive attention measures										
Color naming	200	-0.16	1.44	-11.01	2.15	92	-1.53	1.95	-9.54	1.64
Graphical fluency (accuracy)	199	0.04	1.01	-2.2	3.58	88	-1	1.23	-4.3	2.44
Graphical fluency (error)	199	-0.13	1.23	-5.49	1.25	88	-1.72	2.64	-12.45	1.06
Graphical fluency (perseveration)	199	-0.18	1.41	-8.51	0.98	88	-0.88	2.37	-12.89	0.98
Cancellation (sheet 7)	199	-0.16	1.48	-12.42	1.94	89	-0.62	1.48	-6.62	1.5
Cancellation (sheet 8)	199	-0.12	1.26	-5.21	1.42	89	-0.74	1.86	-8.91	1.71
Cancellation (sheet 10)	198	-0.13	1.22	-5.16	2.53	89	-1.17	4.84	-41.35	1.81
Visual search	198	-0.10	1.23	-5	2.89	89	-0.95	4.80	-39.84	3.18

Enumeration (forward)	156	-0.11	1.32	-9.15	1.95	82	-1.29	2.1	-10.79	1.54
Enumeration (backward)	156	-0.11	1.39	-11.15	1.56	76	-1.94	3.05	-11.35	2.28
Enumeration forward-backward	156	-0.13	1.38	-10.12	1.52	76	-1.77	2.88	-11.54	1.8
Categorization	154	0.12	1.14	-2	4.76	81	-0.77	0.72	-1.91	1.34
PASOT (1200ms)	150	-0.03	1.03	-3.43	1.81	66	-2.15	2.47	-8.93	1.41
PASOT (800ms)	150	-0.06	1.08	-3.24	2.14	60	-1.31	1.71	-4.96	2.01
PASOT	149	-0.07	1.11	-3.8	2.07	60	-1.83	2.13	-6.93	1.75

Note. ***n*** *= subjects;* ***M*** *= mean;* ***SD*** *= standard deviation;* ***min*** *= minimum score;* ***max*** *= maximum score.*

Table 5.4 *Descriptive analysis for autistic children and those with specific learning disorders*

		ASD					SLD			
Variables	***n***	**M**	**SD**	**min**	**max**	***n***	**M**	**SD**	**min**	**max**
Cognitive measures										
Matrix reasoning	59	-0.07	1	-1.96	2	33	0.15	1.01	-1.67	1.66
Comprehension of instructions	57	-1.54	1.66	-4.86	1.41	33	-0.46	1.39	-5.77	1.95
Verbal fluency (semantic)	59	-0.72	1.29	-3.48	2.25	33	-0.23	1.05	-1.97	2.15
Verbal fluency (phonological)	56	-0.67	0.93	-2.51	2.5	33	-0.2	0.98	-2.44	1.75
Visuo-motor precision (time)	58	-0.03	1.92	-7.16	2.78	33	-0.12	1.32	-3.72	2.07

Visuo-motor precision (error)	58	-6.72	11.84	-63.32	0.75	33	-1.76	3.3	-12.38	0.75
Executive attention measures										
Color naming	59	-1.82	2.02	-9.54	1.55	33	-1.01	1.71	-5.48	1.64
Graphical fluency (accuracy)	55	-1.27	1.21	-4.3	1.22	33	-0.55	1.15	-2.69	2.44
Graphical fluency (error)	55	-2.03	2.55	-9.75	1.06	33	-1.2	2.74	-12.45	1.06
Graphical fluency (perseveration)	55	-1.39	2.71	-12.89	0.98	33	-0.03	1.3	-5.28	0.98
Cancellation (sheet 7)	56	-0.73	1.5	-6.62	1.5	33	-0.44	1.47	-4.94	1
Cancellation (sheet 8)	56	-1.07	2.09	-8.91	1.71	33	-0.19	1.24	-4.64	1.35
Cancellation (sheet 10)	56	-1.69	5.97	-41.35	1.81	33	-0.29	1.33	-3.65	1.8
Visual search	56	-1.32	5.95	-39.84	3.18	33	-0.31	1.37	-3.89	2.02
Enumeration (forward)	50	-1.75	2.25	-10.79	1.29	32	-0.57	1.64	-6.19	1.54
Enumeration (backward)	44	-2.46	3.56	-11.35	2.28	32	-1.23	2	-8.27	1.05
Enumeration forward-backward	44	-2.07	3.16	-9.36	1.5	32	-1.37	2.44	-11.54	1.8
Categorization	49	-0.97	0.56	-1.91	1.1	32	-0.47	0.84	-1.74	1.34
PASOT (1200ms)	35	-3.15	2.53	-8.93	0.4	31	-1.02	1.87	-7.9	1.41
PASOT (800ms)	29	-1.92	1.61	-4.53	1.61	31	-0.75	1.62	-4.96	2.01
PASOT	29	-2.76	2.05	-6.5	0.45	31	-0.96	1.84	-6.93	1.75

***Note. n** = subjects; **M** = mean; **SD** = standard deviation; **min** = minimum score; **max** = maximum score.*

5.3 Results

5.3.1 Associations among cognitive and executive attention measures

GLMs are reported in **Table 5.5**. Significant associations were identified between the accuracy parameter of the Graphical fluency task and broader cognitive abilities, controlling for sex and age. Similarly, PASOT performance was significantly associated with cognitive abilities, except for its relationship with time in the Visuo-motor precision task. Moreover, the error parameter of Visuo-motor precision showed associations with all executive function measures except for the Visual search test. Similarly, Comprehension of instructions task is related to all the EF measures, expect with errors parameter of Graphical fluency. Notably, the accuracy parameters of Graphical fluency, Visual search and PASOT were the only tasks significantly associated with Matrix reasoning. Verbal fluency tasks were associated with working memory measures (Enumeration, Categorization, PASOT), Color naming, Visual search and accuracy of Graphical fluency. However, when *group* is included as a factor (***M2***), some relations disappeared (i.e., Comprehension of instructions with color, accuracy and perseverations of Graphical fluency, Categorization; semantic parameter of Verbal fluency with Visual search; time of Visuo-motor precision with errors of Graphical fluency; errors of Visuo-motor precision with all the EF measures).

Additionally, several interaction effects involving diagnosis were observed. These included interactions between perseveration of Graphical fluency with Comprehension of instructions; perseveration of Graphical fluency with Matrix reasoning and errors of Visuo-motor precision; Visual search with phonological parameter of Verbal fluency tasks; Categorization with errors of Visuo-motor precision; PASOT with semantic Verbal fluency tasks.

Table 5.5 *Generalized linear models between executive attention measures and cognitive abilities*

Predictors (cognitive measures)		Outcomes (MEA tasks)															
		Color		GF (accuracy)		GF (error)		GF (pers)		Visual		Enumeration		Categorization		PASOT	
		ES	p^a	ES	p^a	ES	p^a	ES	p^a	ES	p^a	ES	p^a	ES	p^a	ES	p^a
Matrix reasoning	**M1**	.04	.22	.22	**<.001*****	-.02	.58	.06	.06	.06	**.002****	.05	.11	.08	.14	.20	**<.001*****
	M2	.06	.21	.27	**<.001*****	.07	.23	-.01	.76	.13	**.02***	.08	.16	.09	.18	.33	**<.001*****
		-.01	.86	.02	.84	-.11	.10	.14	**.02***	-.08	.19	-.02	.81	.21	.21	-.09	.27
CI	**M1**	.23	**<.001*****	.35	**<.001*****	.07	.09	.13	**.002****	.15	**.001****	.22	**<.001*****	.25	**<.001*****	.26	**<.001*****
	M2	.12	.05	.14	.10	.05	.51	.08	.17	.16	**.03***	.22	**<.001*****	.10	.21	.30	**<.001*****
		.08	.35	.30	**.02***	-.07	.38	.04	.58	-.07	.44	-.06	.42	.24	.20	-.09	.35
Verbal fluency (semantic)	**M1**	.24	**<.001*****	.26	**<.001*****	-.02	.55	-.04	.31	.06	**.02***	.19	**<.001*****	.25	**<.001*****	.23	**<.001*****
	M2	.16	**.005****	.23	**.007****	-.07	.30	-.01	.88	.12	.08	.21	**.002****	.27	**.002****	.36	**<.001*****
		.12	.15	-.02	.87	.004	.96	-.09	.28	-.09	.23	-.05	.52	-.32	.12	-.24	**.04***
Verbal fluency (phonological)	**M1**	.18	**<.001*****	.32	**<.001*****	-.005	.87	.05	.18	.07	**.001****	.14	**<.001 *****	.18	**.003****	.22	**<.001*****
	M2	.10	**.04***	.30	**<.001*****	-.03	.62	.10	.17	.21	**<.001*****	.15	**.01***	.15	**.03***	.29	**<.001*****
		.11	.13	.01	.92	-.02	.79	-.06	.35	-.17	**.007****	-.04	.60	-.06	.71	-.12	.20
Visuo-motor precision (time)	**M1**	.03	.48	.19	**.01***	-.14	**.001****	-.16	**<.001*****	-.07	.16	.07	.10	.03	.70	.07	.26
	M2	.05	.46	.25	**.01***	-.13	.09	-.16	**.02***	.04	.62	.04	.64	.08	.39	.06	.54
		-.01	.94	-.07	.64	-.05	.63	-.01	.88	-.17	.08	.04	.71	-.35	.13	-.04	.78
Visuo-motor precision (error)	**M1**	.61	**.003****	.73	**.02***	.67	**<.001*****	.81	**<.001*****	.40	.05	.44	**<.001*****	.71	**.04***	.25	**.01***
	M2	-.06	.83	-.09	.82	.16	.61	-.02	.93	.11	.74	.09	.62	-.07	.85	-.04	.83
		.71	.09	.64	.31	.36	.36	1.29	**<.001*****	.26	.53	.36	.11	2.05	**.03***	.26	.26

Note. M1 *= model with covariates (Executive Attention measures ~ Cognitive abilities + sex + age),* ***M2*** *= model with covariates and interaction term (Executive Attention measures ~ Cognitive abilities * groups + sex + age).* ***ES*** *= estimated coefficient.* ***GF*** *= Graphical fluency,* ***GF_pers*** *= perseverative errors of Graphical fluency,* ***Visual*** *= Visual search.* ***CI*** *= Comprehension of instructions. [a] Test significance * p < .05, ** p < .01, *** p < .001.*

5.3.2 Group differences in cognitive and executive attention measures

Significant differences in most of the cognitive and executive functioning measures were found between groups, except in Matrix reasoning, Visuo-motor precision (time parameter), and Visual search parameter. For further details, see **Table 5.6**. See **Appendix C (Figure C.1** and **Figure C.2)** for a visualization of the results.

Table 5.6 *Differences between neurotypical and neurodivergent groups*

Variables	Neurotypical	Neurodivergent	*p(BH)*[a]
Cognitive measures			
Matrix reasoning	.05 (.94)	.01 (1.00)	n.s. (.85)
Comprehension of instructions	-.03 (1.1)	-1.14 (1.64)	**NT > ND (<.001***)**
Verbal fluency (semantic)	.09 (1.18)	-.55 (1.23)	**NT > ND (<.001***)**
Verbal fluency (phonological)	.06 (1.07)	-.50 (.97)	**NT > ND (<.001***)**
Visuo-motor precision (time)	-.09 (1.14)	-.06 (1.72)	n.s. (.17)
Visuo-motor precision (error)	-.25 (1.75)	-4.92 (9.92)	**NT > ND (<.001***)**
Executive attention measures			
Color naming	-.16 (1.44)	-1.53 (1.95)	**NT > ND (<.001***)**
Graphical fluency (accuracy)	.04 (1.01)	-1.00 (1.23)	**NT > ND (<.001***)**
Graphical fluency (error)	-.13 (1.23)	-1.72 (2.64)	**NT > ND (<.001***)**
Graphical fluency (perseveration)	-.18 (1.41)	-.88 (2.37)	**NT > ND (.01*)**
Cancellation (sheet 7)	-.16 (1.48)	-.62 (1.48)	**NT > ND (.001**)**
Cancellation (sheet 8)	-.12 (1.26)	-.74 (1.86)	**NT > ND (.002**)**
Cancellation (sheet 10)	-.14 (1.22)	-1.17 (4.84)	**NT > ND (.03*)**
Visual search	-.10 (1.23)	-.95 (4.80)	n.s. (.33)
Enumeration (forward)	-.11 (1.32)	-1.29 (2.10)	**NT > ND (<.001***)**
Enumeration (backward)	-.11 (1.39)	-1.94 (3.05)	**NT > ND (<.001***)**
Enumeration forward-backward	-.13 (1.38)	-1.77 (2.88)	**NT > ND (<.001***)**
Categorization	.12 (1.14)	-.77 (.72)	**NT > ND (<.001***)**
PASOT (1200ms)	-.03 (1.03)	-2.15 (2.47)	**NT > ND (<.001***)**
PASOT (800ms)	-.06 (1.08)	-1.31 (1.71)	**NT > ND (<.001***)**
PASOT	-.07 (1.11)	-1.83 (2.13)	**NT > ND (<.001***)**

Note. NT *= neurotypicals children,* ***ND*** *= neurodivergent children.* ***BH*** *= Benjamini-Hochberg correction.* [a] *Test significance * p < .05, ** p < .01, *** p < .001.*

When comparing the performance of clinical groups, autistic children tended to show lower performance compared to children with SLD in most of the tasks. However, no significant differences emerged in Matrix reasoning, Visuo-motor precision (both time and error parameters), in error of Graphical fluency task, in the Visual search parameter, including sheets 7 and 10 of Cancellation task, and in the Enumeration task, including the backward condition. For detailed see **Table 5.7**.

Table 5.7 *Differences between autistic children and those with specific learning disorders*

Variables	ASD	SLD	*p(BH)*[a]
Cognitive measures			
Matrix reasoning	-.07 (1.00)	.15 (1.01)	n.s. (.35)
Comprehension of instructions	-1.54 (1.66)	-.46 (1.39)	**SLD > ASD (.002**)**
Verbal fluency (semantic)	-.72 (1.29)	-.23 (1.05)	n.s. (.05)
Verbal fluency (phonological)	-.67 (.93)	-.2 (.98)	**SLD > ASD (.02*)**
Visuo-motor precision (time)	-.03 (1.92)	-.12 (1.32)	n.s. (.40)
Visuo-motor precision (error)	-6.72 (11.84)	-1.76 (3.3)	n.s. (.09)
Executive attention measures			
Color naming	-1.82 (2.02)	-1.01 (1.71)	**SLD > ASD (.03*)**
Graphical fluency (accuracy)	-1.27 (1.21)	-.55 (1.15)	**SLD > ASD (.01*)**
Graphical fluency (error)	-2.03 (2.55)	-1.2 (2.74)	n.s (.08)
Graphical fluency (perseveration)	-1.39 (2.71)	-.03 (1.3)	**SLD > ASD (.002**)**
Cancellation (sheet 7)	-.73 (1.5)	-.44 (1.47)	n.s. (.14)
Cancellation (sheet 8)	-1.07 (2.09)	-.19 (1.24)	**SLD > ASD (.02*)**
Cancellation (sheet 10)	-1.69 (5.97)	-.29 (1.33)	n.s. (.20)
Visual search	-1.32 (5.95)	-.31 (1.37)	n.s. (1.00)
Enumeration (forward)	-1.75 (2.25)	-.57 (1.64)	**SLD > ASD (.01*)**
Enumeration (backward)	-2.46 (3.56)	-1.23 (2.00)	n.s. (.31)
Enumeration forward-backward	-2.07 (3.16)	-1.37 (2.44)	n.s. (.83)
Categorization	-.97 (.56)	-.47 (.84)	**SLD > ASD (.005**)**
PASOT (1200ms)	-3.15 (2.53)	-1.02 (1.87)	**SLD > ASD (<.001***)**
PASOT (800ms)	-1.92 (1.61)	-.75 (1.62)	**SLD > ASD (.009**)**
PASOT	-2.76 (2.05)	-.96 (1.84)	**SLD > ASD (.001**)**

Note. ASD *= autistic children,* ***SLD*** *= children with specific learning disorders.* ***BH*** *= Benjamini-Hochberg correction.*

[a] *Test significance * p < .05, ** p < .01, *** p < .001.*

5.3.3 Developmental analysis

The cross-sectional analysis revealed that neurodivergent children exhibited notable changes in Comprehension of instructions, in the Categorization and in the PASOT interval intra-stimuli at 1200ms from ages 8-10 to 11-13 years. Additionally, significant differences emerged in the Visuo-motor precision task, in both time and accuracy parameters, respectively, between the age groups 5-7 and 8-10 and 11-13 years (see **Table 5.8**).

Between-subjects analyses indicated significant differences among groups in Comprehension of instructions at each age range. Furthermore, at age 8-10, autistic children showed reduced performance in both semantic and phonological Verbal fluency, with phonological fluency deficits persisting at 11-13 years. Significant group differences were also observed in Visuo-motor precision time parameters and errors at ages 5-7, with errors remaining significantly higher at 8-10 and 11-13 years. Regarding executive functioning, neurodivergent children showed significant differences at ages 8-10, 11-13, and 14-16 years in Color naming, errors of Graphical fluency, Enumeration scores (except for the backward condition at 8-10 years), Categorization, and PASOT scores (except for the 800ms interval at 14-16 years). Additionally, significant differences in accuracy of Graphical fluency were found at ages 8-10 and 11-13, while perseveration of Graphical fluency and performance on Cancellation sheet 8 were significantly different at 8-10 and 11-13 years. Then, Cancellation sheets 7 and 10 are different at 11-13 years. Finally, Visual search was significantly different at 5-7 years. See **Table 5.8** for further details and **Appendix C (Figure C.3** and **Figure C.4)** for a visualization of the results.

5.3.4 Failures and successes during the execution of executive attention tasks in neurodivergent children

Distinct patterns in failures across tasks emerged. Failures were notably higher for neurodivergent children (see **Table 5.9**). Across tests, failures were higher especially for Enumeration (*ND: 36.05 % vs. NT: 7.69%; OR = .15, 95% CI [.07, .31]; $\chi^2(d) = 30.50$ (1), $p = <.001$*) and PASOT (*ND: 62.79% vs. NT: 10.26%; OR = .07, 95% CI [.04, .14]; $\chi^2(d) = 74.42$ (1), $p = <.001$*). These results indicate that tasks involving particularly higher working-memory demands were more challenging for neurodivergent participants.

Table 5.8 *Within and between subjects' analysis for cognitive and executive attention measures among age-groups*

	5-7 years		8-10 years		11-13 years		14-16 years		Within *(BH)*[a]		Between *(BH)*[a]
Variables	**NT**	**ND**	**NT**	**ND**	**NT**	**ND**	**NT**	**ND**	**NT**	**ND**	
Cognitive measures											
Matrix reasoning	.05 (.94)	-0.31 (0.88)	0.01 (0.99)	-0.11 (0.91)	0.10 (0.87)	0.06 (0.94)	0.00 (1.00)	0.17 (1.27)	n.s	n.s.	5-7 n.s. (.39) 8-10 n.s. (.68) 11-13 n.s. (.68) 14-16 n.s. (.47)
Comprehension of instructions	-0.15 (1.38)	-3.16 (2.66)	-0.11 (1.05)	-2.05 (1.57)	0.10 (1.01)	-0.46 (1.36)	0.01 (1.01)	-0.76 (0.98)	n.s.	**8-10 < 11-13 (<.001***), 14-16 (.02*)**	**5-7 (.04*)** **8-10 (<.001***)** **11-13 (.04*)** **14-16 (.01*)**
Verbal fluency (semantic)	0.06 (1.11)	-0.91 (1.56)	0.06 (0.96)	-0.74 (1.27)	0.19 (1.48)	-0.38 (1.30)	0.00 (1.01)	-0.49 (0.94)	n.s.	n.s.	5-7 n.s (.11) **8-10 (.005**)** 11-13 n.s. (.08) 14-16 n.s. (.08)
Verbal fluency (phonological)	0.09 (1.15)	-1.19 (1.51)	0.06 (1.06)	-0.69 (0.94)	0.02 (1.02)	-0.48 (0.82)	0.10 (1.13)	-0.16 (1.09)	n.s.	n.s.	5-7 n.s. (.06) **8-10 (.005**)** **11-13 (.02*)** 14-16 n.s. (.58)
Visuo-motor precision (time)	-0.08 (1.11)	1.69 (0.86)	-0.08 (1.07)	0.16 (1.72)	-0.13 (1.29)	-0.21 (1.52)	-0.02 (1.06)	-0.57 (1.97)	n.s.	**5-7 < 8-10 (.03*), 11-13 (.004**), 14-16 (.004**)**	**5-7 (.002**)** 8-10 n.s. (.15) 11-13 n.s. (.70) 14-16 n.s. (.44)
Visuo-motor precision (error)	-0.07 (1.10)	-12.18 (7.84)	-0.16 (1.41)	-9.49 (15.52)	-0.43 (2.42)	-2.66 (5.33)	-0.28 (1.49)	-1.28 (2.72)	n.s.	**5-7 < 11-13 (.04*), 14-16 (.02*)** **8-10 < 14-16 (.02*)**	**5-7 (.002*)** **8-10 (<.001***)** **11-13 (.001**)** 14-16 n.s. (.28)

	5-7 years		8-10 years		11-13 years		14-16 years		Within *(BH[a])*		Between *(BH[a])*
Variables	**NT**	**ND**	**NT**	**ND**	**NT**	**ND**	**NT**	**ND**	**NT**	**ND**	
Executive attention measures											
Color naming									n.s.	n.s.	5-7 n.s. (.05)
											8-10 (<.001*)**
	-0.11	-1.95	-0.11	-2.03	-0.27	-1.11	-0.09	-1.53			**11-13 (.01*)**
	(1.24)	(2.45)	(1.36)	(2.1)	(1.76)	(1.65)	(1.21)	(2.07)			**14-16 (<.001***)**
Graphical fluency (accuracy)									n.s.	n.s.	5-7 n.s. (.35)
											8-10 (<.001*)**
	0.09	-0.43	-0.02	-1.24	0.08	-1.09	0.03	-0.60			**11-13 (<.001***)**
	(1.13)	(2.49)	(1.00)	(1.05)	(0.97)	(1.15)	(0.99)	(1.37)			14-16 n.s. (.08)
Graphical fluency (error)									n.s.	n.s.	5-7 n.s. (.37)
											8-10 (<.001*)**
	-0.22	-1.37	-0.07	-1.90	-0.14	-1.29	-0.10	-2.33			**11-13 (.003**)**
	(1.43)	(2.36)	(1.21)	(2.26)	(1.18)	(2.06)	(1.15)	(3.83)			**14-16 (.02*)**
Graphical fluency (perseveration)									n.s.	n.s.	5-7 n.s. (.65)
											8-10 (.02*)
	-0.10	0.21	-0.24	-1.16	-0.13	-0.96	-0.27	-0.54			**11-13 (.02*)**
	(1.16)	(1.02)	(1.34)	(2.11)	(1.61)	(2.27)	(1.47)	(2.97)			14-16 n.s. (.88)
Cancellation (sheet 7)									n.s.	n.s.	5-7 n.s. (.32)
											8-10 n.s. (.06)
	-0.29	-2.71	-0.09	-0.46	-0.11	-0.75	-0.18	-0.29			**11-13 (.01*)**
	(2.12)	(3.71)	(1.10)	(1.14)	(1.30)	(1.46)	(1.39)	(1.35)			14-16 n.s. (.72)
Cancellation (sheet 8)									n.s.	n.s.	5-7 n.s. (.16)
											8-10 (.02*)
	-0.19	-4.11	-0.19	-0.84	-0.10	-0.86	0.02	0.06			**11-13 (.01*)**
	(1.33)	(4.93)	(1.33)	(1.52)	(1.31)	(1.86)	(0.98)	(1.01)			14-16 n.s. (.96)
Cancellation (sheet 10)									n.s.	n.s.	5-7 n.s. (.59)
	-0.27	0.27	-0.23	-2.35	-0.01	-1.11	-0.05	0.02			8-10 n.s. (.08)
	(1.34)	(0.89)	(1.36)	(7.96)	(1.07)	(2.83)	(1.08)	(1.37)			**11-13 (.01*)**

											14-16 n.s. (.51)
Visual search									n.s.	n.s.	**5-7 (.01*)**
											8-10 n.s. (.42)
	-0.20 (1.26)	1.68 (1.29)	-0.16 (1.41)	-1.92 (7.73)	0.02 (1.04)	-0.98 (3.02)	-0.09 (1.22)	-0.02 (1.84)			11-13 (.07)
											14-16 n.s. (.57)
Enumeration (forward)									n.s.	n.s.	**8-10 (.001**)**
			-0.08	-1.34	-0.22	-1.69	0.03	-0.53			**11-13 (.001**)**
	-	-	(1.58)	(1.77)	(1.27)	(2.57)	(0.99)	(1.17)			**14-16 (.04*)**
Enumeration (backward)									n.s.	n.s.	8-10 n.s. (.12)
			-0.17	-1.08	-0.08	-2.59	-0.07	-1.47			**11-13 (<.001***)**
	-	-	(1.82)	(2.26)	(1.08)	(3.66)	(1.15)	(2.10)			**14-16 (.002**)**
Enumeration forward-backward									n.s.	n.s.	**8-10 (.03*)**
			-0.22	-0.87	-0.08	-2.39	-0.08	-1.38			**11-13 (<.001***)**
	-	-	(1.71)	(1.71)	(1.18)	(3.46)	(1.16)	(2.26)			**14-16 (.002**)**
Categorization									n.s.	**8-10 < 11-13 (.02*)**	**8-10 (<.001***)**
			0.09	-1.02	0.18	-0.58	0.04	-0.84			**11-13 (.001**)**
	-	-	(1.24)	(0.42)	(1.16)	(0.66)	(0.98)	(0.98)			**14-16 (.003**)**
PASOT (1200ms)									n.s.	**8-10 < 11-13 (.02*)**	**8-10 (<.001***)**
			-0.10	-2.89	-0.00	-1.31	0.00	-3.05			**11-13 (<.001***)**
	-	-	(1.12)	(1.83)	(0.98)	(1.72)	(1.01)	3.37)			**14-16 (<.001***)**
PASOT (800ms)									n.s.	n.s.	**8-10 (<.001***)**
			-0.06	-1.62	-0.11	-1.23	0.01	-1.27			**11-13 (.001**)**
	-	-	(1.11)	(1.19)	(1.11)	(1.62)	(1.01)	(2.13)			14-16 n.s. (.05)
PASOT									n.s.	n.s.	**8-10 (<.001***)**
			-0.14	-2.32	-0.06	-1.41	0.01	-2.25			**11-13 (<.001***)**
	-	-	(1.23)	(1.30)	(1.07)	(1.74)	(1.01)	(2.95)			**14-16 (.01*)**

***Note. NT** = neurotypicals children, **ND** = neurodivergent children. **BH** = Benjamini-Hochberg correction. [a] Test significance * p < .05, ** p < .01, *** p < .001.*

Table 5.9 *Analysis of failures and successes in executive attention tasks*

Variables	Failures (NT)	Successes (NT)	Failures (ND)	Successes (ND)	% Failures (NT)	% Failures (ND)	OR [95% CI]	χ^2 (df), p
Color naming	10	190	28	64	5	30.43	.12 [.06 - .27]	**36.01 (1), <.001*** **
Graphical fluency (accuracy)	3	197	23	69	1.5	25	.05 [.02 - .17]	**42.90 (1), <.001*** [F]**
Graphical fluency (perseveration)	19	181	20	72	9.5	21.74	.38 [.19 - .75]	**8.16 (1), .004****
Visual search	16	184	18	74	8	19.56	.36 [.18 - .74]	**8.19 (1), .004****
Categorization	3	153	5	81	1.92	5.81	.34 [.07 – 1.32]	2.63 (1), .10[F]
Enumeration forward- backward	12	144	31	55	7.69	36.05	.15 [.07 - .31]	**30.50 (1), <.001*** **
PASOT	16	140	54	32	10.26	62.79	.07 [.04 - .14]	**74.42 (1), <.001*** **
Enumeration and PASOT	6	150	27	59	3.85	31.39	.09 [.04 - .23]	**35.73 (1), <.001*** **

Note. NT *= neurotypicals children,* ***ND*** *= neurodivergent children. Counts and percentages of withdrawn vs. completed by group (NT, ND) for each task. Odds ratios (OR) quantify the increased odds of withdrawal in NT vs. ND;* χ^2 *(or Fisher's exact test) assesses group differences.* [F] *= Fisher's exact test.* [a] *Test significance * p < .05, ** p < .01, *** p < .001*

5.4 Discussion

5.4.1 Associations between executive attention and cognitive abilities

Although this battery was designed to minimize the impact of general cognitive abilities and the influence of non-executive processes, most tasks are strongly linked with cognitive abilities, particularly with language and fine-motor skills, which are frequently implied in the execution of neuropsychological tasks. Specifically, Comprehension of instructions was broadly associated with all the EF measures, except for errors parameter of Graphical fluency, as shown in previous works (Campbell et al., 2017; Ellis Weismer et al., 2018; Yeung et al., 2020). Similarly, Visuo-motor precision errors were associated with EF measures, except for Visual search. Although the link between EFs and language is well documented, less evidence was provided for motor skills. These results highlight the specific role of fine motor skills in modulating executive function performance, particularly on accuracy-related measures (Odermatt et al., 2022; Sung et al., 2024). Associations between EF and broader aspects of intelligence are also well documented (Itskovich et al., 2021; Joseph et al., 2002; Syriopoulou-Delli et al., 2018). However, in this study, only accuracy of Graphical fluency, Visual search and PASOT performance were significantly related to the index of fluid intelligence (Matrix reasoning task), a non-verbal measure that implies the use of visual stimuli. This may reflect the design of the battery to assess EF beyond general intelligence. Interestingly, some relationships disappeared when the diagnostic group was added to the model. Moreover, several associations were moderated by diagnostic group, underscoring the complex interactions between cognitive and executive function measures in neurodivergent versus neurotypical children. These results highlight how difficult it is to avoid the influence of cognitive abilities during the execution of neuropsychological tasks in neurodiverse populations, highlighting the importance of taking these factors into account when evaluating performance and its impact on EF outcomes.

5.4.2 Executive attention in neurodivergent children

Neurotypical children showed higher scores compared to neurodivergent children in overall performance, both in cognitive and executive attention measures, aligned with the preliminary hypothesis (All et al., 2024; Hughes, 2011). Although neurodivergent children tend to commit more errors in the Visuo-motor precision task, the groups did not differ in task completion time. This

behavior could highlight challenges in fine-motor skills, which are frequently reported in the literature, an area of difficulty for neurodivergent children evident from the preschool years and considered a key developmental milestone to assess during neuropsychological evaluations for detecting neurodiversity (Strooband et al., 2023; Wan et al., 2025). Indeed, in the Graphical fluency, lower scores are reported for accuracy and higher error rates for neurodiverse children compared to neurotypicals. Similarly, lower performances are reported when a more challenging task was required that involved both precision and speed dimensions of fine-motor skills, as shown by the score obtained in the Cancellation tasks. This conclusion is further supported by the absence of performance differences in the final score obtained by the Visual search, where fine-motor demands are controlled. Indeed, this task measures selective attention without relying on fine-motor speed or accuracy. The structured nature of this task, alongside clear administration procedures and the possibility of practicing the tasks multiple times, may have contributed to improved performance among neurodivergent children by enabling their abilities to emerge under optimal conditions (Hendry & Scerif, 2023). These results suggest that neurodivergent children's ability to discriminate visual stimuli remains intact, aligning with studies that showed visual ability as a strength in the neurodivergent profile (Brunsdon et al., 2015; Cardillo et al., 2020).

5.4.3 Comparison between autistic children and SLD

Notable findings emerged when comparing autistic children with those who have specific learning disorders. Overall, although both neurodivergent groups performed more poorly than neurotypical children on executive attention tasks, as expected from the preliminary hypothesis, autistic children exhibited greater difficulties in specific domains (Aita et al., 2022; Lievore et al., 2025), but some similarities are also found.

Differences in cognitive and executive attention abilities

Neurodivergent children generally performed below neurotypical peers on Verbal fluency tasks; however, no differences emerged between the autistic and SLD groups in the semantic condition, suggesting that both generated a similar number of words within specific categories. While this task was used primarily as an indicator of expressive language abilities in this study, it also reflects generative thinking and is often included in executive functioning assessments. In contrast, autistic

children showed poorer performance compared to the SLD group in the phonological version of the Verbal fluency task, consistent with evidence indicating that such tasks are particularly challenging for them (Cantio et al., 2016; Grob & Hagmann-von Arx, 2018). These results suggest that autistic children have greater difficulty generating words based solely on a phonemic prompt, whereas retrieving words within familiar, concrete categories, such as animals or food, is easier, enabling them to produce a larger number of words (Zarokanellou et al., 2023). This may be explained by the cognitive style often observed in autistic children and the broader neurodiverse population, where words and objectives are categorized into specific, familiar groups (Kunda & Goel, 2011). Furthermore, autistic children exhibited greater difficulties compared to children with SLD in graphical generative thinking processing, as demonstrated during the execution of Graphical fluency tasks. Indeed, they obtained lower accuracy and greater perseverance. This pattern is similar to findings by Karalunas et al. (2018), who reported slower performance in autistic children on graphical tasks requiring set-shifting and generative thinking abilities. Such results mirror their weaker performance on overall generative thinking processes, both in verbal and graphical tests. Allowing additional time for task completion and providing support by adults or through visual prompts may improve performance among neurodivergent children. Autistic children also demonstrated weaker performance in other EF tasks involving verbal skills, including Color naming, forward condition of Enumeration, Categorization, and the PASOT task, suggesting difficulties in working memory and processing speed are particularly present when verbal demands are high (Hume et al., 2014). Similarly, Pastor-Cerezuela et al. (2020) reported that autistic children required more time to complete a Color naming task, reflecting slower processing speed. Moreover, Garcia-Molina and Clemente-Estevan (2019) found that performance increases in autistic children when instructions are provided through both verbal and visual modalities, highlighting the benefit of integrating visual cues to support the execution of the tasks.

Similarities in cognitive and executive attention abilities

Although these differences in the cognitive profiles between autistic children and children with SLD exist, some similarities also emerged. Indeed, no differences were found between autistic and SLD groups in fine-motor skills, in terms of accuracy and execution speed (visuo-motor task), as well as in errors committed in the Graphical fluency task, nor in tests requiring integration of these dimensions, such as Cancellation tasks. Interestingly, both groups performed similarly on highly structured tasks (sheet 7 of Cancellation), which require sequential line barraging, as well as in visual

discrimination tasks (sheet 10 of Cancellation and Visual search). However, autistic children showed lower performance in tasks that require rapid fine-motor production in a less structured context (sheet 8 of Cancellation), indicating that their performance decreases when tasks demand fine-motor speed combined with sequential attention processing. Finally, both groups demonstrated comparable performance in working memory tasks, particularly in the backward condition of Enumeration (counting from 100 to 1) and in the composite Enumeration score. This finding is consistent with previous research indicating that children with SLD often struggle to automate and manipulate numerical information, a difficulty also evident in autistic children (Morsanyi et al., 2018). However, when working memory tasks involved verbal processing, and specifically the manipulation of words, such as in Categorization tasks, autistic children performed worse, as found by Lievore et al. (2025). These findings suggest how specific types of material can differentiate between children with ASD and those with SLD. In particular, numbers appear to be more challenging for children with SLD compared to word stimuli, who showed weaker performance in this area, whereas autistic children tend to struggle with both numbers and words.

5.4.4 Changes in cognitive and executive attention functions across development

Age-group analyses revealed that cognitive skills and executive attention showed some age-related improvements in certain tasks in neurodivergent children compared to the baseline provided by the neurotypical group. Specifically, differences were shown in Comprehension of instructions and Visuo-motor precision error parameters. Regarding EF abilities, they seem to stay relatively stable across ages, except in working memory tasks, such as PASOT and Categorization. As expected, these changes were especially evident at the onset of adolescence, suggesting a more pronounced developmental increase in these abilities consistent with previous studies (Albert & Steinberg, 2011; Korkman et al., 2001; Kouklari et al., 2018). Indeed, most tasks showed marked differences between neurotypical and neurodivergent groups at ages 11-13, supporting the idea of a developmental delay in certain skills, including executive attention, which becomes evident through significant improvements compared to earlier ages (Kouklari et al., 2018). Nevertheless, group differences are evident from early developmental stages (Wan et al., 2025). In the present study, fine-motor skill challenges were evident as early as 5-7 years, while differences in most cognitive tasks became noticeable from primary school age, around 8-10 years.

5.4.5 Weaknesses in working memory tasks

Considering the weaknesses observed in executive attention tasks, including instances in which children were unable to complete the tasks due to execution difficulties (rather than voluntary withdrawal) or obtained performances under -2 SD, some important patterns emerged. Neurodivergent children failed from tasks at significantly higher rates compared to their neurotypical peers. Notably, the tasks that posed the greatest challenges for neurodivergent children were those assessing working memory. Although performance was generally lower in neurodivergent groups, the proportion of children exhibiting specific difficulties in the Categorization task was minimal (5.81%), with no differences compared to the neurotypical group. Whereas the Enumeration task presented greater challenges, with 36.05% of neurodivergent children demonstrating weaknesses. Clinically, this suggests that not all neurodivergent children display weaknesses in working memory tasks requiring the manipulation of familiar information, such as Categorization and Enumeration. In contrast, the PASOT task, a n-back task, where disengagement rates were highest, proved especially valuable in capturing difficulties in these functions, with 62.79% of neurodivergent children performing below expectations. Although it posed challenges for both groups, neurodivergent children demonstrated a stronger tendency to fail compared to their neurotypical peers. Emotional regulation demands may have contributed to this disengagement. Children are required to verbally report the opposite of the word heard immediately before the final word in an audio sequence, delivered without breaks or adaptations to individual pace. This combination of sustained cognitive load and rigid timing can trigger heightened arousal and anxiety, leading to task unsuccess and reduced engagement. Given that neurodivergent children, particularly those with autism, often experience difficulties with emotional regulation (Conner et al., 2021; Samson et al., 2015), emotionally charged or high-demand situations, such as novel tasks, fast-paced instructions, lack of breaks, or unfamiliar testing contexts, can exacerbate anxiety and psychomotor agitation, further compromising task performance (Bellato et al., 2021; Lory et al., 2020). Although observational notes point in this direction, no direct measures of emotional regulation were used, so this explanation remains speculative. Anecdotal observational data during working memory tasks, especially PASOT, further highlighted individual differences in coping with stress. For example, one adolescent with above-average cognitive abilities completed the first trial with high accuracy but then refused to continue, requesting a self-regulating activity (e.g., watching YouTube videos) to restore emotional balance. Other children refused to begin the task even after explanation and demonstration trials, requesting alternative activities instead. Additionally, some autistic children were unable to complete the task due to cognitive limitations such as difficulties understanding instructions, lacking knowledge of opposites, or exhibiting echolalia (i.e., repeating words from the audio or examiner).

Some children also took long breaks mid-task, remaining silent during the audio presentation. Conversely, among neurotypical children, the primary reason for failures was a lack of familiarity with specific linguistic contrasts required by the task, likely reflecting not yet knowledge of contraries. Overall, 31.39% of neurodivergent children exhibited weaknesses in both Enumeration and PASOT tasks, compared to only 3.85% of neurotypical children. These results underscore the capacity of these tasks in identifying executive attention challenges within neurodiverse populations. Moreover, the diverse responses observed highlight that each child experiences and uniquely responds to stress. These insights can be invaluable for gaining a comprehensive understanding of the child's functioning, which can then be effectively communicated to practitioners and teachers. These findings highlight the importance of considering both cognitive and emotional regulation factors when assessing executive attention. They also emphasize the need for flexible and individualized testing approaches to ensure assessments capture true capacities rather than reflecting the confounding effects of external stress or emotional overwhelm. Importantly, observations made during test administration are crucial for a better understanding of the attitudes of neurodiverse children toward different tasks. These insights can enhance knowledge, enabling the implementation of personalized strategies to tailor rehabilitation and educational interventions effectively.

5.4.6 Limitations and future directions

This study has several limitations. First, the sample was not balanced across groups (neurotypical, ASD, SLD) or age ranges, which may limit the generalizability of the findings. Future studies should prioritize gathering additional data, especially from neurodivergent children, with a particular focus on those with specific learning disorders, as this group was underrepresented in the current sample. This would allow for a more thorough analysis of the similarities and differences between neurotypicals, autistic children, and those with specific learning disorders, leading to more informative and interpretable results. Additionally, the uneven distribution of females within the neurodivergent group limited the ability to explore potential gender differences in executive attention profiles. Therefore, future research should aim to recruit more balanced samples across groups, age ranges, and gender to enhance representativeness and facilitate subgroup analyses. Moreover, the assessment relied primarily on performance-based cognitive tasks, which may not fully capture the complexity of executive functioning across different contexts. Additionally, the length of the assessment may cause participant fatigue, potentially impairing performance on cognitively demanding tasks. Incorporating computerized tasks could increase engagement for children and

provide more dynamic measures of executive functioning. Moreover, integrating parent and teacher reports alongside performance-based assessments would offer a more comprehensive view of each child's functioning across diverse real-world environments. Finally, implementing a structured observational coding scheme could enhance our understanding of the attitudes of neurodiverse children during the execution of various executive attention tasks.

5.5 Conclusion

This study offers important insights into executive attention in neurodiverse children by employing a multidimensional battery that accounts for cognitive, motor, and linguistic abilities. Specifically, neurodivergent children demonstrate difficulties on tasks assessing cognitive flexibility and generative thinking within graphical contexts, as well as on working memory tasks, specifically those that imply emotionally demanding conditions, compared to neurotypicals. However, when additional abilities such as fine-motor skills are considered, group differences disappeared for tasks like Visual search. The age-group analyses reveal that differences between neurodivergent and neurotypical children emerge early in development, although neurodivergent children show consistent improvement in their abilities from adolescence onwards. When examining specific subgroups, autistic children show more pronounced weaknesses in both cognitive and executive functioning compared to children with SLD, especially in those requiring linguistic skills. However, a few performance similarities are also observed. For instance, both groups show comparable outcomes on Visual search, errors committed in Graphical fluency tests, and Enumeration tasks involving, respectively, visual discrimination, fine-motor precision, and working memory in familiar requests. Moreover, tasks assessing working memory, such as Enumeration and n-back tests, which also implicate emotional regulation demands, are particularly effective in identifying executive attention deficits in neurodivergent populations. These results highlight the importance of considering both cognitive and emotional regulation in assessments, supporting the use of flexible and individualized testing approaches that accurately reflect children's abilities without being influenced by stress or emotional difficulties. Broader perspectives and multidimensional approaches to assess executive functioning may provide valuable insights in studying these functions among neurodiverse populations, improving the implementation of personalized educational and rehabilitation strategies.

Chapter 6

Mapping executive attention and broader cognitive profiles in neurodiverse children: insights beyond diagnostic labels

Summary

Autism Spectrum Disorders (ASD) and specific learning disorders (SLD) are commonly associated with cognitive challenges, particularly in executive functions (EFs). Cluster analysis is frequently used to identify patterns of performance and to explore similarities and differences across clinical groups, especially in relation to core clinical features. Yet only a limited number of studies have applied these methods to investigate cognitive profiles, beyond traditional diagnostic categories in neurodiverse populations.

The present study explores executive functioning profiles, both in isolation and in conjunction with broader cognitive abilities, in a neurodiverse sample of 249 children aged 8 to 16, including neurotypical, autistic, and SLD participants. Neuropsychological assessment included tools to evaluate executive attention and broader cognitive abilities (linguistic, fine-motor and fluid intelligence measures). A two-level cluster analysis approach (EF-only vs. EF+COGN) was employed to determine whether EF patterns remain consistent or vary when broader cognitive

abilities are taken into account. The results indicated that, despite minor variations in participant distribution, the overall group patterns remained largely stable, suggesting that both the EF-only and EF+COGN models capture a similar underlying structure of executive functioning. However, the EF-only model appears preferable in terms of parsimony and interpretability. Although all groups were represented across clusters, certain clusters were enriched for specific profiles. Specifically, autistic children were mainly grouped in clusters characterized by more pronounced executive and cognitive challenges, while children with SLD and neurotypical peers tended to fall into clusters with more average or balanced performance profiles. Overall, the results suggest that executive attention challenges manifest in distinct functional patterns, with specific areas of weakness occurring alongside relative strengths, independent of diagnostic classification. This highlights the individuality of each person's cognitive profile and underscores that relying solely on a diagnostic label provides an overly reductive view.

Keywords

Executive attention, cognitive abilities, autism, specific learning disorders, cluster analysis

Key points

- The EF-only and EF+COGN models reveal a comparable organizational structure of executive functioning.
- While all participant groups appear across clusters, some clusters are dominated by specific profiles.
- Autistic children are predominantly associated with clusters showing broader executive attention and cognitive challenges.
- Children with SLD and neurotypical participants are more frequently found in clusters reflecting average or balanced performance.
- Executive difficulties tend to follow distinct functional patterns, with weaknesses often coexisting alongside relative strengths, beyond the diagnosis classification.

6.1 Introduction

6.1.1 Variability in executive functions performance

Both Autism Spectrum Disorders (ASD) and Specific Learning Disorders (SLD) are associated with cognitive challenges, particularly in Executive Functions (EFs) (Booth et al., 2010; Kenworthy et al., 2008; Yerys et al., 2007; Reiter et al., 2005; Valeri et al., 2020; Varvara et al., 2014). Although EFs are observed as a challenge for neurodivergent children, research often lacks clear differentiation between clinical groups. For instance, Dajani et al. (2016) identified three distinct EF performance profiles ("above average," "average," and "impaired") among autistic children and those with Attention-Deficit/Hyperactivity Disorders (ADHD); however, these profiles did not correspond to diagnostic categories. The authors suggested that substantial variability in EF abilities exists within each clinical group, underscoring the heterogeneity of diagnostic classifications, a finding later confirmed by subsequent studies (Demetriou et al., 2019; Sankalaite et al., 2025). However, heterogeneity in EF performance is not limited to neurodivergent populations but is also frequently observed among neurotypical individuals. Indeed, several studies have reported EF weaknesses within neurotypical samples, even in the absence of a specific diagnostic classification (Meltzer & Krishnan, 2007; Wilding, 2003).

6.1.2 Cluster analysis studies in neurodivergent populations

In the literature, cluster analysis is often employed to classify performance patterns and to identify similarities and differences within various neurodivergent populations, particularly concerning core clinical features. For instance, Klopper et al. (2017) identified two distinct subgroups across 61 autistic children without intellectual disabilities, showing dissociated profiles across core autistic trait dimensions. These findings challenge the adequacy of a purely dimensional classification system for ASD. Similarly, a review highlighted that studies examining the heterogeneity of ASD support the existence of distinct subtypes within the spectrum (Syriopoulou-Delli & Papaefstathiou, 2020). However, it remains unclear whether these represent qualitatively different subgroups with characteristic profiles of autistic traits or rather reflect variations along a continuous severity gradient across symptom domains. Also, in children with SLD, distinct profiles of cognitive strengths and weaknesses were identified, revealing four clusters characterized by deficits in broader cognitive

processing, verbal abilities, executive functioning, or isolated difficulties in coding tasks (Poletti et al., 2018). Each cluster was associated with different patterns of academic proficiency, reflecting variations in the subtype and severity of impairment. Another study identified four major subgroups of children with SLD (reading disorder, spelling disorder, disorder of arithmetical skills, and mixed disorder of scholastic skills), showing that all groups exhibited similar weaknesses in working memory and processing speed, yet displayed partially distinct intellectual profiles (Toffalini et al., 2017). For instance, children with mixed learning disorders demonstrated the lowest intellectual levels, whereas those with reading or spelling disorders performed above the average range. Focusing specifically on developmental dyslexia, two distinct clusters emerged: one characterized by a more pronounced deficit in the phonological component, while both clusters showed impairments in visual processing. These findings suggest that dyslexia may encompass multiple profiles rather than a single homogeneous pattern of difficulties (Giofrè et al., 2019).

Moving beyond the traditional focus on identifying differences between neurodivergent and neurotypical groups, and instead emphasizing person-centered characteristics, a growing trend in neurodiversity research and advocacy supports the use of cluster analysis to better characterize cognitive performance beyond conventional diagnostic frameworks (Jaarsma & Welin, 2012). However, only a limited number of studies have applied these approaches to examine cognitive performance, particularly EFs, beyond clinical diagnoses in neurodiverse populations. For example, Vaidya et al. (2020) identified three transdiagnostic EF subtypes characterized by distinct behavioral profiles: one showing weaknesses in flexibility and emotion regulation, another in inhibition, and a third in working memory, organization, and planning. These subtypes were observed not only among children with ASD and ADHD but also within neurotypical groups, highlighting shared patterns of executive functioning across diagnostic boundaries.

6.1.3 Aims and hypotheses

This study aims to examine different profiles of executive functioning, both independently and in combination with broader cognitive abilities, in a neurodiverse sample that includes neurotypical children as well as children with autism spectrum disorders and specific learning disorders, aged 8 to 16. A two-level approach (EF-only versus EF+COGNITIVE) enables the examination of whether EF profiles remain stable or vary according to broader cognitive abilities, beyond the diagnostic labels. It is anticipated that at least three clusters would emerge at each level (Dajani et al., 2016). Moreover, a different distribution of participants across clusters is expected when cognitive abilities are analyzed alongside EF performance. Additionally, overlapping performance patterns across groups are

anticipated, along with pronounced weaknesses among neurodiverse participants, particularly autistic children (Booth et al., 2010; Kenworthy et al., 2008; Yerys et al., 2007; Reiter et al., 2005; Valeri et al., 2020; Varvara et al., 2014). However, it is expected that not all individuals in clinical groups are classified within the lower-performance cluster, reflecting high intraindividual variability in task performance, beyond the diagnostic classification (Demetriou et al., 2019; Vaidya et al., 2020).

6.2 Methods

6.2.1 Participants

The study involved 249 children, aged 8 to 16 years, recruited from schools in Italy and the ODFLab (Laboratory of Observation, Diagnosis, and Education) within the Department of Psychology and Cognitive Science at the University of Trento, Rovereto. School-based participants came from inclusive classrooms, which included both neurotypical children and students with special educational needs or disabilities. Participants were classified into neurotypical (n = 161) and neurodivergent (n = 88) groups, the latter comprising autistic children (n = 55) and those with specific learning disorders (n = 33). A detailed description of the groups was provided in **Chapter 5, Section 5.2.1**; however, in the present study, only children aged 8-16 were included (see **Table 6.1** for children's demographic features).

Table 6.1 *Samples' demographic characteristics*

Variables	**Groups**	***n***	**M**	**SD**	**min**	**max**
Age	All	249	11.67	2.29	8	16
	Autism	55	11.71	2.51	8	16
	SLD	33	12.27	1.79	8	16
	Typical	161	11.53	2.30	8	16
			n	**%**		
Sex	All	Males	165	66.3		
		Females	84	33.7		
	Autism	Males	50	90.9		
		Females	5	9.1		

SLD	Males	23	69.7
	Females	10	30.3
Typical	Males	92	57.1
	Females	69	42.9

***Note. n** = subjects; **M** = mean; **SD** = standard deviation; **min** = minimum score; **max** = maximum score. **SLD** = Specific Learning Disorders.*

6.2.2 Procedure

All assessments were conducted individually in a quiet setting, either at the ODFLab or in the child's school by trained master's students in Clinical Psychology or psychologists. Each participant was assessed using a battery of cognitive assessments, including *Matrix reasoning*, *Comprehension of instructions*, *Verbal fluency*, and *Visuo-motor precision*. Moreover, executive attention tasks administered were *Color naming*, *Graphical fluency*, *Cancellation and visual search*, *Enumeration*, *Categorization*, and *PASOT*. Task administration followed a randomized order to control for order effects. The assessment lasted 1 hour.

6.2.3 Materials

Z-scores ($M = 0$, $SD = 1$) were provided for each parameter, where higher scores indicate greater executive functioning abilities (see **Appendix B** for further details). The EF tasks included Color naming, Graphical fluency, Visual search, Enumeration, Categorization, and PASOT from the Measures of Executive Attention Battery (Benso et al., 2019). While the cognitive measures included Matrix reasoning from the Wechsler Intelligence Scale for Children (Orsini et al., 2015), used as an index of fluid intelligence, and selected tasks from the NEPSY-II battery (Korkman et al., 2007), specifically, Comprehension of instructions to assess receptive language skills, Verbal fluency as a measure of expressive language abilities, and Visuo-motor precision to evaluate fine-motor skills. A summary of the tasks is presented in **Table 6.2**, but for a full description of the tools, see **Chapter 3 (Section 3.2.2)** for executive attention tasks and **Chapter 5 (Section 5.2.2)** for cognitive measures.

Table 6.2 *Brief description of the cognitive and executive attention tasks*

Task	Description
Cognitive measures	
Matrix reasoning	Choose the correct option that completes an incomplete visual pattern from several alternatives
Comprehension of instructions	Select the corresponding image that matches the instructions that vary in syntactic complexity
Verbal fluency	Produce as many words as possible within one minute under two conditions: semantic fluency and phonemic fluency
Visuo-motor precision	Trace a series of paths with a pencil, which increase in complexity as the task progresses
Executive Attention measures	
Color naming	Denominate verbally the name of the colors as quickly as possible. Derived from the studies of Denckla and Rudel (1976), this task represents the final output of a processing stream involving the integration of attentional and mnemonic processes, culminating in a relative automatization of verbal label retrieval.
Graphical fluency	Draw various configurations, using 5 points, in a minute providing different measures (accuracy, errors and perseverations). Adapted and modified from the Five-Point Test by Regard et al. (1982), this task is widely used in clinical settings, particularly in the assessment of frontal lobe syndromes (see also Tucha et al., 2012).
Cancellation and visual search	This task requiring participants to mark only the target items on various sheets (Sheets 7 and 8 assess fine-motor speed; Sheet 10 assess fine-motor speed in combination with visual search speed).
Enumeration forward-backward	Tell the number from 1 to 100 (forward condition) as quickly as possible and then from 100 to 1 (backward condition).
Categorization	Repeat only the words verbally provided by the examiner that belong to a specified category. This task is derived from the studies of Haarmann et al. (2003), who developed a *conceptual span task* in which list recall had to be recognized according to semantic elements. It requires active manipulation within working memory. Conceptual span performance showed higher correlations with reading comprehension and problem-solving abilities.
Paced Auditory Serial Opposites Task (PASOT)	Say the opposite of the word heard just before the last one in two different timing between the stimuli (1200ms and 800ms). This task is adapted and modified from Gow and Deary (2004) and consists of a demanding *n-back-like task*. It assesses working memory updating and manipulation, involving attentional and executive control processes.

6.2.4 Analytic plan

Statistical analyses were performed using RStudio (R Core Team, 2024). The significance threshold is set at $\alpha = .05$.

For participants who did not complete a task due to administration interruption for overwhelming behaviors or distress, an arbitrary value of -2 SD was assigned to indicate lower performance compared to the normative value ($M = 0$, $SD = 1$) within the group ($n = 259$). This approach was adopted to ensure a conservative inclusion strategy and to avoid excluding a substantial number ($n = 25$) of autistic children, as only 212 participants ($n = 151$ neurotypical children, $n = 30$ autistic children, $n = 31$ children with SLD) had complete data across all measures (see **Chapter 5, Section 5.3.4** for a deeper analysis of EF task failures and successes in neurodivergent children). **Table 6.3** reports descriptive analyses.

The contribution of EFs to the clustering groups was first examined. Subsequently, statistical analyses were repeated using EF scores in combination with broader cognitive measures, enabling comparison of cluster structures and group associations between EF-only and combined EF+COGNITIVE (EF+COGN) profiles. The statistical features of the models (Bayesian Information Criterion - BIC and Integrated Completed Likelihood - ICL) will be compared to determine which one provides a better understanding.

Table 6.3 *Sample's descriptive analysis*

Variables	Groups	*n*	M	SD	min	max
Cognitive measures						
Matrix reasoning	All	249	-0.08	1.24	-7.88	2.42
	Autism	55	-0.23	1.55	-7.88	2
	SLD	33	0.06	1.07	-2.07	1.66
	Typical	161	-0.06	1.15	-6.89	2.42
Comprehension of instructions	All	249	-0.42	1.41	-7.22	2.41
	Autism	55	-1.51	1.82	-7.22	1.41
	SLD	33	-0.53	1.35	-5.77	1.95
	Typical	161	-0.02	1.03	-3.52	2.41
Visuo-motor precision	All	249	0	1.05	-6.46	3.75

	Autism	55	-0.32	1.81	-6.46	3.75
	SLD	33	0.01	0.78	-1.56	2.01
	Typical	161	0.11	0.65	-1.7	2.86
Verbal fluency	All	249	0	1.19	-4.43	3.13
	Autism	55	-0.66	1.23	-4.43	1.86
	SLD	33	-0.17	1.06	-2.55	1.66
	Typical	161	0.26	1.11	-2.24	3.13
Executive attention measures						
Color naming	All	249	-0.72	2.46	-28.03	2.15
	Autism	55	-2.18	4.04	-28.03	1.55
	SLD	33	-1.04	1.68	-5.48	1.64
	Typical	161	-0.16	1.48	-11.01	2.15
Graphical fluency (accuracy)	All	249	-0.38	1.2	-4.62	2.49
	Autism	55	-1.31	1.3	-4.62	1.22
	SLD	33	-0.63	1.03	-2.69	1.91
	Typical	161	-0.01	1	-2.2	2.49
Graphical fluency (perseveration)	All	249	-0.45	1.86	-12.89	0.98
	Autism	55	-1.37	2.69	-12.89	0.98
	SLD	33	-0.05	1.29	-5.28	0.98
	Typical	161	-0.22	1.48	-8.51	0.98
Visual search	All	249	-0.36	3.08	-39.86	6.33
	Autism	55	-1.35	5.99	-39.86	3.14
	SLD	33	-0.38	1.36	-3.89	2.02
	Typical	161	-0.02	1.32	-5	6.33
Enumeration forward-backward	All	249	-0.72	2.1	-11.54	1.8
	Autism	55	-2.01	2.85	-9.36	1.5
	SLD	33	-1.47	2.47	-11.54	1.8
	Typical	161	-0.13	1.36	-10.12	1.52
Categorization	All	249	-0.26	1.12	-2	4.76

	Autism	55	-1.06	0.61	-2	1.1
	SLD	33	-0.49	0.83	-1.74	1.34
	Typical	161	0.05	1.16	-2	4.76
PASOT	All	249	-0.79	1.64	-6.93	2.07
	Autism	55	-2.46	1.56	-6.5	0.45
	SLD	33	-1.02	1.8	-6.93	1.75
	Typical	161	-0.17	1.15	-3.8	2.07

***Note. n** = subjects; **M** = mean; **SD** = standard deviation; **min** = minimum score; **max** = maximum score. **SLD** = Specific Learning Disorders.*

Data pre-processing

When cognitive variables were included, to reduce dimensionality in the verbal and performance domains, separate PCAs were performed: a composite score of Verbal fluency was derived by the semantic and phonological domains, and a composite score of Visuo-motor precision was obtained by combining time and error parameters. The final dataset for clustering included Executive Functions variables (Color naming, accuracy and perseveration parameters of Graphical fluency, Enumeration, Categorization and PASOT), broader cognitive variables (fluid intelligence, Comprehension of instructions, Verbal fluency, and Visuo-motor precision), and groups (autism, specific learning disorders, and typical).

Model-based clustering

Model-based clustering was performed using the *Mclust* algorithm (Scrucca et al., 2023) on the standardized dataset. It is an R package for model-based clustering, classification, and density estimation based on finite Gaussian mixture modelling fitted by the EM algorithm. This approach identifies the optimal number of clusters based on the Bayesian Information Criterion (BIC) and assigns each participant to a cluster. Cluster membership was subsequently added as a categorical variable for downstream analyses. Moreover, a PCA was conducted on the standardized dataset to visualize clusters in a reduced two-dimensional space. The first two principal components (PC1 and PC2) were retained for plotting. Loadings were calculated to determine each variable's contribution to PC1 and PC2: PC1 represents the direction of maximum variance, while PC2 captures the second-

most orthogonal direction of variance. Additionally, cluster plots were generated using *ggplot2* (Wickham, 2016), with participants colored by group and shaped by cluster membership.

Cluster characterization and prevalence

Clusters were characterized through heatmaps showing mean profiles across cognitive and/or executive function measures. Additionally, cluster plots were generated using *ggplot2* (Wickham, 2016), with participants colored by group and shaped by cluster membership. This approach allowed the identification of various patterns and profiles distinguishing clusters in EF and cognitive performance. Moreover, to examine the relationship between clusters and groups, contingency tables were computed, with both row and column percentages to assess relative prevalence. Finally, chi-square tests and post-hoc pairwise chi-square comparisons were conducted for each cluster between all pairs of groups, with p-values adjusted using the Bonferroni correction.

6.3 Results

6.3.1 Model 1: EF-only

Cluster analysis

A model-based clustering approach (Mclust, VVI: diagonal, varying volume and shape) identified six clusters in the sample. Cluster sizes were: Cluster 1 = 19 (7.63%), Cluster 2 = 8 (3.21%), Cluster 3 = 36 (14.46%), Cluster 4 = 45 (18.07%), Cluster 5 = 68 (27.31%) and Cluster 6 = 73 (29.32%). The model achieved a log-likelihood of -1706.75 with 89 degrees of freedom, and BIC and ICL values of -3904.55 and -3979.71, respectively, indicating a good balance between model fit and complexity.

Principal component loadings

Variable contributions to the first two principal components were as follows:

- PC1 was most strongly influenced by the accuracy parameter of Graphical fluency (0.43), Color naming (0.42), PASOT (0.40), Visual search (0.37), Enumeration (0.35), Categorization (0.35), and perseveration errors of Graphical fluency (0.29).
- PC2 was primarily associated with Visual search (-0.61), Categorization (0.42), Color naming (-0.38), PASOT (0.34), Enumeration (0.34), perseveration errors of Graphical fluency (-0.25), and the accuracy parameter of Graphical fluency (0.12).

Cluster composition by group

The distribution of groups across clusters and the proportion of participants represented within each cluster is reported in **Table 6.4**. *Cluster 2* appeared to include children showing the greatest weaknesses across various EF and broader cognitive tasks, with particularly weaknesses in visual discrimination (Visual search task), perseverative errors of Graphical fluency, and in Color naming. *Cluster 3* also reflected a group with marked challenges, particularly in working memory tasks such as Enumeration and PASOT, and with some additional challenges in Color naming related to inhibitory control. While *Cluster 1* showed weaknesses mainly in perseverative errors of Graphical fluency and in PASOT. In contrast, *Cluster 6* represented children with generally higher overall performance, where clinical groups are less represented, followed by *Cluster 4,* where specific fragility in the perseverative parameter of Graphical fluency emerged, and *Cluster 5,* with weaknesses in working memory tasks (Enumeration and PASOT). Overall, autistic children were more highly represented in *Cluster 3*, whereas children with specific learning disorders were primarily found in *Cluster 5*, like neurotypical children. Moreover, a high distribution of neurotypical children was also presented in *Cluster 6*, followed by *Cluster 4*. The distribution of clusters is illustrated in the heatmap in **Figure 6.1**.

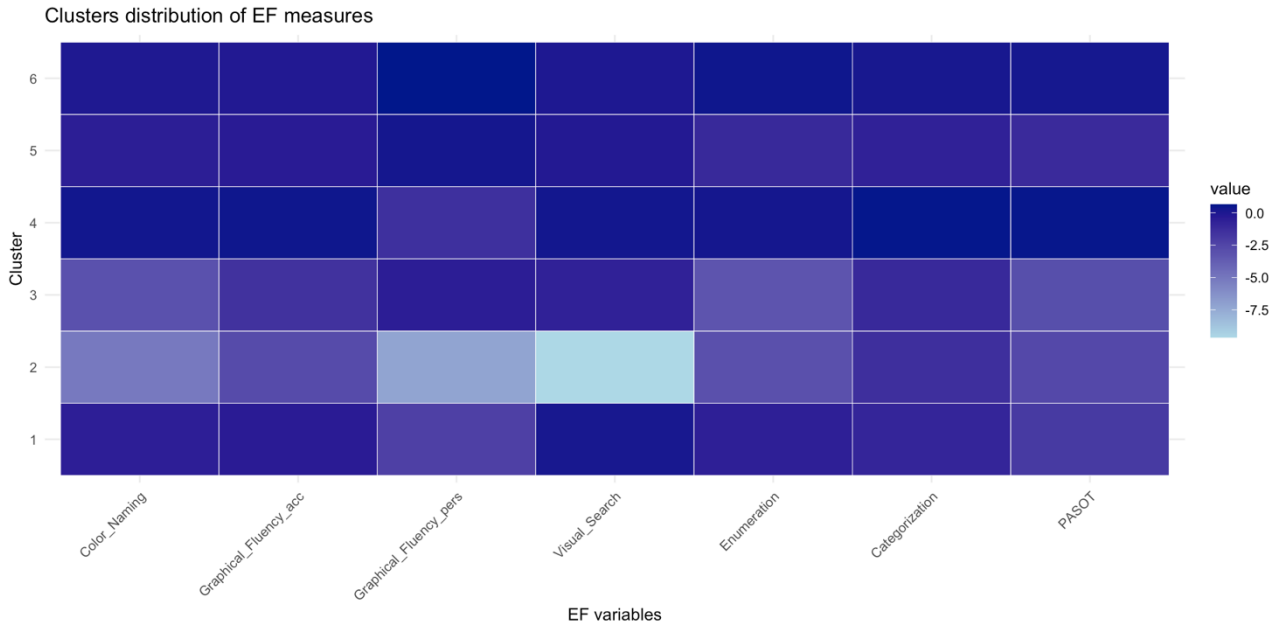
Table 6.4 *Table of contingency and proportion of participants in each cluster*

Cluster	**Autism**		**SLD**		**Typical**	
	n	***%***	***n***	***%***	***n***	***%***
1	11	20.0%	2	6.1%	6	3.7%
2	6	10.9%	1	3.0%	1	0.6%
3	23	41.8%	6	18.2%	7	4.3%
4	2	3.6%	1	3.0%	42	26.1%
5	11	20.0%	16	48.5%	41	25.5%

Cluster	Autism		SLD		Typical	
6	2	3.6%	7	21.2%	64	39.8%

Note. ***n*** *= subjects.* ***SLD*** *= Specific Learning Disorders.*

Figure 6.1 *The heatmap of cluster distribution for executive attention measures*



Note. ***EF*** *= executive functions;* ***Graphical_Fluency_acc*** *= accuracy parameter of Graphical fluency task;* ***Graphical_Fluency_pers*** *= perseveration parameter of Graphical fluency task.*

Post-hoc pairwise comparisons

Post-hoc chi-square tests with Bonferroni correction revealed significant differences between clusters and groups (see **Table 6.5**).

Table 6.5 *Clusters comparison across groups*

Cluster	Comparison	χ^2	p^a	Post-hoc[a]
1	autism vs typical	12.81	**<.001*** **	**.006** **
1	autism vs SLD	2.17	.14	1.00
1	typical vs SLD	.02	.89	1.00

2	autism vs typical	10.75	**.001****	**.02***
2	autism vs SLD	.84	.36	1.00
2	typical vs SLD	.09	.76	1.00
3	autism vs typical	45.04	**<.001*****	**<.001*****
3	autism vs SLD	4.20	**.04***	.73
3	typical vs SLD	6.32	**.01***	.21
4	autism vs typical	11.39	**.001****	**.01***
4	autism vs SLD	.00	1.00	1.00
4	typical vs SLD	7.15	**.007****	.13
5	autism vs typical	.40	.52	1.00
5	autism vs SLD	6.59	**.01***	.18
5	typical vs SLD	5.93	**.01***	.27
6	autism vs typical	23.53	**<.001*****	**<.001*****
6	autism vs SLD	5.16	**.02***	.42
6	typical vs SLD	3.30	.07	1.00

*Note. **SLD** = Specific Learning Disorders. [a] Test significance * p < .05, ** p < .01, *** p < .001.*

6.3.2 Model 2: EF+COGNITIVE

Cluster analysis

Using a model-based clustering approach (Mclust, VVI: diagonal, varying volume and shape), six clusters in the sample. Cluster sizes were: Cluster 1 = 43 (17.27%), Cluster 2 = 8 (3.21%), Cluster 3 = 47 (18.88%), Cluster 4 = 74 (29.72%), Cluster 5 = 43 (17.27%), and Cluster 6 = 34 (13.65%). The model showed a log-likelihood of -2874.76, with 137 degrees of freedom, and BIC and ICL values of -6505.42 and -6558.48, respectively, indicating a good balance between model fit and parsimony.

Principal component loadings

Analysis of variable contributions to the first two principal components revealed the following:

- PC1 was most strongly influenced by Comprehension of instructions (0.37), Verbal fluency (0.35), Colour naming (0.35), accuracy parameter of Graphical fluency (0.34), PASOT (0.33),

Visual search (0.30), Matrix reasoning (0.29), Categorization (0.27), Enumeration (0.27), perseveration errors of Graphical fluency (0.22), and Visuo-motor precision (0.16).

- PC2 was primarily associated with Visuo-motor precision (-0.55), Visual search (-0.46), perseveration errors of Graphical fluency (-0.35), PASOT (0.28), Enumeration (0.26), Categorization (0.25), Verbal fluency (0.24), Colour naming (-0.22), accuracy parameter of Graphical fluency (0.18), Matrix reasoning (-0.06), and Comprehension of instructions (0.06).

Cluster composition by group

A contingency analysis showed the distribution of groups across clusters and the proportion of participants represented within each cluster is reported in **Table 6.6**. *Cluster 2* appeared to include children showing the greatest weaknesses across various EF and broader cognitive tasks, with particularly weaknesses in visual discrimination (Visual search task), perseverative errors of Graphical fluency and in Color naming. Notably, no SLD children are present in this cluster. *Cluster 3* also represented a group with notable challenges, particularly in working memory tasks (Enumeration and PASOT), with some additional challenges in Color naming related to inhibitory control, while showing relatively fewer difficulties in broader cognitive tests. Moreover, *Cluster 4* showed few difficulties in working memory tasks. In contrast, *Cluster 6* represented children with generally higher overall performance, where clinical groups were less represented, followed by *Cluster 1* and *Cluster 5* (specific fragility in perseveration parameter of Graphical fluency). Overall, autistic children were more highly represented in *Cluster 3*, whereas children with SLD were primarily found in *Cluster 4*, together with most neurotypical children. Additionally, in *Cluster 5*, a high distribution of neurotypical children was also presented. See **Figure 6.2** for the heatmap showing the distribution of clusters.

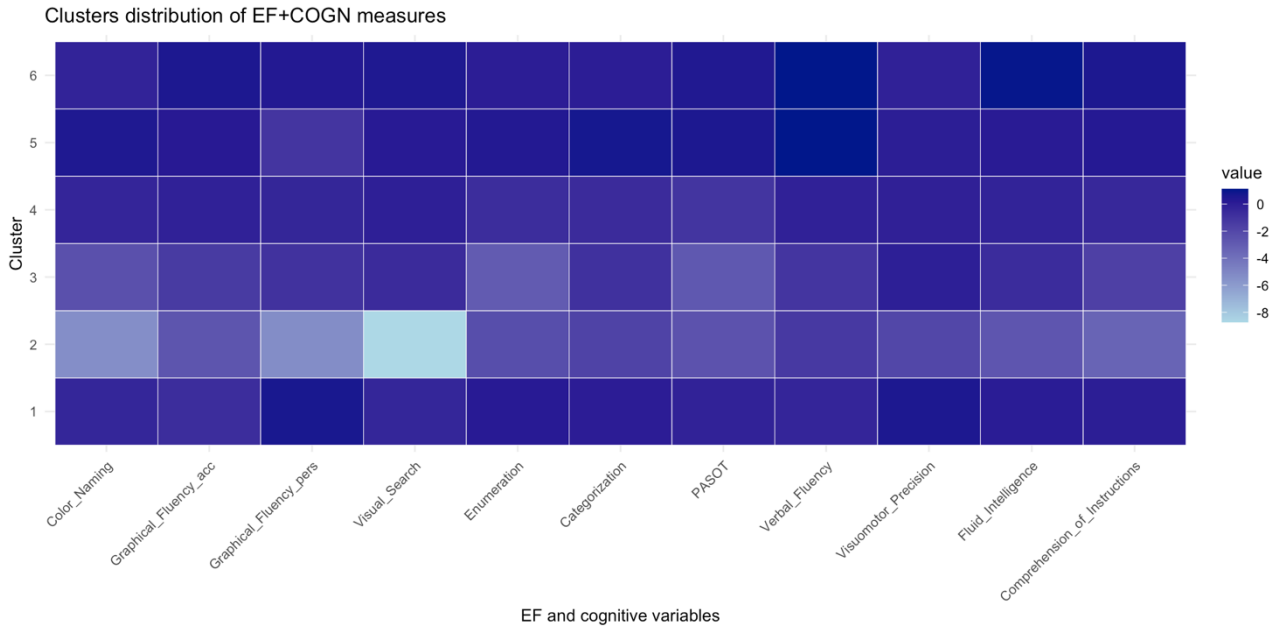
Table 6.6 *Table of contingency and proportion of participants in each cluster*

Cluster	**Autism**		**SLD**		**Typical**	
	n	**%**	***n***	**%**	***n***	**%**
1	6	10.9%	7	21.2%	30	18.6%
2	7	12.7%	0	0.0%	1	0.6%
3	25	45.5%	9	27.3	13	8.1%
4	15	27.3%	12	36.4%	47	29.2%

Cluster	Autism		SLD		Typical	
5	1	1.8%	1	3.0%	41	25.5%
6	1	1.8%	4	12.1%	29	18.0%

Note. n *= subjects.* ***SLD*** *= Specific Learning Disorders.*

Figure 6.2 *The heatmap of cluster distribution for executive attention and cognitive measures*



Note. EF *= executive functions;* ***Graphical_Fluency_acc*** *= accuracy parameter of Graphical fluency task;* ***Graphical_Fluency_pers*** *= perseveration parameter of Graphical fluency task.*

Post-hoc pairwise comparisons

Post-hoc chi-square tests with Bonferroni correction revealed significant differences between clusters and groups (see **Table 6.7**).

Table 6.7 *Clusters comparison across groups*

Cluster	Comparison	χ^2	p^a	Post-hoc[a]
1	autism vs typical	1.25	.26	1.00
1	autism vs SLD	1.02	.31	1.00
1	typical vs SLD	.01	.92	1.00

2	autism vs typical	13.62	**<.001*** **	**.004** **
2	autism vs SLD	2.99	.08	1.00
2	typical vs SLD	.00	1.00	1.00
3	autism vs typical	36.97	**<.001*** **	**<.001*** **
3	autism vs SLD	2.16	.14	1.00
3	typical vs SLD	8.22	**.004** **	.07
4	autism vs typical	.10	.92	1.00
4	autism vs SLD	.43	.51	1.00
4	typical vs SLD	.37	.54	1.00
5	autism vs typical	13.16	**<.001*** **	**.005** **
5	autism vs SLD	.00	1.00	1.00
5	typical vs SLD	6.86	**.009** **	.16
6	autism vs typical	7.69	**.006** **	.10
6	autism vs SLD	2.39	.12	1.00
6	typical vs SLD	.32	.57	1.00

***Note. SLD** = Specific Learning Disorders. [a] Test significance * p < .05, ** p < .01, *** p < .001.*

6.4 Discussion

These results indicate that, although participants from all groups are distributed across clusters, certain clusters are enriched for specific groups, reflecting heterogeneity in EF and cognitive profiles that extends beyond diagnostic categories (Jaarsma & Welin, 2012). The core EF structure is relatively stable across models, with consistent identification of key tasks driving group separation.

6.4.1 Clusters classification

The cluster analysis reveals distinct profiles of executive functioning, primarily differing in the efficiency of control processes, cognitive flexibility, visual discrimination and working memory.
Cluster 2 exhibited the most challenges in executive profile: children in this group show marked difficulties across multiple EF domains, especially in visual discrimination, inhibitory control and cognitive flexibility, as indicated by score in Visual search, perseverative errors in Graphical fluency

and Color naming tasks. These results suggest that higher difficulty levels are spared across both basic cognitive components and higher-order abilities, such as regulatory and cognitive control processes. Similar patterns emerge across both analytic levels (EF-only and EF+COGN). However, when cognitive variables are included, additional weaknesses emerge, particularly in receptive language (Comprehension of instructions task), followed by fine-motor skills (Visuo-motor precision test) and fluid intelligence (Matrix reasoning). Overall, these distributions highlight a close relationship between EFs and cognitive abilities, with lower EF associated with poorer general cognitive performance (Cochrane et al., 2019; Itskovich et al., 2021; Joseph et al., 2002; Syriopoulou-Delli et al., 2018).

Cluster 3 (both in EF-only and EF+COGN) also displayed executive vulnerabilities, but with a different profile. Their primary weaknesses involve working memory tasks (Enumeration and PASOT) and relative challenges in inhibitory control (Color naming task). When cognitive abilities are included, these difficulties appear more circumscribed and less pervasive than those observed in *Cluster 2*, reflecting specific challenges in managing and manipulating information rather than deficits in overall cognitive control as well as in receptive language skills. It seems that linguistic abilities tend to exert a strong influence on EF performance, as evidenced by persistent weaknesses in verbal EF tasks (e.g., Enumeration, PASOT and Color naming), with some additional challenges in inhibitory control. These measures are closely tied to receptive language and contribute to children's overall cognitive functioning (Benso et al., 2025; Ellis Weismer et al., 2018; Friedman & Miyake, 2017; Yeung & Chan, 2020). In these clusters, autistic children are more prominently represented across both levels of analysis, suggesting the higher level of challenges in cognitive processes, particularly in EFs, compared to neurotypicals as reported in literature (Kenworthy et al., 2008; Yerys et al., 2007; Valeri et al., 2020).

Cluster 4 (EF-only) and *Cluster 5 (EF+COGN)* presented a more balanced pattern, with generally normative performance and mild vulnerabilities in perseveration, suggesting reduced cognitive flexibility resources. Similar profiles, but with preserved abilities, were shown in *Cluster 5 (EF-only)* and *Cluster 4 (EF+COGN)*. Participants in these groups display efficient and stable functioning across working memory domains and higher levels of executive control, indicating a broadly homogeneous and well-integrated EF profile. Overall, these clusters reflect strong executive and regulatory abilities, though not entirely devoid of specific vulnerabilities. Indeed, weak fragilities in Enumeration and PASOT are reported. Notably, children with SLD were predominantly represented in these clusters, alongside most neurotypical participants. However, both neurotypical and SLD children were represented across the other clusters, including those with greater challenges, while some autistic children also appeared in clusters characterized by average functioning. These results

suggest that EF weaknesses may arise even in the absence of a specific diagnostic classification (Meltzer & Krishnan, 2007; Wilding, 2003). Finally, *Cluster 6 (both EF-only and EF+COGN)* exhibited the strongest overall executive and cognitive tasks, suggesting a more balanced distribution of cognitive functioning. This is followed by *Cluster 1*, in which the EF-only model shows a few weaknesses in flexibility and PASOT, whereas in the EF+COGN model, the pattern is similar to that of *Cluster 6*.

6.4.2 Stability and changes between EF-only and EF+COGN models

Across all models, a high degree of stability was observed between the EF-only and EF+COGN solutions. The PASOT, accuracy parameter of Graphical fluency, Color naming, and Visual search tasks consistently emerged as the main contributors to the first principal component (PC1), indicating that these measures capture the core dimensions of executive functioning common to both neurotypical and neurodivergent groups. The clustering solutions also demonstrated structural robustness, as the same model type and comparable cluster features were repeatedly obtained. This consistency supports the reliability of the underlying data structure. While the distribution of participants across clusters varied slightly, the overall prevalence patterns for each group remained stable, confirming that the EF-only and EF+COGN models capture a similar organizational framework of EF, reflecting consistently strong EF and cognitive performance profiles. However, the EF-only model appears to be preferable compared to the alternative models in term of complexity and parsimony, although from a statistical point of view the EF+COGN model was better (BIC and ICL values were lower compared to EF-only model). However, the inclusion of additional cognitive variables seems to increase model complexity without yielding meaningful improvements in classification performance. Despite a few comparable features between models, differences among them primarily involved cluster composition, for instance, which participants are grouped and the distribution of diagnostic categories, and interpretability, rather than fundamental changes in EF structure. The inclusion of cognitive indices (receptive and expressive linguistic skills, fine motor abilities and fluid intelligence measures) allowed the models to represent broader cognitive ability profiles, underscoring the influence of general intellectual functioning on the organization of EF profiles (Cochrane et al., 2019; Itskovich et al., 2021; Joseph et al., 2002; Syriopoulou-Delli et al., 2018).

6.4.3 Differentiation between groups

Including a broader range of abilities, most participants remained in the same clusters, although their relative proportions shifted. Most autistic children were concentrated in a cluster characterized by greater EF challenges with weaknesses in inhibitory control and working memory, reflecting higher difficulties in EF and cognitive tasks compared to neurotypical children and those with SLD (Booth et al., 2010; Kenworthy et al., 2008; Yerys et al., 2007; Valeri et al., 2020). However, this cluster also included some neurotypical children and children with SLD, indicating overlapping profiles across diagnostic groups (Vaidya et al., 2020). Conversely, several neurodivergent children, including both autistic and SLD participants, were assigned to clusters with fewer EF difficulties, similar to their neurotypical peers (Demetriou et al., 2019; Vaidya et al., 2020). Children with SLD were predominantly represented in clusters with relatively mild challenges, performing better than autistic children but below the level of neurotypical peers, although a notable subset appeared in clusters showing slight difficulties resembling profiles of some autistic children (Aita et al., 2022; Lievore et al., 2025; Varvara et al., 2014). Overall, these distributions highlight substantial heterogeneity in EF performance, both independently and alongside broader cognitive measures, with some neurotypical children appearing in clusters with greater difficulties and some neurodivergent children in clusters with fewer challenges (Meltzer & Krishnan, 2007; Wilding, 2003). These findings underscore that each child exhibits a unique cognitive profile of strengths and weaknesses, emphasizing that categorizing individuals solely by diagnostic label is overly reductionistic and suggesting that inconsistencies in EF research may arise from focusing on neurodivergent group averages rather than individual variability (Dajani et al., 2016; Vaidya et al., 2020).

6.4.4 Limitations and future directions

Several limitations should be acknowledged when interpreting these findings. First, the sample was not fully balanced across groups, which may have affected the stability and generalizability of the cluster solutions. Increasing the sample size, particularly for children with neurodevelopmental disorders such as SLD, allows for more reliable subgroup comparisons. Moreover, applying bootstrapped validation models to test result stability would enhance statistical power. Additionally, the limited distinctions observed between children with SLD and neurotypical peers in executive attention profiles may reflect the specific tasks included in this study. Future research could extend these findings by incorporating additional measures of executive functioning, such as parent or teacher reports, which provide a more sensitive assessment of EF challenges in neurodivergent

children within ecologically valid contexts. Second, age-related variations in EF profiles and the developmental trajectories of cognitive control were not considered. Future studies should account for developmental differences by conducting separate cluster analyses for distinct age groups (e.g., children versus adolescents). Third, clearer and more specific criteria should be established for handling participants who fail to complete task administrations, as such cases may affect the representativeness and accuracy of the results. Implementing these methodological improvements in future research will strengthen the robustness, interpretability, and clinical relevance of findings on executive functioning in neurodiverse populations.

6.5 Conclusion

The cluster analysis identifies six distinct performance profiles. One group exhibit pronounced weaknesses in executive attention abilities, particularly in Visual search, Color naming, and perseverative parameter of Graphical fluency tasks, alongside broader cognitive difficulties, most notably in language comprehension. A second group shows specific challenges in tasks requiring the management and manipulation of information, especially in the Enumeration and PASOT tasks, with additional weaknesses in Color naming related to inhibitory control. A third group demonstrates generally average performance across both executive and cognitive measures. Two groups of high-performing children are also identified: one showing strong overall abilities with mild difficulties in perseveration and visuomotor coordination, and another displaying subtle weaknesses in working memory, particularly in Enumeration and PASOT. Finally, a sixth group presents selective weaknesses in flexibility and PASOT. Although the distribution of participants across clusters varies slightly, the overall prevalence patterns for each group remains stable, indicating that the EF-only and EF+COGN models capture a comparable organizational framework of executive functioning. However, the EF-only model appears preferable in terms of both complexity and interpretability. While participants from all groups are represented in each cluster, certain clusters are enriched for specific groups, reflecting heterogeneity in executive attention and cognitive profiles that transcends traditional diagnostic boundaries. Specifically, autistic children are predominantly represented in clusters marked by broader executive and cognitive challenges, whereas children with SLD and neurotypical peers are more often found in clusters with average or balanced performance profiles. A notable proportion of children with SLD appears in clusters with mild challenges, reflecting greater difficulties compared to neurotypical peers, who are also highly represented in the highest-performing cluster. Overall, the findings indicate that executive challenges do not follow a uniform pattern but

instead emerge as distinct functional profiles, where specific weaknesses coexist with relative strengths beyond diagnostic categories. This variability highlights the unique cognitive profiles of each individual and underscores that defining a person solely by their diagnostic label is overly reductive.

Chapter 7

General discussion

Lower performance in executive functions (EFs) is reported for neurodivergent children; however, existing research on EFs yields mixed and often contradictory findings (Leung et al., 2016; Jones et al., 2018). These inconsistencies stem not only from variations in how participant groups are characterized but also from the predominant use of reductionist approaches to EF assessment (Christoforou et al., 2023; Craig et al., 2016; Friedman & Sterling, 2019; Karr et al., 2018; Van Eylen et al., 2015). Since broader cognitive and various executive processes are inherently interconnected, traditional single-task paradigms that attempt to discrete EF components fail to capture the full complexity of executive functioning (Benso et al., 2019; Enkavi et al., 2019; Miyake & Friedman, 2012; Snyder et al., 2015; Tiego et al., 2020; Yangüez et al., 2024). The present thesis aims to identify more context-sensitive tools for assessing EFs in neurodivergent children aged 5 to 16, with a particular focus on those with autism. The *first part* of the dissertation explores the relationship between autistic traits and EFs performance, while considering intelligence and demographic variables. As EF task performance typically engages multiple overlapping domains, such as linguistic and fine-motor abilities, the study also considers how these factors may influence EF tasks outcomes. The *second part* of the thesis introduces a more comprehensive and contextually grounded framework for understanding executive functioning, namely the Executive Attention, employing novel neuropsychological tools. The underlying constructs of executive attention tasks are analyzed, and the ecological validity of these measures are examined in neurodiverse children. Overall, this research advances understanding of executive functioning in neurodiverse populations, including autistic children, those with specific learning disorders and neurotypicals, by investigating developmental

trajectories, group differences and similarities, task successes and failures, and the interrelations between executive attention and broader cognitive skills such as intelligence, language, and fine-motor coordination. The findings underscore the uniqueness of individual cognitive profiles and highlight the importance of employing assessment tools capable of capturing executive attention abilities consistently across both structured clinical settings and dynamic real-world contexts. Applying these multidimensional tasks may advance the implementation of more tailored and personalized intervention strategies in clinical and educational contexts.

7.1 Advancing neuropsychological tools for assessing executive attention in neurodivergent children

The relation between traditional EF performance-based assessments and autistic traits showed distinct patterns depending on who provided the information (clinician or parent), the context of measurement (structured testing or everyday settings), and the child's cognitive level. Increased repetitive and restricted behaviors (RRBs) as reported by clinicians are linked to inhibition and cognitive flexibility deficits (Augé et al., 2024; Bednarz et al., 2020; Faja & Nelson Darling, 2019; Lopez et al., 2005). In contrast, better planning and problem-solving performance are aligned with higher autistic traits as reported by parents, suggesting no correspondence between lab-based EF tasks and informant-based reports (Jones et al., 2018; Leung et al., 2016). Considering intelligence levels, relations between cognitive flexibility and autistic traits were observed for the higher IQ group, while only social communication influences cognitive flexibility for the lower IQ group. However, when analyzed within these subgroups, associations were confined to variables assessed within the same context, specifically laboratory-based EF tasks and clinician observations, while links with parent-report measures disappeared. These findings highlight the contextual nature of EF-autistic traits associations. Additionally, intelligence resources more strongly influence performance-based and clinician-rated social communication but have a limited role in RRBs and parent-reported traits observed in everyday settings (Olde Dubbelink & Geurts, 2017). This underscores the necessity for more sensitive and ecologically valid assessment tools that consider individual cognitive profiles to more accurately reflect children's strengths and challenges.

In light of these results, the *Measures of Executive Attention* (Benso et al., 2019), a comprehensive, multidimensional battery specifically designed to address task impurity, was utilized to assess executive attention in autistic children. Initially, three latent factors emerged from the analysis of the structure of executive attention tasks in neurodiverse children (8-16 years) with shared and distinct

aspects of EFs (Friedman & Miyake, 2017; Miyake et al., 2000). Although it is difficult to isolate unique and clearly separable dimensions of EFs, because any given task simultaneously engages multiple executive and non-executive processes, the involvement of these abilities may be more pronounced in certain tasks than in others (Benso, 2018; Enkavi et al., 2019; Rabbitt, 1997; Snyder et al., 2015; Tiego et al., 2020). Therefore, the first factor primarily reflects working memory and cognitive flexibility, with additional involvement of linguistic or fine-motor processes; the second is associated with Visual search and inhibitory control, with a stronger contribution from fine-motor skills; and the third represents primarily working memory in combination with linguistic abilities. However, results are often highly sensitive to the arbitrary selection of tasks and the methodologies implied, which vary widely across studies (Draheim et al., 2021; Karr et al., 2018; Messer et al., 2018; Poldrack, 2006). From this perspective, the latent factorial structures observed across tests may depend more on the type of index used than on a shared underlying cognitive construct, which could be a reductive interpretation (Messer et al., 2018; Yangüez et al., 2024). This highlights the importance of carefully considering the specific index each task provides. Accordingly, it may be proposed that a reformulation of the factors based on task-specific indexes and the non-executive abilities involved in the execution: the first factor is defined by accuracy and incorporates linguistic or fine-motor demands; the second factor is characterized by inverse efficiency indices, reflecting contributions from fine-motor abilities; and the third factor is also defined by inverse efficiency indices, but with greater involvement of verbal components. Interestingly, the use of composite measures, such as the inverse efficiency score, yielded a clearer distinction among executive attention tasks, particularly in differentiating those dependent on verbal abilities from those requiring visuospatial processing. This underscores the methodological value of composite indices in delineating broader cognitive domains within EF assessments.

Additionally, these tasks showed good ecological validity in assessing executive functioning in the neurodiverse population, as given by their associations with a parent report measure, typically considered more ecologically valid compared to performance-based tools (Berenguer et al., 2018; Demetriou et al., 2018; Townes et al., 2023). This underscores the importance of using a comprehensive battery of tasks rather than single measures, as frequently done in previous research, to capture the multifaceted nature of EF in neurodiverse children. However, once group membership was incorporated into the model, this convergence disappeared, suggesting that the association between parent-reported and performance-based executive functions may not be stable within each group. Taken together, these findings indicate that the convergence observed in the full sample is likely driven primarily by between-group differences in executive functioning, rather than by robust within-group alignment between parent reports and task-based measures. Thus, incorporating

multiple contextual measures may be necessary to obtain a more comprehensive picture of the child's functioning. Additionally, although these performance-based tasks are designed to assess executive attention abilities beyond general intelligence, few associations with broader cognitive abilities emerged, particularly with linguistic skills, both receptive and expressive (Campbell et al., 2017; Ellis Weismer et al., 2018; Yeung & Chan, 2020). These results suggest that avoiding the influence of cognitive dimensions during the execution of neuropsychological tasks in neurodiverse populations is still difficult, underscoring the importance of taking these factors into account when assessing EFs.

7.2 Weaknesses, strengths and individual variability in executive attention profiles of neurodivergent children

Developmental differences between neurotypical and neurodivergent children in EF and broader cognitive abilities, such as fine-motor and linguistic skills, emerged early, around preschool age (All et al., 2024; Aita et al., 2022; Hughes, 2011; Lievore et al., 2025; Wan et al., 2025). However, stable intelligence abilities in children with average IQ were observed, although visual-spatial skills were higher among early adolescents (Magiati et al., 2014). Additionally, receptive language and fine-motor skills showed age-related improvements in neurodivergent children. Regarding executive functioning, cognitive flexibility and executive control remained stable across development (Granader et al., 2014; Kenworthy et al., 2022; Van Eylen et al., 2015). Working-memory-related tasks and planning abilities improved gradually through adolescence (Albert & Steinberg, 2011; Korkman et al., 2001; Kouklari et al., 2018), although younger children completed planning tasks faster, likely reflecting impulsivity that decreases with age as self-regulation strengthens (Raffaelli et al., 2005). Cognitive progression was also accompanied by a decline in clinician-reported restricted and repetitive behaviors during late adolescence (Berry et al., 2018; Esbensen et al., 2009), though parents reported increased socio-communication difficulties in early adolescence, possibly due to rising social and academic demands.

Although significant differences in EF performances emerged between neurodivergent and neurotypical children, results suggest that the ability to discriminate visual stimuli remains largely intact, consistent with evidence highlighting visual processing as a relative strength within the neurodivergent profile (Brunsdon et al., 2015; Cardillo et al., 2020), although this is not true for all the sample involved in the study. Additionally, autistic children and those with SLD produced a similar number of words in semantic Verbal fluency tests, but autistic children performed worse in phonological condition of Verbal fluency and in Graphical fluency tasks, suggesting broader

weaknesses in generative thinking across both verbal and visual domains (Karalunas et al., 2018). Moreover, autistic children showed more challenges in EF tasks involving verbal processing, highlighting weaknesses in working memory and processing speed when verbal demands are high. Conversely, those clinical groups showed similar performances in working memory measures requiring numerical operations (Hume et al., 2014; Morsanyi et al., 2018; Pastor-Cerezuela et al., 2020). Regarding fine-motor skills, autistic children exhibited reduced proficiency on low structured tests that demanded quick fine-motor execution and sequential attentional control (Lievore et al., 2025). Overall, neurodivergent children failed from EF tasks more frequently than their neurotypical peers, particularly on measures of working memory. Specifically, it was found that while neurodivergent children generally showed a lower performance, specific patterns emerged across tasks. Particularly, a n-back task (PASOT) posed the greatest difficulty, with 63% of neurodivergent children underperforming. This task imposes high cognitive demands and time pressure that may trigger emotion regulation systems, thereby influencing the occurrence of failures, consistent with prior research linking autism to increased anxiety and arousal under stressful conditions (Conner et al., 2021; Bellato et al., 2021; Lory et al., 2020; Samson et al., 2015).

Although analyzing cognitive profiles within groups yields valuable insights, considerable heterogeneity in performance remains that is not fully captured by such traditional analyses (Demetriou et al., 2017; Vaidya et al., 2020). Advanced models, such as cluster analysis, allowed to reveal six groups of performance, with overlap across clusters suggesting that EF strengths and weaknesses can arise independently of the diagnostic category (Meltzer & Krishnan, 2007; Jaarsma & Welin, 2012; Wilding, 2003). Specifically, autistic children were primarily represented in clusters characterized by broader executive attention weaknesses, particularly in regulatory and cognitive control processes, and cognitive challenges, mostly in verbal comprehension. In contrast, children with SLD and neurotypical peers were more frequently grouped in clusters showing balanced or high performance, marked by generally strong executive attention and broader cognitive abilities, but mild weaknesses in working memory tasks. Some children with SLD, however, also appeared in clusters with moderate difficulties in information management, manipulation, and inhibitory control, performing below neurotypical peers, who were largely represented in the highest-performing cluster with an overlap with several neurodivergent children (Aita et al., 2022; Lievore et al., 2025; Varvara et al., 2014).

7.3 Clinical implications

The multidimensional battery of tasks employed demonstrates good usability with autistic and neurodivergent children more broadly, offering a comprehensive picture of each child's executive profile, enabling the identification of individual strengths and vulnerabilities independent of the diagnostic status. These tasks may be particularly useful for assessing EFs in neurodivergent children due to their design. Primarily, the presence of visually supported tasks helped neurodivergent children in the comprehension of instructions. Thus, the use of these visual aids should be prioritized in task design to enable their potential to emerge. Conversely, reliance solely on verbal tasks, where most of these children tend to underperform in both EFs and broader cognitive domains, should be minimized. Incorporating visual supports within can better reveal children's true abilities, optimize engagement and performance (García-Molina & Clemente-Estevan, 2019). These strategies may also boost social motivation, which is crucial for developing social skills (Neuhaus et al., 2021), thereby promoting better inclusion, cooperative learning, and meaningful peer interactions. Moreover, these tasks allowed the child to become more familiar with the procedure and provided a demonstration of the test execution. Providing opportunities for familiarization through practice sessions can further facilitate understanding of demands, allowing children's true potential to emerge. Additionally, the structured nature of the EF tasks used, combined with clear administration procedures and opportunities for repetition, likely contributed to improved performance among neurodivergent children by enabling their abilities to manifest under optimal conditions (Hendry & Scerif, 2023).

Additionally, high heterogeneity in executive attention and broader cognitive abilities underscores the individuality of cognitive profiles and illustrates that defining a person solely by their diagnostic label is overly reductive. While diagnostic classifications remain essential for understanding individual characteristics, explaining behaviors themselves (particularly in cases of late diagnosis), and guiding early educational and therapeutic interventions, they should not be viewed as deterministic, but they may be considered in a more person-centered approach (Jaarsma & Welin, 2012). Early identification of executive functioning challenges is particularly crucial to allow early targeted intervention implementation and the adoption of effective educational strategies due to their strong associations with learning and academic achievement (Kheirollahzadeh et al., 2021; Spiegel et al., 2021; Zelazo & Carlson, 2020) and socio-emotional competencies (Fong & Iarocci, 2020; Razza & Blair, 2009; Torske et al., 2018). In this battery, Enumeration and PASOT, as measures of working memory, highlight the capacity of these measures in detecting executive attention difficulties in neurodivergent children, suggesting that, in educational settings, their combined use may serve as a rapid yet effective tool for identifying executive weaknesses sooner. Additionally, particular

attention in EF assessments may be taken during the crucial transition from childhood to adolescence, where an increase in social and contextual demands arises and may impact the performance in cognitive tasks. For example, planning abilities show significant improvement during adolescence, indicating that introducing preparatory activities earlier in development could lead to better outcomes later. In contrast, cognitive flexibility remains a challenging area across the lifespan. Therefore, incorporating specific activities in rehabilitation and educational settings, such as card sorting or rule-based object to categorize, may be both engaging and beneficial, particularly for students struggling with this skill. These types of activities can, in turn, promote peer collaboration in school settings and help address social-communication difficulties.

Nevertheless, cognitive tests alone cannot fully capture an individual's profile. Integrating additional tools that capture executive functioning across multiple life domains, such as parent and teacher questionnaires, remains essential, where subtle nuances are crucial to fully understanding the individual. This is especially relevant given that autistic children frequently find it difficult to generalize their abilities across settings, underscoring the need for precise assessments in each context, as these offer complementary perspectives on real-world cognitive functioning (Bitsika & Sharpley, 2019). Performance-based measures primarily assess cognitive regulation, whereas parent-report tools more effectively capture behavioral and emotional regulation. Since emotional and behavioral control are often shaped by contextual and relational factors not directly assessed through laboratory tasks (Balart et al., 2021; Chen & Liao, 2021), incorporating multiple contextual measures may be necessary to achieve a more holistic understanding of the child's functioning. Additionally, observational data, particularly concerning task failures or disengagement, provided crucial insights through the clinician's perspective, highlighting that each child experiences and responds to cognitive demands in unique ways. Combining standardized cognitive measures with structured observational rating scales (see **Table 7.1** as an example), completed after each task, would provide a more nuanced understanding of the child's regulatory abilities (cognitive, behavioral, and emotional). Such tools would complement performance scores, which can be overly reductive, and could serve as valuable supports in clinical data collection. Considering both cognitive and emotional regulation in EF assessment may support the use of flexible and individualized approaches that accurately reflect children's abilities, taken in account the influence of emotional challenges.

Table 7.1 *Example of the novel observational rating scale for regulation assessment*

Domain	Administered	Yes	Intermediate	No
General information	**Completed**	yes	-	no
	Withdrawals	administer decision	child request	no
	Breaks	administer decision	child request	no
Emotional regulation	**Frustration/distress**	yes	not influence the task's execution	no
	Positive emotions during the task	yes	neutral	no
	Positive emotions at the end of the task	yes	neutral	no
Behavioral regulation	**Psycho-motor agitation**	moving around the room	standing up	no
	Waiting between trials/part of the task	yes	adult support	no
Cognitive regulation	**Attention on the instructions**	yes	repetitions	no
	Sustained attention on the task	yes	verbal prompts	no
	Losing attention in front of distracting stimuli	yes	adult support	no
	Maintaining goals/rules	yes	adult support	no
	Shifting between tasks	yes	adult support	no

7.4 Research implications

A persistent challenge in both research and clinical contexts lies in the time-intensive nature of comprehensive EF assessments. These findings indicate that certain EF measures may be used interchangeably, potentially streamlining assessment procedures. This could reduce cognitive load for children and shorten administration time, thereby minimizing fatigue, stress, and disengagement that might otherwise compromise the accuracy of the evaluations (Behrens et al., 2023). The development of shorter EF batteries would therefore be highly advantageous in both research and applied settings. This EF battery can be administered in about 20 minutes for younger children and 35 minutes for older children, offering a comprehensive yet time-efficient assessment of executive functioning. Furthermore, analyses revealed strong concordance between mothers' and fathers' evaluations of their children's executive functioning (Gioia et al., 2015). Importantly, parental perceptions did not differ between neurotypical and neurodivergent groups, suggesting that both caregivers tend to hold comparable views regarding their child's EF. This supports the interchangeable use of either parent's report in both research and clinical contexts and aligns with evidence highlighting that mothers and fathers play equally crucial roles in the development and regulation of EF (Meuwissen & Englund, 2016; Ribner et al., 2022).

From a methodological perspective, studies employing confirmatory and exploratory factor analyses may have identified EF structures that are partly dependent on the instruments used. Establishing tools with comparable measurement metrics would therefore help clarify the developmental structure of EF and facilitate cross-study comparability. This concordance would strengthen the conceptual validity of EF constructs and support the identification of universal and context-specific dimensions across development. Given that the cluster analysis highlights interesting insights into EF profiles in neurodiverse children, future research should prioritize the analysis of performance clusters among neurodiverse individuals rather than relying solely on between-group comparisons. While group-based analyses can yield valuable insights, they may overlook the substantial heterogeneity, and unique cognitive profiles present within each diagnostic category. Using alternative approaches, such as analysis of task failures and successes in neurodivergent population may advantaging our understanding of their cognitive profiles. Moreover, focusing on intra-group variability and individual cognitive trajectories would better capture the nuanced interplay of strengths and weaknesses that characterize neurodiversity profiles, avoiding the reductionism inherent in group-average interpretations.

7.5 Conclusion

This thesis aims to identify context-sensitive tools for assessing executive functioning in neurodivergent children, particularly those with autism, by accounting for individual cognitive profiles and real-world functioning. A multidimensional framework, the Executive Attention, based on the Working Memory Capacity model, is employed. Several neuropsychological tasks from *the Measures of Executive Attention Battery* were administered to neurodiverse children aged 5-16, including autistic participants, those with specific learning disorders, and neurotypicals. Findings show that this multidimensional battery demonstrates good ecological validity and usability across neurodiverse populations. Analyses of task successes and failures, performance patterns and latent factors provided insights into developmental trajectories, intergroup differences, and links between executive functioning and broader cognitive abilities (e.g., linguistic skills, fine-motor abilities, intelligence). Moreover, the high variability in performance highlights the uniqueness of individual cognitive profiles, underscoring the limitations of relying solely on diagnostic labels. Overall, a multidimensional, contextually grounded approach to executive functioning assessment fosters a deeper understanding of neurodivergent cognition and supports the implementation of more personalized interventions in clinical and educational contexts.

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Appendix A

Table A.1 *Correlations between executive function scores and autistic traits*

	ADOS			SRS		
	Social	**RRBs**	**Total score**	**Social**	**RRBs**	**Total score**
Variables	**r[a]**	**r[a]**	**r[a]**	**r[a]**	**r[a]**	**r[a]**
Wisconsin Card Sorting Test						
Categories	**-.19***	.005	**-.21***	.12	.01	.09
Cards	-.18	.16	-.14	.05	-.01	.03
Correct responses	-.08	-.11	-.16	.1	.04	.09
Errors	.15	.002	-.17	.17	.05	.14

Perseverative errors	**-.22***	-.02	**-.23***	.17	.07	.14
Other errors	.05	.06	.05	.06	-.03	.04
Tower of London						
Decision time	-.06	-.04	-.03	.06	-.06	.02
Execution time	.08	-.06	.08	-.04	-.06	-.06
Total time	.03	-.09	.04	-.08	-.17	-.13
Rules violation	**.25***	.13	**.30****	0	-.03	-.02
Points	-.10	**-.28****	**-.22***	**.37*****	**.26***	**.36****

Note. ***ADOS*** *= Autism Diagnostic Observation Schedule,* ***SRS*** *= Social Responsiveness Scale,* ***RRBs*** *= Restricted and repetitive behaviors. [a] Test significance * p < .05, ** p < .01, *** p < .001. Spearman correlation coefficient: weak (0.1-0.3), moderate (0.3-0.5) and strong (>0.5).*

Table A.2 *Correlations between executive function scores and autistic traits for the lower IQ group*

	ADOS			**SRS**		
	Social	**RRBs**	**Total score**	**Social**	**RRBs**	**Total score**
Variables	r^a	r^a	r^a	r^a	r^a	r^a
Wisconsin Card Sorting Test						
Categories	-.07	-.06	-.12	.13	-.03	.11
Cards	**-.59*****	-.08	**-.66*****	-.01	-.01	-.01
Correct responses	.08	0	.08	.36	.17	.33

Errors	.04	-.03	.01	.32	.15	.29
Perseverative errors	-.03	-.07	-.06	.29	.16	.27
Other errors	.24	-.21	.13	-.1	-.12	-.13
Tower of London						
Decision time	-.15	.16	-.02	-.03	-.31	-.07
Execution time	**.43***	.22	**.44***	-.32	-.3	-.3
Total time	.28	.19	.33	-.34	-.34	-.33
Rules violation	-.23	.26	-.19	.04	-.05	.03
Points	.03	-.32	0	**.46***	.32	.42

Note. ADOS *= Autism Diagnostic Observation Schedule,* ***SRS*** *= Social Responsiveness Scale,* ***RRBs*** *= Restricted and repetitive behaviors. [a] Test significance * p < .05, ** p < .01, *** p < .001. Spearman correlation coefficient: weak (0.1-0.3), moderate (0.3-0.5) and strong (>0.5).*

Table A.3 *Correlations between executive function scores and autistic traits for the higher IQ group*

	ADOS			**SRS**		
	Social	**RRBs**	**Total score**	**Social**	**RRBs**	**Total score**
Variables	r^a	r^a	r^a	r^a	r^a	r^a
Wisconsin Card Sorting Test						
Categories	-.12	.1	-.12	.09	0	.07
Cards	.01	**.26***	.08	.07	-.01	.05

Correct responses	0	-.09	-.08	-.02	-.02	-.01
Errors	-.08	.13	-.07	.13	0	.1
Perseverative errors	-.15	.1	-.13	.12	-.02	.09
Other errors	.05	.18	.07	.12	.03	.1
Tower of London						
Decision time	.01	-.11	-.01	.07	-.02	.04
Execution time	-.08	-.15	-.08	.07	0	.05
Total time	-.08	-.16	-.09	.05	-.11	0
Rules violation	**.28***	.12	**.36****	0	0	-.01
Points	.05	-.22	-.11	**.34****	.2	**.32***

Note. RRBs *= Restricted and repetitive behaviors. [a] Test significance * p < .05, ** p < .01, *** p < .001. Spearman correlation coefficient: weak (0.1-0.3), moderate (0.3-0.5) and strong (>0.5).*

Table A.4 *Generalized linear models between Wisconsin Card Sorting Test scores and autistic traits, controlling for sex, age and intelligence abilities (verbal comprehension and visual-spatial skills) in the lower IQ group*

Outcomes	Predictors	Beta	SE	*t*	*p*[a]	CI_lower	CI_upper
Categories	**ADOS_Social**	-.08	.08	-.96	.35	-.27	.06
	ADOS_RRBs	-.03	.16	-.18	.86	-.35	.34

	SRS_Social	.004	.01	.28	.79	-.03	.04
	SRS_RRBs	-.003	.01	-.21	.83	-.03	.02
Cards	**ADOS_Social**	-.09	.04	-2.13	**.04***	-.19	.003
	ADOS_RRBs	-.04	.09	-.46	.65	-.25	.09
	SRS_Social	.002	.005	.51	.62	-.007	.01
	SRS_RRBs	.001	.004	.38	.71	-.006	.008
Correct responses	**ADOS_Social**	-.07	.09	-.79	.44	-.22	.08
	ADOS_RRBs	.11	.17	.68	.50	-.12	.48
	SRS_Social	.02	.02	1.10	.28	-.01	.05
	SRS_RRBs	.008	.01	.56	.58	-.02	.04
Errors	**ADOS_Social**	-.08	.07	-1.25	.22	-.21	.05
	ADOS_RRBs	.01	.13	.09	.93	-.19	.25
	SRS_Social	.01	.01	.88	.39	-.01	.03
	SRS_RRBs	.003	.01	.32	.75	-.02	.03
Perseverative errors	**ADOS_Social**	-.27	.18	-1.53	.14	-.61	.08
	ADOS_RRBs	.07	.37	.19	.85	-.46	.82
	SRS_Social	.04	.03	1.01	.32	-.02	.11
	SRS_RRBs	.02	.03	.65	.53	-.04	.09
Other errors	**ADOS_Social**	.09	.06	1.45	.16	-.03	.21
	ADOS_RRBs	-.14	.13	-1.07	.30	-.39	.10

	SRS_Social	-.01	.009	-1.36	.19	-.03	.01
	SRS_RRBs	-.009	.008	-1.13	.27	-.03	.01

Note. ***SE*** *= Standard Error,* ***CI*** *= Confidence Interval.* ***ADOS*** *= Autism Diagnostic Observation Schedule,* ***SRS*** *= Social Responsiveness Scale,* ***RRBs*** *= Restricted and repetitive behaviors. [a] Test significance * p < .05, ** p < .01, *** p < .001.*

Table A.5 *Generalized linear models between Tower of London scores and autistic traits, controlling for sex, age and intelligence abilities (verbal comprehension and visual-spatial skills) in the lower IQ group*

Outcomes	**Predictors**	**Beta**	**SE**	***t***	***p*[a]**	**CI_lower**	**CI_upper**
Decision time	**ADOS_Social**	-.64	.46	-1.39	.18	-1.63	.32
	ADOS_RRBs	.68	1.11	.61	.55	-1.73	5.07
	SRS_Social	.006	.08	.08	.94	-.19	.28
	SRS_RRBs	-.005	.07	-.07	.95	-.17	.21
Execution time	**ADOS_Social**	.01	1.02	.01	.99	-2.21	1.82
	ADOS_RRBs	1.04	2.42	.43	.67	-6.65	5.64
	SRS_Social	.007	.19	.04	.97	-.48	.34
	SRS_RRBs	.10	.15	.65	.53	-.24	.52
Total time	**ADOS_Social**	-.63	.81	-.77	.45	-2.38	.93
	ADOS_RRBs	1.32	1.91	.69	.50	-3.44	5.67

	SRS_Social	.02	.15	.16	.88	-.44	.35
	SRS_RRBs	.10	.12	.77	.45	-.22	.48
Rules violation	**ADOS_Social**	-2.57	1.05	-2.44	**.03***	-5.73	.55
	ADOS_RRBs	-4.90	2.60	-1.88	.08	-11.12	7.00
	SRS_Social	.17	.26	.64	.53	-.34	1.10
	SRS_RRBs	.03	.22	.14	.89	-.62	.47
Points	**ADOS_Social**	-.11	.09	-1.27	.22	-.27	.06
	ADOS_RRBs	-.16	.20	-.80	.43	-.7	.16
	SRS_Social	.03	.02	1.61	.13	-.01	.07
	SRS_RRBs	.02	.02	.96	.35	-.02	.05

Note. ***SE*** *= Standard Error,* ***CI*** *= Confidence Interval.* ***ADOS*** *= Autism Diagnostic Observation Schedule,* ***SRS*** *= Social Responsiveness Scale,* ***RRBs*** *= Restricted and repetitive behaviors. [a] Test significance * p < .05, ** p < .01, *** p < .001.*

Table A.6 *Generalized linear models between Wisconsin Card Sorting Test scores and autistic traits, controlling for sex, age and intelligence abilities (verbal comprehension and visual-spatial skills) in the higher IQ group*

Outcomes	**Predictors**	**Beta**	**SE**	***t***	***p*[a]**	**CI_lower**	**CI_upper**
Categories	**ADOS_Social**	-.12	.06	-2.17	**.03***	-.24	.01
	ADOS_RRBs	.08	.10	.77	.44	-.12	.24

	SRS_Social	0	.01	.04	.97	-.02	.02
	SRS_RRBs	.001	.009	.06	.96	-.02	.02
Cards	**ADOS_Social**	.007	.05	.15	.88	-.10	.12
	ADOS_RRBs	.27	.08	3.59	**.001****	.08	.42
	SRS_Social	.001	.008	.15	.88	-.01	.02
	SRS_RRBs	-.001	.007	-.15	.88	-.02	.01
Correct responses	**ADOS_Social**	-.06	.05	-1.09	.28	-.16	.04
	ADOS_RRBs	-.11	.09	-1.16	.25	-.25	.07
	SRS_Social	-.005	.009	-.54	.60	-.03	.02
	SRS_RRBs	-.004	.009	-.50	.62	-.02	.02
Errors	**ADOS_Social**	-.06	.05	-1.36	.18	-.16	.05
	ADOS_RRBs	.13	.08	1.59	.12	-.05	.29
	SRS_Social	.001	.008	.15	.88	-.01	.02
	SRS_RRBs	-.001	.007	-.19	.85	-.02	.02
Perseverative errors	**ADOS_Social**	-.12	.06	-2.07	**.04***	-.24	.001
	ADOS_RRBs	.09	.10	.85	.40	-.15	.27
	SRS_Social	.002	.01	.22	.83	-.02	.02
	SRS_RRBs	.001	.01	.15	.88	-.01	.02
Other errors	**ADOS_Social**	-.003	.05	-.06	.95	-.10	.09
	ADOS_RRBs	.11	.08	1.44	.16	-.07	.24

SRS_Social	.001	.008	.15	.88	-.02	.02
SRS_RRBs	-.003	.007	-.38	.71	-.02	.01

Note. ***SE*** *= Standard Error,* ***CI*** *= Confidence Interval.* ***ADOS*** *= Autism Diagnostic Observation Schedule,* ***SRS*** *= Social Responsiveness Scale,* ***RRBs*** *= Restricted and repetitive behaviors. [a] Test significance * p < .05, ** p < .01, *** p < .001.*

Table A.7 *Generalized linear models between Tower of London scores and autistic traits, controlling for sex, age and intelligence abilities (verbal comprehension and visual-spatial skills) in the higher IQ group*

Outcomes	Predictors	Beta	SE	*t*	*p*[a]	CI_lower	CI_upper
Decision time	**ADOS_Social**	-.07	.57	-.12	.90	-.76	.79
	ADOS_RRBs	-.18	.94	-.20	.85	-2.06	1.95
	SRS_Social	-.06	.11	-.55	.58	-.24	.14
	SRS_RRBs	-.13	.10	-1.36	.18	-.33	.06
Execution time	**ADOS_Social**	-.32	.66	-.48	.64	-1.96	1.27
	ADOS_RRBs	-.77	1.07	-.72	.47	-3.66	1.42
	SRS_Social	-.05	.12	-.40	.69	-.30	.15
	SRS_RRBs	-.14	.10	-1.33	.19	-.34	.03
Total time	**ADOS_Social**	-.69	.63	-1.10	.28	-1.94	.65
	ADOS_RRBs	-1.27	1.03	-1.23	.23	-3.41	.96

	SRS_Social	-.10	.11	-.83	.41	-.34	.10
	SRS_RRBs	-.20	.10	-2.02	.05	-.40	-.02
Rules violation	**ADOS_Social**	2.57	1.05	2.45	**.02***	.77	4.70
	ADOS_RRBs	1.93	1.81	1.07	.29	-1.60	6.02
	SRS_Social	.06	.18	.35	.73	-.28	.40
	SRS_RRBs	-.05	.16	-.34	.74	-.36	.24
Points	**ADOS_Social**	-.02	.06	-.30	.77	-.11	.09
	ADOS_RRBs	-.12	.10	-1.25	.22	-.28	.06
	SRS_Social	.01	.01	1.43	.16	-.006	.03
	SRS_RRBs	.02	.01	1.69	.10	-.002	.03

***Note. SE** = Standard Error, **CI** = Confidence Interval. **ADOS** = Autism Diagnostic Observation Schedule, **SRS** = Social Responsiveness Scale, **RRBs** = Restricted and repetitive behaviors. ª Test significance * p < .05, ** p < .01, *** p < .001*

Appendix B

This appendix provides the *Z-scores* driven by the neurotypical sample included in the study, which served as the reference for calculating the scores for the participants included in the analyses in **Chapter 4**, **5**, and **6**.

Participants

206 participants were involved, aged 5 to 16 years old. Most of the data were collected from public schools in the northern Italy region, specifically within the province of Trento. The participating schools included primary schools (ages 5-11), lower secondary schools (ages 11-14), and extended up to the third year of upper secondary school (ages 14-16).

Only children who were native Italian speakers and had a history of neurotypical development were included. Children were excluded if they had a diagnosed psychiatric condition (e.g., specific learning disorders, autism spectrum disorders), socio-emotional or environmental disadvantages impacting learning (e.g., non-native language background or behavioral emotional dysregulation), or any neurological or medical diagnoses (e.g., epilepsy or other relevant conditions). Information about each child's medical and psychological history was collected from teachers or parents, in accordance with privacy and data protection regulations. Demographic information is reported in **Table B.1**.

Table B.1 *Children and adolescents' demographic characteristics*

		Characteristics					
		Cognitive		School		Sex	
Age	***n***	**MR**	**CI**	**Grade**	**Class**	**M (%)**	**F (%)**
5	5	11.2 (6.54)	18.67 (6.54)	Primary	1 (*n* = 5)	3	2
6	24	12.21 (5.56)	22.33 (5.56)	Primary	1 (*n* = 23) 2 (*n* = 1)	9	15
7	16	15.94 (4.99)	23.63 (4.99)	Primary	1 (*n* = 6) 2 (*n* = 9) 3 (*n* = 1)	8	8
8	15	13.8 (3.03)	23.53 (3.03)	Primary	2 (*n* = 5) 3 (*n* = 10)	9	6
9	29	18.59 (5.67)	25.35 (5.67)	Primary	3 (*n* = 6) 4 (*n* = 22) 5 (*n* = 1)	19	10
10	12	19.42 (6.50)	26 (6.50)	Primary	4 (*n* = 1) 5 (*n* = 11)	7	5
11	25	20.72 (4.78)	27.04 (4.78)	Primary (*n* = 3) Lower Secondary (*n* = 22)	5 (*n* = 3) 1 (*n* = 17) 2 (*n* = 5)	17	8
12	23	23 (4.72)	27.04 (4.72)	Lower Secondary	1 (*n* = 9) 2 (*n* = 12) 3 (*n* = 2)	12	11
13	18	22.78 (6.39)	27.22 (6.39)	Lower Secondary	1 (*n* = 1) 2 (*n* = 3) 3 (*n* = 14)	12	6
14	21	25.43 (5.39)	29.48 (5.39)	Lower Secondary (*n* = 1) Upper Secondary (*n* = 20)	3 (*n* = 1) 1 (*n* = 20)	6	13
15	12	25.08 (3.18)	28.42 (3.18)	Upper Secondary	1 (*n* = 2) 2 (*n* = 10)	5	6
16	6	26 (3.85)	30.17 (3.85)	Upper Secondary	2 (*n* = 1) 3 (*n* = 5)	3	3

Note. n *= subjects.* ***MR*** *= Matrix Reasoning test from the Wechsler Intelligence Scale for Children-IV (Orsini et al., 2015) as a measure of fluid intelligence.* ***CI*** *= Comprehension of instructions from the NEPSY-II battery (Korkman et al., 2007) as a measure of receptive linguistic skills.*

Analytic plan

Data were analyzed by dividing the sample into age subgroups (5-7, 8-9, 10-11, 12-13, 14-16 years), and all task scores were normalized into z-scores. Outliers were defined as values exceeding ±2.5

standard deviations and were excluded from the analysis. Descriptive statistics for the sample, including mean, standard deviation, minimum, and maximum values for each score, are reported separately for each age subgroup, after outlier exclusion, in **Table B.2-6.**

Table B.2 *Descriptive analysis of 5 to 7-year-old participants*

Variables	*n*	M	SD	min	max
Cognitive measures					
Matrix reasoning	45	13.42	5.67	0	22
Comprehension of instructions	42	22.93	2.57	18	29
Verbal fluency (semantic)	44	20.34	5.84	10	35
Verbal fluency (phonological)	42	9.79	4.25	1	19
Visuo-motor precision (time)	44	125.84	39.89	56	235
Visuo-motor precision (error)	44	11.64	11.17	0	42
Executive attention measures					
Color naming	44	42.18	10.61	24	73
Graphical fluency (accuracy)	44	8.23	4.41	0	18
Graphical fluency (error)	43	3.98	3.18	0	15
Graphical fluency (perseveration)	44	5.52	5.72	0	21
Cancellation (sheet 7)	44	1.43	0.69	0.79	5
Cancellation (sheet 8)	43	1.51	0.47	0.86	2.5
Cancellation (sheet 10)	42	3.7	1.44	1.73	7.5
Visual search	43	2.24	1.41	0.5	6.78

Note. n *= subjects;* ***M*** *= mean;* ***SD*** *= standard deviation;* ***min*** *= minimum score;* ***max*** *= maximum score.*

Table B.3 *Descriptive analysis of 8 to 9-year-old participants*

Variables	*n*	M	SD	min	max
Cognitive measures					
Matrix reasoning	44	16.95	5.4	7	30
Comprehension of instructions	43	24.93	2.54	19	30
Verbal fluency (semantic)	44	30.64	7.32	14	43
Verbal fluency (phonological)	43	15.93	5.16	7	29
Visuo-motor precision (time)	43	109.14	29.7	56	179
Visuo-motor precision (error)	43	2.33	3.47	0	14

Executive attention measures					
Color naming	43	29.91	7.22	19	57
Graphical fluency (accuracy)	43	18.05	6.4	4	34
Graphical fluency (error)	42	2.19	2.14	0	7
Graphical fluency (perseveration)	41	3.44	3.72	0	16
Cancellation (sheet 7)	42	0.94	0.3	0.54	1.77
Cancellation (sheet 8)	42	1.06	0.35	0.63	1.91
Cancellation (sheet 10)	41	2.24	0.49	1	3.21
Visual search	41	1.16	0.49	0.02	2.31
Enumeration (forward)	43	68.63	10.09	49	91
Enumeration (backward)	43	115.09	48.59	59	278
Enumeration forward-backward	43	46.5	44.41	6	195
Categorization	42	10.67	6.72	3	29
PASOT (1200ms)	38	38.82	10.72	9	57
PASOT (800ms)	38	32.29	10.59	4	55
PASOT	36	72.64	17.55	44	109

Note. ***n*** *= subjects;* ***M*** *= mean;* ***SD*** *= standard deviation;* ***min*** *= minimum score;* ***max*** *= maximum score.*

Table B.4 *Descriptive analysis of 10 to 11-year-old participants*

Variables	*n*	M	SD	min	max
Cognitive measures					
Matrix reasoning	37	20.3	5.34	7	29
Comprehension of instructions	37	26.7	2.2	23	32
Verbal fluency (semantic)	36	35.83	8.53	22	54
Verbal fluency (phonological)	37	18.49	8.31	0	35
Visuo-motor precision (time)	36	99.86	33.9	42	192
Visuo-motor precision (error)	35	1.23	1.86	0	7
Executive attention measures					
Color naming	36	25.17	3.98	19	36
Graphical fluency (accuracy)	37	22.59	6.09	11	34
Graphical fluency (error)	36	1.72	1.63	0	6
Graphical fluency (perseveration)	36	4.06	4.93	0	21
Cancellation (sheet 7)	36	0.84	0.35	0.41	1.87
Cancellation (sheet 8)	35	0.89	0.28	0.5	1.67
Cancellation (sheet 10)	36	1.89	0.51	1.15	3
Visual search	36	0.96	0.35	0.32	1.89
Enumeration (forward)	35	62.57	13.63	45	94

Enumeration (backward)	36	88.58	25.51	56	159
Enumeration forward-backward	36	23.5	24.94	-9	90
Categorization	35	14.6	7.11	4	28
PASOT (1200ms)	35	48.89	5.58	39	59
PASOT (800ms)	35	41.66	7.65	23	53
PASOT	36	89.22	12.97	62	112

Note. ***n*** *= subjects;* ***M*** *= mean;* ***SD*** *= standard deviation;* ***min*** *= minimum score;* ***max*** *= maximum score.*

Table B.5 *Descriptive analysis of 12 to 13-year-old participants*

Variables	***n***	**M**	**SD**	**min**	**max**
Cognitive measures					
Matrix reasoning	40	23.27	4.95	11	33
Comprehension of instructions	41	27.12	3.45	20	32
Verbal fluency (semantic)	40	36.05	8.34	17	56
Verbal fluency (phonological)	41	20.32	7.16	8	36
Visuo-motor precision (time)	40	97.3	36.64	50	209
Visuo-motor precision (error)	40	1.07	1.69	0	6
Executive attention measures					
Color naming	40	25.45	3.93	17	32
Graphical fluency (accuracy)	41	25.93	6.67	12	41
Graphical fluency (error)	40	1.62	1.71	0	7
Graphical fluency (perseveration)	40	3.98	5.5	0	21
Cancellation (sheet 7)	40	0.66	0.17	0.33	1.11
Cancellation (sheet 8)	40	0.79	0.19	0.52	1.18
Cancellation (sheet 10)	41	1.68	0.38	0.78	2.37
Visual search	40	0.89	0.27	0.4	1.46
Enumeration (forward)	39	57.74	9.85	42	81
Enumeration (backward)	40	82.85	20.1	56	129
Enumeration forward-backward	40	23.52	13.65	3	60
Categorization	40	16.5	10.41	3	40
PASOT (1200ms)	40	47.45	11.43	14	60
PASOT (800ms)	39	42.13	8.99	23	59
PASOT	39	90.44	17.59	49	117

Note. ***n*** *= subjects;* ***M*** *= mean;* ***SD*** *= standard deviation;* ***min*** *= minimum score;* ***max*** *= maximum score.*

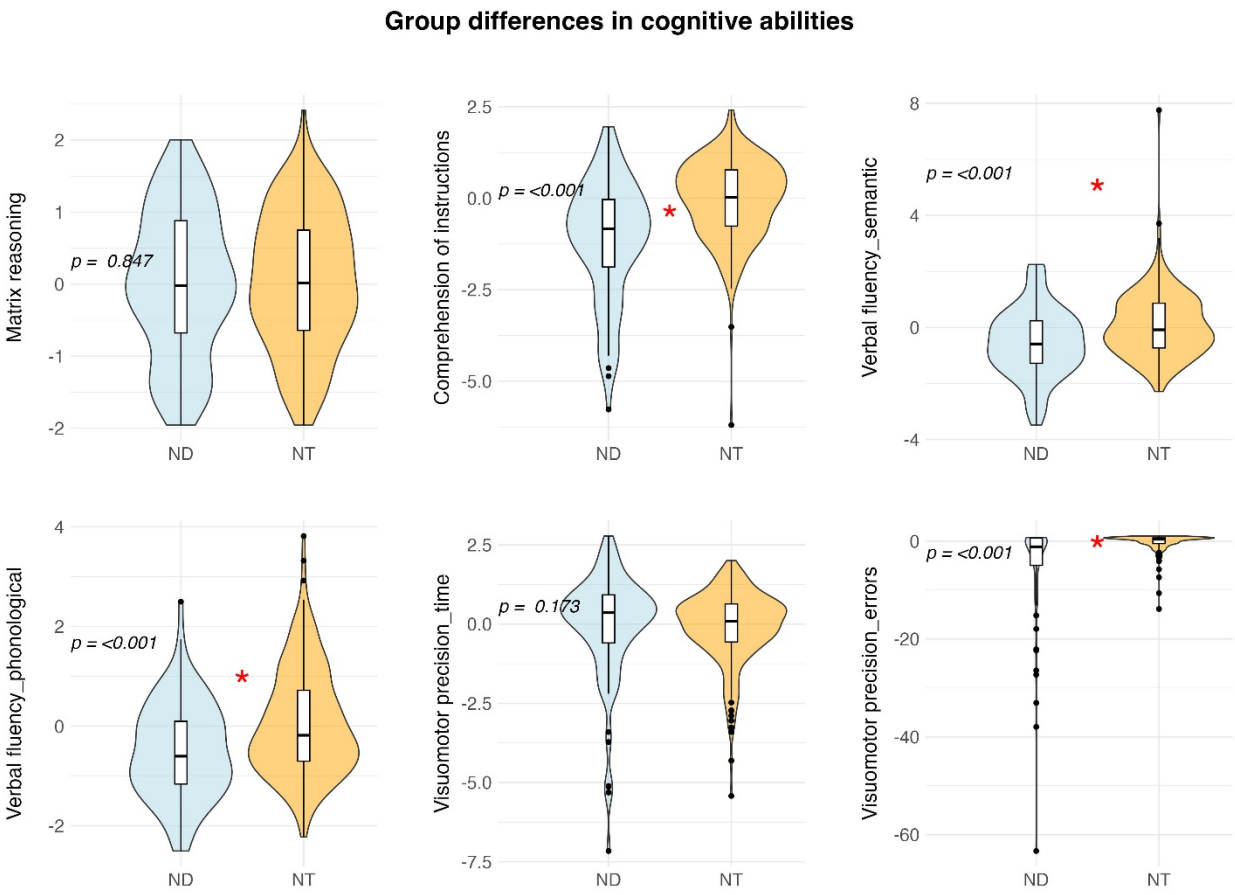
Table B.6 *Descriptive analysis of 14 to 16-year-old participants*

Variables	*n*	M	SD	min	max
Cognitive measures					
Matrix reasoning	38	25.95	3.04	20	31
Comprehension of instructions	39	29.26	2.53	23	33
Verbal fluency (semantic)	39	41.74	8.99	23	60
Verbal fluency (phonological)	38	23.84	6.07	15	39
Visuo-motor precision (time)	38	75.5	15.71	44	117
Visuo-motor precision (error)	37	1.27	1.69	0	7
Executive attention measures					
Color naming	38	21.08	3.03	15	29
Graphical fluency (accuracy)	39	31.03	6.28	18	43
Graphical fluency (error)	38	1.18	1.11	0	4
Graphical fluency (perseveration)	37	3.03	3.1	0	12
Cancellation (sheet 7)	38	0.62	0.12	0.43	0.91
Cancellation (sheet 8)	39	0.72	0.17	0.49	1.13
Cancellation (sheet 10)	37	1.35	0.32	0.75	2.14
Visual search	37	0.63	0.21	0.23	1.1
Enumeration (forward)	39	56.64	8.85	42	77
Enumeration (backward)	38	71.24	13.64	50	105
Enumeration forward-backward	38	14.63	10.96	-2	46
Categorization	39	18.97	7.47	4	30
PASOT (1200ms)	39	54.56	3.87	45	60
PASOT (800ms)	39	48.31	6.71	32	60
PASOT	39	102.87	9.21	81	120

Note. n *= subjects;* ***M*** *= mean;* ***SD*** *= standard deviation;* ***min*** *= minimum score;* ***max*** *= maximum score.*

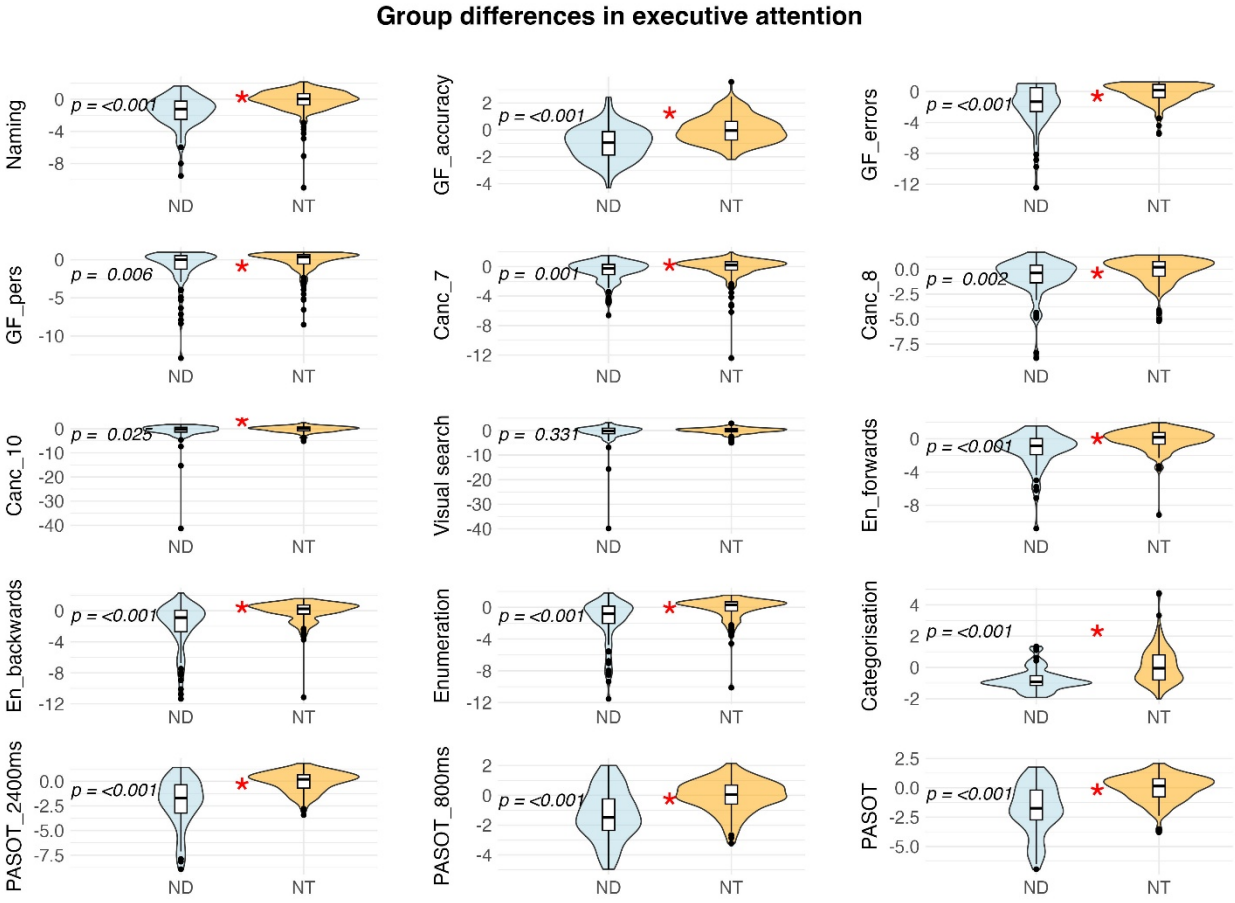
Appendix C

Figure C.1 *Differences in cognitive abilities between neurotypical and neurodivergent children*



Note. Naming *= Color naming;* ***GF*** *= Graphical fluency task;* ***GF_pers*** *= perseveration parameter of Graphical fluency task;* ***Canc*** *= Cancellation and visual search task;* ***En*** *= Enumeration task;* ***ND*** *= neurodivergent children;* ***NT*** *= neurotypical children. * Test significance.*

Figure C.2 *Differences in executive attention measures between neurotypical and neurodivergent children*



Note. Naming *= Color naming;* ***GF*** *= Graphical fluency task;* ***GF_pers*** *= perseveration parameter of Graphical fluency task;* ***Canc*** *= Cancellation and visual search task;* ***En*** *= Enumeration task;* ***ND*** *= neurodivergent children;* ***NT*** *= neurotypical children.* * *Test significance.*

Figure C.3 *Age related trajectories in cognitive abilities between neurotypical and neurodivergent children*

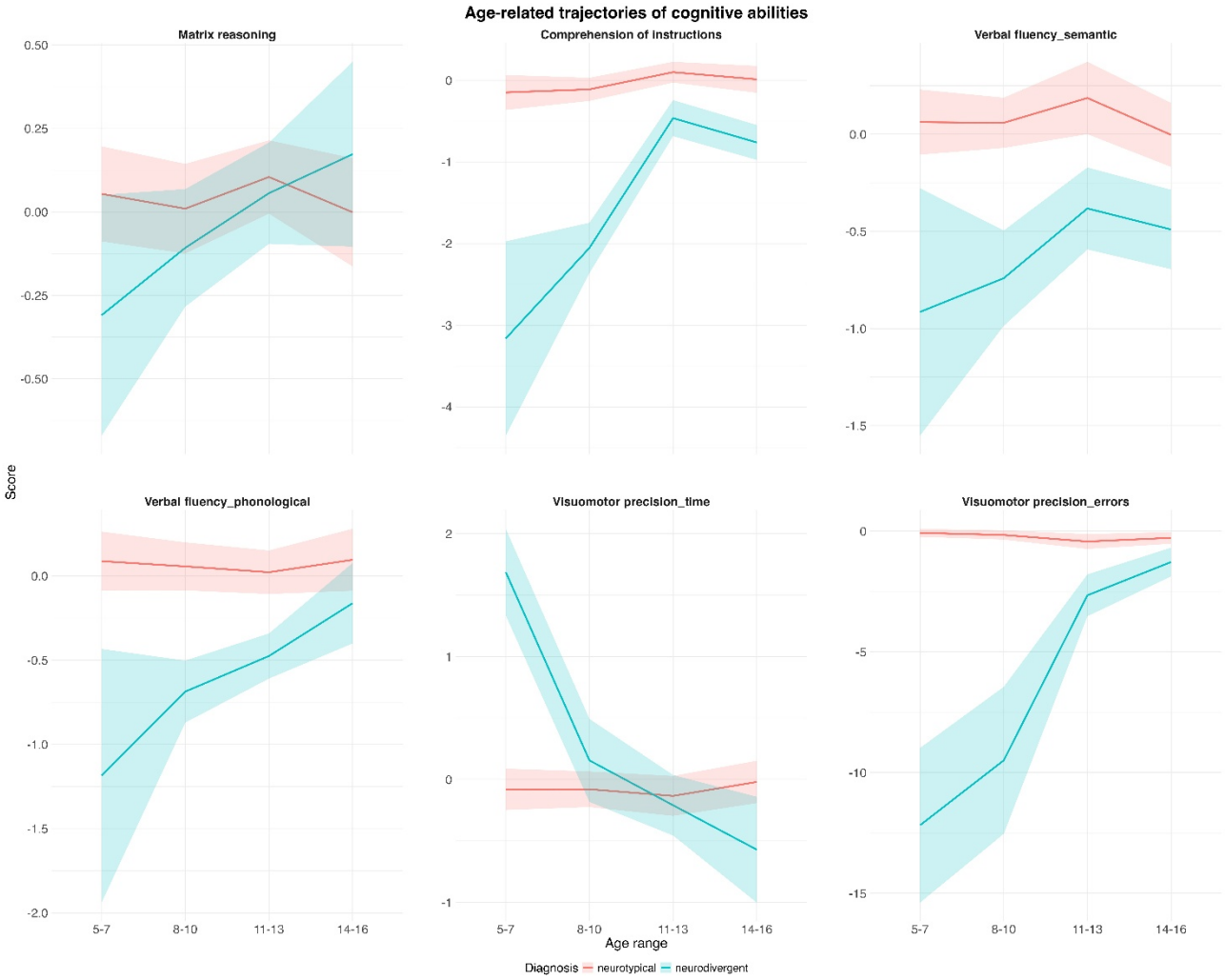
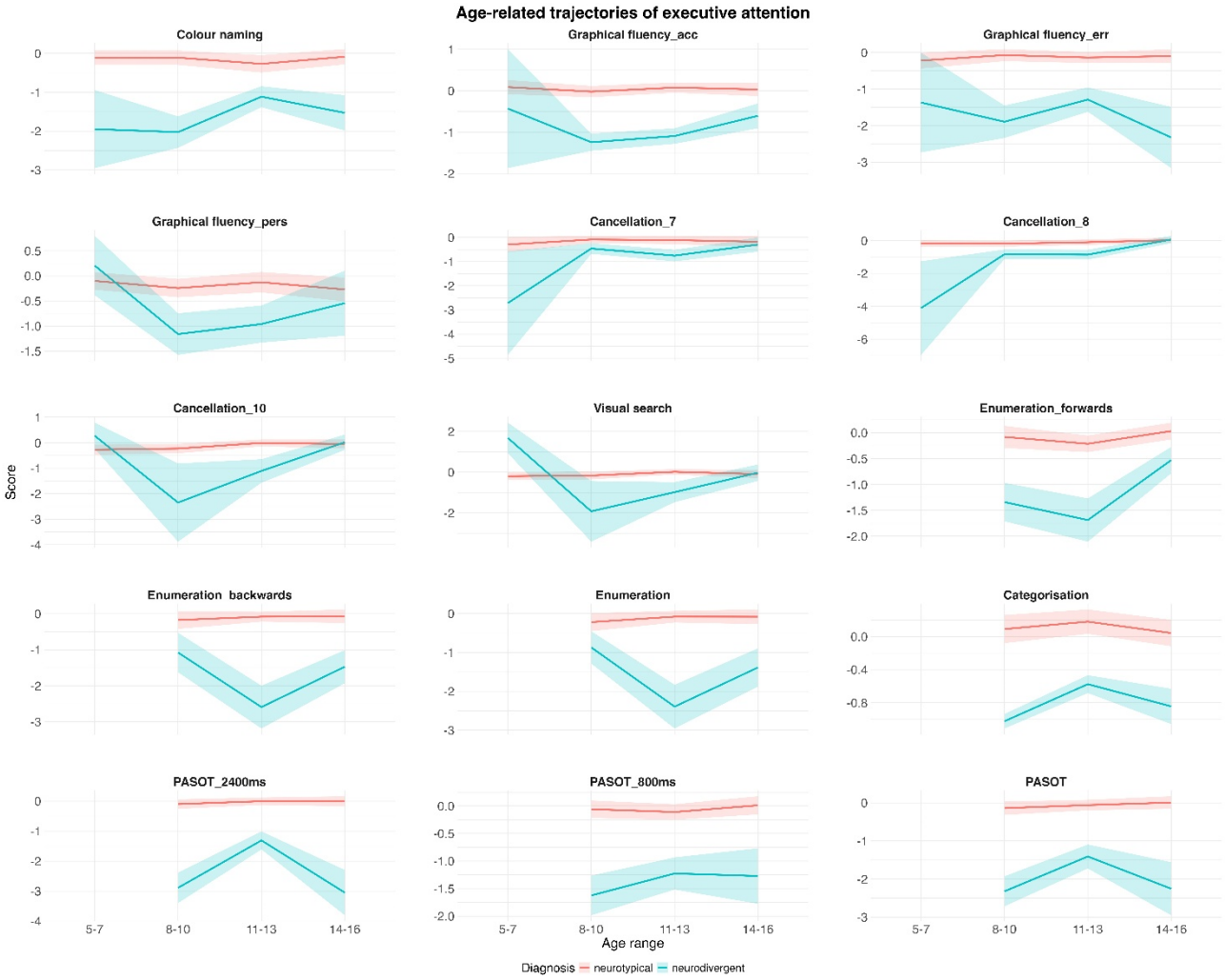


Figure C.4 *Age related trajectories in executive attention measures between neurotypical and neurodivergent children*



Note. Naming = *Color naming;* ***Graphical fluency_acc*** = *accuracy parameter of Graphical fluency;* ***Graphical fluency_err*** = *errors parameter of Graphical fluency task;* ***Graphical fluency_pers*** = *perseveration parameter of Graphical fluency task.*