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Immersive Virtual Reality Gameplay Alters Embodiment, Time Perception, and States of Consciousness

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Abstract

Immersive virtual environments are increasingly investigated as tools capable of modulating conscious experience, yet the specific contribution of graded immersion to altered states of consciousness (ASC), time perception, and cognition remains unclear. The present study examined how different levels of immersion during videogame play influence subjective experience and post-experience cognitive performance. Seventy-two participants played an identical 35 min segment of the videogame Half-Life: Alyx under one of three conditions: desktop PC (low immersion), head-mounted virtual reality (VR; medium immersion), or VR combined with full-body locomotion via an omnidirectional treadmill (high immersion). Following gameplay, participants completed validated measures of presence (IPQ), immersion (IEQ), ASC (5D-ASC), retrospective time estimation, and cognitive flexibility (Stroop task and Alternative Uses Test). Presence was selectively enhanced in VR relative to desktop play, whereas immersion was highest in the VR plus treadmill condition. Specific ASC dimensions related to embodiment and self-experience were selectively elevated in immersive conditions, with the most robust effects observed for disembodiment and positive depersonalization. Retrospective time-estimation accuracy was reduced in the highest immersion condition, indicating increased temporal distortion. Immersive gameplay did not produce widespread changes in executive function. Overall, the findings indicate that immersive virtual reality gameplay selectively alters embodiment-related aspects of conscious experience and retrospective time perception, without broadly changing executive function.

Keywords: virtual reality; immersion; presence; altered states of consciousness; executive functions; time perception; videogames; cognitive flexibility; embodiment

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1. Introduction

Virtual reality (VR) and immersive videogames are not only entertainment media but also emerging tools for modulating human consciousness and cognition. Players often report losing track of time during gameplay, and a large survey identified altered time perception as one of the primary reasons people play videogames [1]. Notably, a distorted sense of time is a hallmark of altered states of consciousness (ASCs) [2], suggesting that engaging digital environments can induce mild ASC-like experiences. In recent years, researchers have increasingly explored the capacity of immersive technologies to evoke ASC in a controlled, non-pharmacological manner [3,4]. This trend has given rise to the concept of digitally induced ASC (DIAL), referring to ASC experiences facilitated by modern media [5]. Early examples include attempts to induce trance-like states with binaural beat

audio programs [6] and pervasive reports of profound absorption in videogames. More recent approaches leverage VR's multisensory simulations, for instance, VR-generated hallucinatory visuals, aimed at safely reproducing aspects of ASCs such as self-transcendence, disembodiment, and altered reality [3]. Fundamentally, ASCs have long been recognized as an important part of human experience [7], and technology now provides a novel means to access some of their features without pharmacological agents [8–10].

A crucial distinction in this domain is between immersion and presence. Immersion denotes the objective qualities of a system that make a virtual experience perceptually convincing, such as high-fidelity graphics, surround sound, and interactive content [11,12]. In contrast, presence refers to the subjective psychological state of "being there" in the virtual world [13]. Prior work has shown that greater technological immersion generally leads to a stronger sense of presence [13,14]. Immersion can therefore be considered a major determinant, built by hardware and software, and presence the effect, namely the user's mental acceptance of the virtual environment as real. In VR games, higher immersion is achieved not only via rich sensory inputs (e.g., wide field-of-view visuals, spatial audio, haptic feedback) but also through interactivity and embodiment.

Embodiment refers to providing the user with a virtual body that moves in synchrony with their real movements, while agency refers to the user's ability to intentionally act on the virtual world [15]. These factors are known to amplify presence and engagement. For example, allowing natural locomotion and full-body movement in VR, through motion tracking or omnidirectional treadmills, can heighten the feeling of incorporation into the virtual space. When a VR system lines up with the user's sensorimotor expectations, such that visual and proprioceptive feedback match real movements, the brain more readily treats the virtual body as its own and the virtual environment as real [15,16].

From a theoretical perspective, these effects can be interpreted through predictive processing accounts of perception. The VR experience generates sensory inputs that fulfill the brain's learned predictions for normal interaction, thereby minimizing prediction errors and creating a compelling illusion of reality [17,18]. In simple terms, a well-designed immersive system "tricks" the brain's predictive model into accepting the virtual scenario, resulting in high presence. By contrast, mismatches in expected feedback, such as tracking latency or sensorimotor incongruence, can disrupt presence or induce unusual sensations, highlighting how tightly embodiment and presence are linked to multisensory integration mechanisms.

The intensity of an immersive experience has important consequences for subjective state and cognitive processes. Deep immersion is often accompanied by a state of focused attention and reduced self-awareness akin to flow [19]. In a flow state, individuals become so absorbed in the task at hand that they lose track of external factors, including time. Highly immersive games readily induce this phenomenon: players engaging in immersive games (even non-VR experiences) frequently underestimate how much time has passed when reflecting afterward [1]. According to attentional models of time perception, when attention is fully occupied by the environment, fewer cognitive resources remain available to monitor the passage of time [20]. Thus, greater immersion can lead to greater temporal distortion, often experienced as time "flying by" during play.

Immersion may also temporarily alter cognitive control and self-referential processing. Individuals deeply absorbed in an activity can experience diminished awareness of their physical self or surroundings, sometimes described as a mild dissociative state [21]. In the context of VR, a strong sense of presence can overwrite everyday reality, leading users to respond to virtual situations as if they were real [17]. While this property has beneficial applications (e.g., eliciting genuine emotional responses in therapeutic settings), it also demonstrates the profound impact of immersive presence on cognition. Indeed, VR

immersion has been shown to induce temporary reductions in real-world presence and symptoms of dissociation, particularly in individuals predisposed to absorption [21]. Other research similarly indicate that highly immersive experiences can momentarily reduce executive control; for example, problem gamblers often report trance-like dissociative states during gameplay [22]. Together, these observations suggest that increasing immersion is associated with more pronounced subjective alterations in consciousness, including changes in time perception, self-awareness, and cognitive control.

Time perception is particularly sensitive to immersion because subjective time is not directly perceived but reconstructed from internal signals related to attention, memory, and contextual cues [23,24]. Temporal judgments are commonly distinguished into retrospective and prospective paradigms, which rely on partially distinct mechanisms [20]. Retrospective timing depends primarily on memory encoding and contextual change, with richer or more eventful experiences yielding longer reconstructed durations [25,26]. Prospective timing, in contrast, is governed by attentional allocation and arousal, as formalized in the attentional-gate model [27]. Immersive videogame play, especially in VR, simultaneously increases attentional load, emotional engagement, and sensorimotor complexity, making it a powerful context for disrupting temporal metacognition.

Empirical findings on time perception in VR remain mixed. While altered time passage is robustly reported in videogames, VR studies have documented underestimation, overestimation, or null effects [28–31]. These discrepancies likely reflect differences in duration, embodiment, emotional content, and the availability of external temporal cues. Time and space are tightly coupled cognitive dimensions, and visual or spatial manipulations can directly influence perceived duration [32]. Moreover, embodiment itself modulates temporal experience: recent work shows that the presence of a virtual body accelerates the felt passage of time without necessarily affecting explicit duration estimates, revealing a dissociation between experiential and reconstructive aspects of time perception [33]. Emotional valence further shapes temporal judgments, with enjoyable experiences compressing perceived duration and boredom producing temporal dilation [34–36]. Importantly, it appears that affective engagement, rather than the medium per se, primarily drives temporal distortion [37].

Beyond temporal effects, immersive media have also been used to study broader ASC-like phenomena, although these effects depend strongly on content and design. A recent systematic review identified a range of altered experiences reported in virtual environments, including visual pseudo-hallucinations, spatial disorientation, derealization-like feelings, out-of-body experiences, and feelings of unity [38]. In specially designed paradigms, immersive VR has been used to induce strong self-transcendent or mystical-type experiences, in some cases with ratings on selected dimensions comparable to moderate psychedelic effects [39,40]. Likewise, surreal or *DeepDream*-based panoramic VR environments have been shown to increase scores on the 5D-ASC questionnaire and, in some cases, to improve post-experience cognitive flexibility [3]. These studies are important because they show that digital environments can, under certain conditions, elicit altered phenomenological profiles that overlap with some classic ASC dimensions [3,38–40]. At the same time, these paradigms are typically designed precisely to maximize such effects. By contrast, more naturalistic gameplay paradigms, such as the present one, are more likely to reveal milder and more selective experiential shifts, especially in dimensions related to embodiment, absorption, and time perception.

From a broader theoretical perspective, immersive experiences may also be considered in relation to neurocognitive frameworks of altered consciousness, although the present study does not test these directly. For example, the entropic brain hypothesis links altered experience to changes in the complexity of brain activity [41], whereas the global neuronal

workspace theory emphasizes changes in the broadcasting and prioritization of conscious contents across distributed networks [42]. In this sense, immersive VR may offer a useful behavioral context for exploring how specific dimensions of subjective experiences are modulated, even in the absence of direct neuroscientific measures.

Cognitive flexibility is an executive function of particular interest here, because it reflects the capacity to adapt to new rules, shift perspectives, and move beyond rigid response patterns [43]. Prior work suggests that some ASCs, including those induced by psychedelics, may transiently reduce cognitive rigidity and facilitate flexible thinking under certain conditions [44]. Likewise, VR experiences explicitly designed to be psychedelic-like have been associated with creative insight, idea generation, and improvements in some measures of flexibility [3,44]. Experimental work also suggests that disrupting habitual response patterns, even with relatively simple interventions, can promote more flexible cognition [45]. It is therefore conceivable that highly immersive VR, especially when it increases novelty, bodily engagement, and sensorimotor adaptation, could also influence subsequent cognitive performance. Enriched environments are often associated with benefits for executive functions [46], and VR may constitute a potent form of environmental complexity. Nevertheless, the available findings remain mixed, and it is plausible that cognitive outcomes depend on the type of content, the balance between stimulation and cognitive load, and the degree to which the experience actually alters ongoing thought patterns. For this reason, any effects of ordinary immersive gameplay on cognitive flexibility should be treated as plausible but not guaranteed.

In summary, the existing literature suggests that (1) the level of immersion provided by a digital experience modulates the intensity of presence and ASC-like effects, and (2) these altered experiences may influence subsequent cognitive performance, including creativity and flexibility. Nevertheless, important gaps remain. Previous VR studies have rarely isolated graded levels of immersion within the same gameplay context and have generally not examined how such differences jointly shape altered states of consciousness, time perception, and post-experience cognitive control. Few controlled experiments have systematically compared graded levels of immersion while holding task content constant. Most studies either examine VR in isolation or compare VR with non-VR conditions that differ substantially in context, making it difficult to isolate the specific contribution of immersion. In particular, the role of active locomotion and whole-body engagement, such as VR treadmills or motion platforms, has been hypothesized to amplify immersion and presence [39] but remains rarely tested with validated psychological outcome measures. Moreover, although presence and engagement questionnaires are commonly used, relatively few studies have incorporated standardized ASC instruments, such as the 5D-ASC, alongside cognitive measures.

The present study addresses these gaps by experimentally manipulating immersion level during a continuous, naturalistic videogame experience and assessing its effects on presence, subjective ASC, time perception, and cognitive flexibility. Using a between-subjects design, participants played the same 35 min segment of the videogame *Half-Life: Alyx* under three conditions: desktop PC (low immersion), head-mounted VR (medium immersion), and VR combined with full-body locomotion via an omnidirectional treadmill (high immersion). These three gameplay conditions were expected to differ not only in overall immersion but also in the specific experiential dimensions they elicited. In particular, VR was expected to enhance presence relative to standard PC gameplay, whereas the treadmill condition was expected to further increase engagement and bodily involvement. Following gameplay, participants completed validated measures of presence, immersion, ASC, retrospective time estimation, and cognitive flexibility. Among the ASC dimensions assessed, embodiment-related alterations and changes in time/space expe-

rience were considered of primary theoretical interest, whereas the remaining subscales were included to provide a broader exploratory characterization of subjective experience. Accordingly, we formulated the following hypotheses: H1: Presence would increase as a function of immersion level. H2: Embodiment-related ASC dimensions would increase as a function of immersion level. H3: Retrospective time-estimation error would increase with immersion level. H4: Cognitive flexibility would increase with immersion level. By testing these hypotheses, the study aims to clarify how graded immersion in VR reshapes conscious experience and cognition, informing both theoretical models of presence and practical applications of immersive technologies.

2. Materials and Methods

2.1. Procedure

Participants were individually guided into a laboratory room with closed curtains to prevent exposure to zeitgebers that might indicate the passage of time. Upon entering the room, participants were instructed to remove watches and place mobile phones on a designated table near the entrance to eliminate external cues regarding time.

Following this, participants were briefed about the experiment's objectives and procedure. They then completed an informed consent form and a questionnaire assessing their gaming habits.

Pre-Gameplay Preparation

All participants completed a Stroop task training session consisting of 10 trials to familiarize themselves with the task mechanics, but they did not perform the full task on this occasion. They subsequently filled out the Gaming Habits and Demographics questionnaire.

Experimental Conditions

Participants were randomly assigned to one of three experimental conditions:

1. **Low-Immersion Condition:**

Participants sat at a desktop computer and played Half-Life: Alyx (NoVR) (Valve Corporation, Bellevue, Washington, DC, USA) using a mouse and keyboard.

2. **Medium-Immersion Condition:**

Participants were instructed to stand at the center of the room and to minimize physical movement. They used a Meta Quest 3 VR headset (Meta Platforms, Inc., Menlo Park, CA, USA) and handheld controllers with joystick functionality to navigate the game environment.

3. **High-Immersion Condition:**

Participants first put on specialized footwear for the KATVR platform (Hangzhou, China) and stepped onto the platform, where they secured safety belts. They completed a brief familiarization session to practice walking on the platform and finally donned a Meta Quest 3 VR headset and handheld controllers.

Gameplay Session

Participants in all conditions engaged in free, uninstructed, and unrestricted gameplay for exactly 35 min.

Post-Gameplay Assessments

Upon completion of the gameplay session, all participants underwent the following assessments:

- **Temporal Perception**: Participants completed a modified version of the Subjective Time, Self, Space (STSS) questionnaire to estimate the duration of the gaming session [47].
- **State of Consciousness**: Participants filled out the 5D-ASC questionnaire to assess alterations in their state of consciousness [2].
- **Presence and Immersion**: Participants completed the IPQ and IEQ questionnaires to evaluate their sense of presence and immersion, respectively [48,49].
- **Cognitive Flexibility**: Participants performed two cognitive tasks:
  - The Alternative Uses Task (AUT)
  - The Stroop task
- **Cybersickness**: Participants completed the CSQ-VR to identify any symptoms of cybersickness felt during the gaming session [50].

To minimize order effects, the administration of the questionnaires (IPQ and IEQ) was counterbalanced with the cognitive tasks (AUT and Stroop task).

The STSS and 5D-ASC questionnaires were always administered right after the end of the gaming session, while the CSQ-VR was administered as the last questionnaire of the experiment.

2.2. Participants and Recruitment

A total of 93 participants were initially recruited for the study. However, 21 participants were excluded from the final analysis. Specifically, five participants were excluded due to a technical issue with the online platform used for collecting Stroop task data, which resulted in the loss of their responses. An additional sixteen participants were excluded because they did not complete the gaming session, primarily due to cybersickness, with reported symptoms including nausea and dizziness. Total discontinuation and cybersickness-specific attrition are reported in Table 1 (see also Table 2).

Table 1. Participants' flow across immersion conditions (PC, VR, KAT). The table reports the number of participants initially assigned and completing the study, as well as total discontinuations and discontinuations due to cybersickness, together with dropout and attrition rates by condition.

Condition	Initially Assigned	Completed	Discontinued (Total)	Discontinued Due To Cybersickness	% Drop Rate [1]	% Attrition [2]
PC	25	24	1	0	4	0
VR	37	24	13	11	35	30
KAT	31	24	7	5	23	16
Total	93	72	21	16	23	17

[1] % Drop rate was calculated as Discontinued (Total)/Initially Assigned × 100. [2] % Attrition was calculated as Discontinued Due To Cybersickness/Initially Assigned × 100.

Table 2. Descriptive statistics for participants who completed the study versus participants who discontinued due to cybersickness. Values include number of participants, mean age, percentage female, and gaming experience level (light, moderate, heavy).

	Number	Mean Age	% Female	Light	Moderate	Heavy
Completers	72	21	42	39	13	20
Non-completers [1]	16	21	81	14	1	1

[1] Discontinued due to cybersickness.

The final sample consisted of 72 participants, with a mean age of 21.07 years (SD = 2.07). Of these, 58.33% identified as male. All participants were native Italian speakers and reported no prior VR experience.

Participants were recruited via flyers posted throughout the Department of Cognitive Science at the University of Trento and through the SONA research participation platform, where students can sign up for studies and obtain a certificate of participation that may be eligible for university credit (CFU).

Prior to the experiment, participants were informed that the study involved videogames and whether they would be playing on a PC or in VR. Those assigned to the VR condition were not informed in advance whether they would use the KATVR locomotion platform, as assignment to conditions was randomized.

Based on their responses on the Gaming Habits and Demographic questionnaire, participants were categorized into three groups reflecting gaming experience: light, moderate, and heavy. Participants who reported playing daily for more than two hours per session were classified as heavy players; those playing one to three times per week for sessions lasting at least four hours were considered moderate players; and those playing less frequently and for shorter durations were categorized as light players.

The study was reviewed and approved by the University of Trento Ethics Committee (Approval Code: 2024-074). All participants provided written informed consent before taking part in the experiment.

2.3. Materials

2.3.1. Self-Report Questionnaires

During the protocol, all participants were asked to complete six questionnaires:

- A custom-designed Gaming Habits and Demographic questionnaire that collected demographic data (age and gender) and information about participants' gaming habits, using multiple-choice items.
- A modified version of the STSS questionnaire [47] that was used to assess subjective time perception and consisted of one open-ended question estimating the duration of the gaming session and two 10-point scale items evaluating the perceived passage of time.
- The 5D-ASC [2] that was a 94-item questionnaire rated on a 10-point Likert scale designed to assess various dimensions of ASC.
- The IEQ [49] that comprised 31 items rated on a 7-point Likert scale and an additional single-item immersion measure rated on a 10-point scale, to evaluate the level of cognitive and emotional engagement experienced in virtual environments, reflecting the participant's immersion.
- The IPQ [48] that included 14 items scored on a 5-point Likert scale and yielded a composite score reflecting the participant's overall sense of presence in the virtual environment.
- The CSQ-VR [50] that consisted of six items rated on a 7-point Likert scale, which measured symptoms of cybersickness experienced during the VR session.

The custom questionnaire was administered before the gaming session, while all other questionnaires were completed afterward.

2.3.2. Stimuli

Half-Life: Alyx was selected for this study due to its high level of interactivity and visually realistic virtual environments, making it particularly well suited for assessing constructs related to presence and immersion.

Participants in the VR conditions interacted with Half-Life: Alyx (Valve Corporation, Bellevue, Washington, DC, USA), a first-person VR game designed for high-immersion environments. Participants assigned to the low-immersion condition played a modded version of the game, known as Half-Life: Alyx (NoVR). Participants in the VR condi-

tions donned a Meta Quest 3 headset (Meta Platforms, Inc., Menlo Park, CA, USA) and controllers and used Steam Link to connect to a VR-ready machine where the game was played. Participants in the low-immersion condition directly accessed the game through the Steam application.

Each participant engaged with a 35 min segment drawn from the early stages of the game (Chapter 1: Entanglement and Chapter 2: The Quarantine Zone), which featured environmental exploration, object interaction, and introductory narrative content. These chapters were selected because they required players to manipulate virtual objects and resolve spatial or logical challenges to progress. The same gameplay segment, narrative progression, and core in-game events were maintained across PC, VR, and KAT conditions to maximize comparability between modes.

To assess cognitive flexibility, the AUT and the Stroop task were administered. Stroop task visual stimuli consisted of 120 colored words in Italian (10 practice items and 110 experimental trials) presented on a black background. The task included both congruent trials (e.g., the word "GIALLO", which means "yellow", displayed in yellow) and incongruent trials (e.g., the word "ROSSO", which means "red", displayed in blue). Each stimulus was preceded by a white fixation cross on a black background.

After each response, participants received visual feedback in the form of a message displayed in black text on a gray background, indicating whether their answer was correct or incorrect.

In the AUT, participants were presented with a common object and asked to write down as many creative alternative uses as possible on a sheet of paper. For each object, participants were given two minutes to produce their responses. The objects used were a ping-pong ball, a wooden plank, and a paperclip, presented in this order.

2.3.3. Platform

All self-report measures were delivered using the Qualtrics XM platform, a secure, web-based survey tool for collecting participant responses.

The Stroop task was administered using PsyToolkit [51,52], an online software package for programming and conducting psychological experiments. The test was run on Google Chrome.

Participants responded to the AUT by using pen and paper.

The Stroop task was conducted on a PC running Windows 10 Enterprise, equipped with an Intel Core i7-10700K processor, 32 GB RAM, a NVIDIA GeForce GTX 1660 GPU, and a 512 GB Western Digital SN730 NVMe SSD.

For all conditions, the game Half-Life: Alyx (Valve Corporation, 2020) was accessed and launched through the Steam platform (Valve Corporation, n.d.; v. 1.0.0.81). The low-immersion condition was conducted on a PC running Windows 11 Education, equipped with an Intel Core i7-4790 processor, 16 GB RAM, a NVIDIA GeForce GTX 1060 GPU, and a 250 GB Samsung SSD 850 EVO, and an additional 1 TB Barracuda ST1000DM003 HDD.

The keyboard used for input controls was an HP KU-1469 model, and the mouse was a Dell MS111-P.

The medium- and high-immersion conditions were conducted on a PC running Windows 11 Enterprise, featuring an Intel Core i7-14700F processor, 32 GB RAM, a NVIDIA GeForce RTX 4060 GPU, and a 1 TB Samsung MZVL41T0HBLB-00BH1 SSD. The connection between the VR headset and PC was established using Steam Link.

In the medium-immersion condition, participants used standard Meta Quest 3 controllers (Meta Platforms, Inc., Menlo Park, CA, USA) in room-scale mode, allowing for physical movement within a 3×3 m area. The Meta Quest 3 offers a display resolution of 2064×2208 pixels per eye, a refresh rate of 120 Hz, and a 110° horizontal field of view.

Participants were instructed to stand at the center of the room and to minimize physical movement, navigating the environment primarily through the controllers' joysticks.

In the high-immersion condition, the KAT Walk C2 Plus (Hangzhou, China) was used. This is an omnidirectional treadmill designed to enable full-body locomotion in VR within a confined physical space. The device allows users to walk, run, turn, and crouch while remaining in place, translating lower-body motion into corresponding in-game movement.

Participants stood on a concave, low-friction platform wearing specialized footwear provided by the manufacturer. They were secured with a waist harness attached to a rear-mounted support arm, which stabilized posture while allowing for natural gait and lower-body freedom. The treadmill and the shoes include an integrated motion-tracking system that detects steps, walking direction, and rotational movement in real time.

For this study, the KAT Walk C2 Plus (Hangzhou, China) was used in combination with the Meta Quest 3 headset (Meta Platforms, Inc., Menlo Park, CA, USA), connected to the PC via Steam Link. Locomotion data were synchronized with SteamVR, allowing participants to navigate the virtual environment using natural gait. Object interaction and menu navigation were performed using the handheld controllers.

Before starting the experimental task, participants completed a brief familiarization phase. During this phase, the treadmill was calibrated to their walking style, and they were trained in basic actions such as walking, stopping, and turning.

2.4. Data Analysis Techniques

All statistical analyses were performed using RStudio (version 2024.09.0). The analyses were designed to address the main research questions regarding ASCs, time perception, and cognitive flexibility, across the three experimental conditions.

Descriptive statistics (mean, standard deviation, median) were computed for all key variables, stratified by experimental condition. Data visualization techniques such as histograms, together with density lines and boxplots, were used to assess distribution shapes and potential violations of normality. Assumptions for parametric testing were evaluated through Shapiro–Wilk tests (normality) and Levene's tests (homogeneity of variance). In cases of non-normality, histograms and density lines were visually inspected. If distributions were right-skewed, logarithmic or square-root transformations were applied. When assumptions remained unmet even after transformation, the Kruskal–Wallis nonparametric test was employed. In case of a significant result, Dunn's post hoc test with Bonferroni's correction was applied.

To address potential confounding by cybersickness, primary analyses were re-estimated including the CSQ-VR score as a covariate for the main between-group analyses. Given the number of 5D-ASC subscales analyzed, the false discovery rate was controlled across the family of subscale tests using the Benjamini–Hochberg procedure ($q = 0.05$). Pearson correlation coefficients were calculated to examine relationships between IEQ, IPQ, and the 5D-ASC subscales, providing additional insights into the link between immersion and ASCs.

For the time-perception task, absolute estimation error was used as the primary outcome. In addition, signed error (overestimation vs underestimation) was computed and visualized using distribution plots by condition for exploratory purposes.

Raw Stroop task files were pre-processed to retain only the relevant columns: congruency, accuracy, and reaction time (RT). Participants were assigned to experimental groups based on their numeric ID.

Accuracy was analyzed using generalized linear mixed-effects models (GLMMs; binomial link), and RTs were analyzed using linear mixed-effects models (LMMs) on log-transformed RTs. For completeness, aggregated Stroop effect scores (mean

incongruent–congruent RT difference) were also computed per participant and compared between groups. Responses to the AUT were rated for creativity based on the guidelines developed by [53], which define creativity along three subjective dimensions: uncommon, remote, and clever. Ratings were made on a 5-point Likert scale, where 1 indicated a response that was not at all creative and 5 indicated a highly creative response. According to these criteria, uncommon responses are those that occur infrequently in the sample, remote responses are conceptually distant from typical uses, and clever responses are marked by insight, irony, or aesthetic appeal.

The scoring was performed by two independent psychologists who had no involvement in the experimental design, data collection, or hypotheses of the study. The two raters reviewed all responses, initially gaining an overview of response commonness, and then evaluated each according to the creativity dimensions reported above. Ratings were aggregated using the mean to obtain the final creativity score. Raters were instructed to use the full scale, overlook minor spelling errors, and apply consistency checks, in line with the original rubric. Inter-rater reliability for the AUT creativity ratings was assessed using an intraclass correlation coefficient (two-way mixed-effects model, consistency, average measures), yielding good-to-excellent reliability, ICC(3,2) = 0.82, 95% CI [0.70, 0.88], $p < 0.001$.

All statistical tests were two-tailed, and a significance threshold of $p < 0.05$ was adopted. Adjustments for multiple comparisons were applied where appropriate. In addition, a sensitivity analysis was conducted for the three-group design ($\alpha = 0.05$, power = 0.80) to quantify the minimum detectable effect size ($f = 0.37$; $\eta^2 \approx 0.12$), and null effects were interpreted accordingly.

3. Results

The classification developed from the Gaming Habits and Demographic questionnaire was used to verify whether the gaming experience was evenly distributed across experimental conditions (see Table 3). A chi-square test of independence was conducted between the variables group and gaming habits, which yielded a non-significant result, $\chi^2(4) = 2.53$, $p = 0.639$, indicating no evidence of association between condition and prior gaming experience.

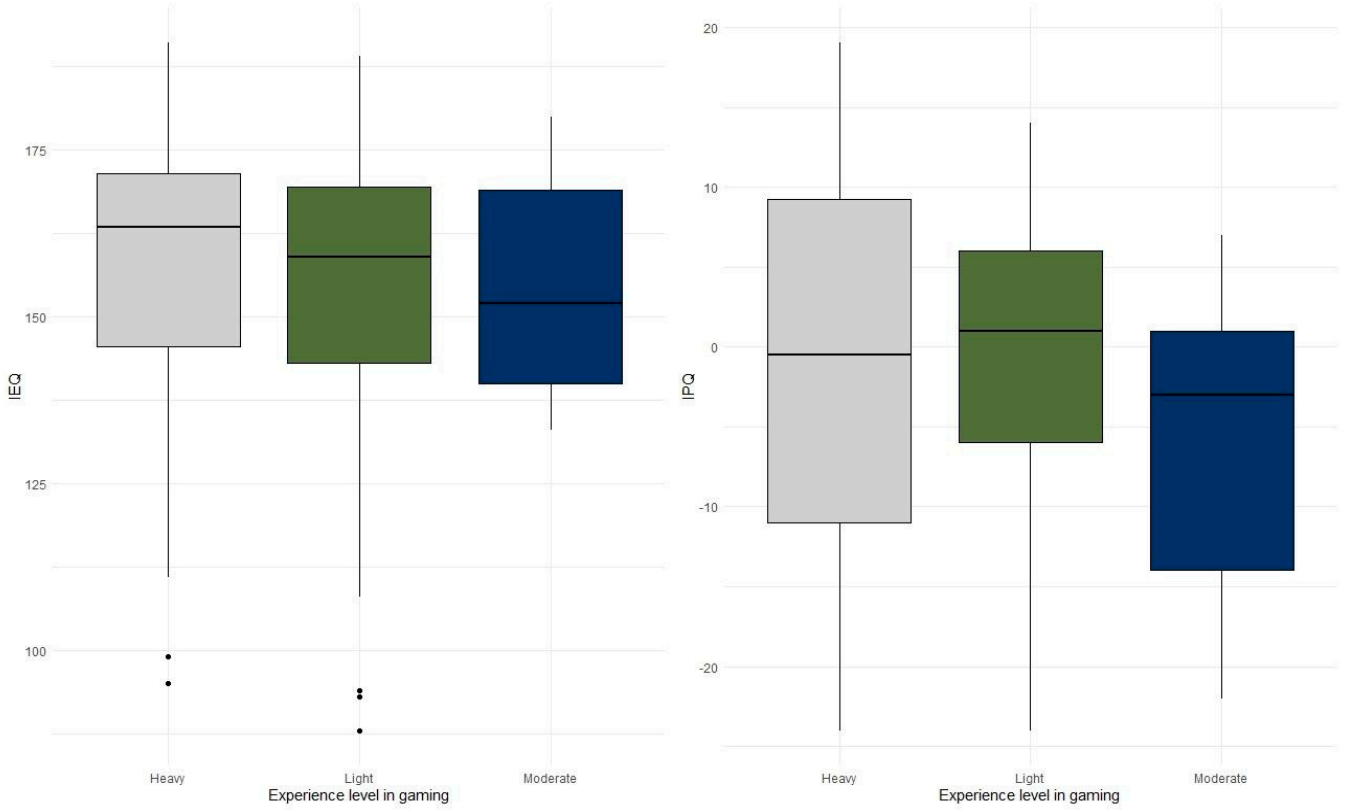
Table 3. Distribution of participants by immersion condition (PC, VR, KAT) and gaming experience level (light, moderate, heavy). No significant association was observed between conditions and prior gaming experience.

Experimental Group	Light	Moderate	Heavy
PC	12	3	9
VR	13	6	5
KAT	14	4	6

To ensure that immersion and presence scores were not confounded by gaming habits, both IEQ and IPQ scores were compared across gaming experience groups. Descriptive statistics did not reveal obvious differences (see Table 4). To further verify this, two linear regression models were fitted, one predicting IEQ scores and one predicting IPQ scores from gaming experience. The regression model predicting IEQ yielded no significant effect, $F(2, 69) = 0.078$, $p = 0.925$, $R^2 = 0.002$, adjusted $R^2 = -0.027$. Similarly, the model predicting IPQ was also non-significant, $F(2, 69) = 1.86$, $p = 0.164$, $R^2 = 0.051$, adjusted $R^2 = 0.024$. These small R^2 values support the interpretation that immersion and presence are more likely influenced by other factors than participants' prior gaming habits (see Figure 1).

Table 4. Mean (SD) scores of the IEQ and IPQ by gaming experience level. Descriptive statistics are reported for light, moderate, and heavy gamers.

Experience Level in Gaming	IEQ Mean (SD)	IPQ Mean (SD)
Light	152.7 (24.1)	−0.6 (9.7)
Moderate	155.5 (17.0)	−6.9 (10.5)
Heavy	154.3 (28.3)	−1.0 (12.2)



(a) **(b)**

Figure 1. Boxplots showing the Immersive Experience Questionnaire (IEQ; (**a**)) and Igroup Presence Questionnaire (IPQ; (**b**)) scores as a function of experience level in gaming (light, moderate, heavy). No significant differences were observed between experience levels for either measure.

Then, the analysis focused on verifying if the experimental manipulation of immersion levels was effective. To this end, scores from the IPQ and the IEQ were analyzed. IPQ scores met both the normality assumption (Shapiro–Wilk $p = 0.085$) and the homogeneity of variance assumption (Levene's test $p = 0.154$), permitting the use of a one-way ANOVA. The analysis revealed a significant main effect of condition on the IPQ scores, $F(2, 69) = 6.36$, $p = 0.003$, $\eta^2 = 0.16$. Tukey's Honestly Significant Difference (HSD) test indicated that the medium-immersion condition (VR) differed significantly from the low-immersion condition ($p = 0.002$, Cohen's d = 1.01) (see Figure 2). To address potential confounding by cybersickness, the IPQ scores were additionally re-analyzed, including the CSQ-VR as a covariate. The main effect of the condition remained significant, $F(2, 68) = 5.22$, $p = 0.008$, $\eta p^2 = 0.1$, whereas the CSQ-VR was not a significant predictor, $F(1, 68) = 0.82$, $p = 0.369$, $\eta p^2 = 0.01$, indicating that differences in presence were not attributable to cybersickness severity.

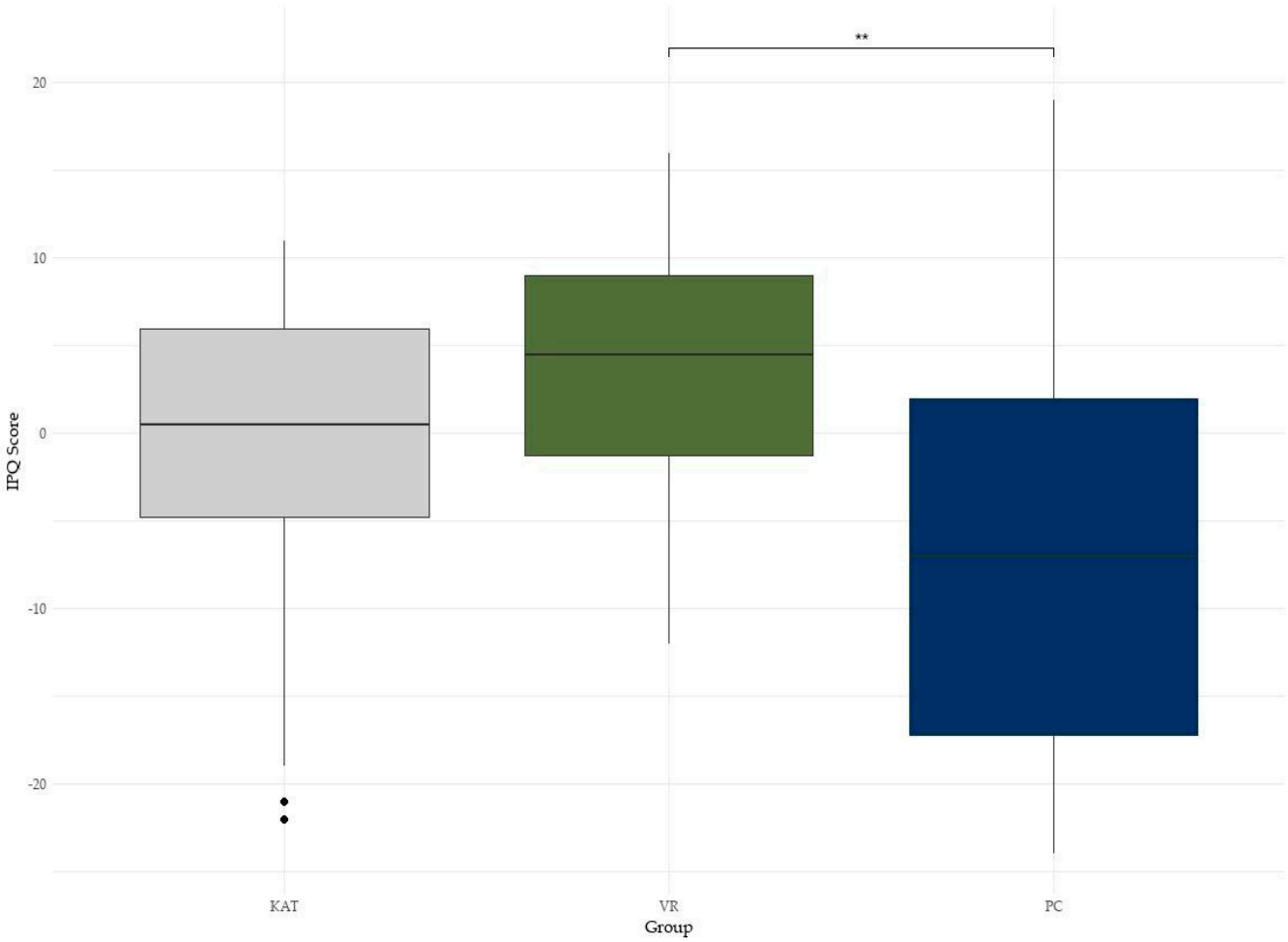


Figure 2. Boxplots showing IPQ scores across experimental conditions (PC, VR, KAT). A significant main effect of immersion condition was observed, with higher presence scores in the VR condition compared with PC (p = 0.002).

For the IEQ scores, the normality assumption was not met. A Kruskal–Wallis test was therefore conducted, yielding a significant result (H(2) = 11.6, p = 0.003, ε^2 = 0.14). Post hoc comparisons using the Dunn's test revealed significantly higher IEQ scores in the KAT condition compared with the PC condition (p = 0.002, r = 0.40) (see Figure 3). To further examine the potential influence of cybersickness, a linear model including the CSQ-VR as a covariate was estimated. The effect of the group remained significant, F(2, 68) = 4.23, p = 0.008, ηp^2 = 0.16, while the CSQ-VR was not a significant predictor (p = 0.658, $\eta p^2 < 0.01$), suggesting that group differences in the IEQ were not driven by cybersickness.

Overall, the results support the effectiveness of the experimental manipulation of immersion. Both questionnaires detected significant differences between the immersion conditions, suggesting that the experimental setup successfully elicited varying levels of immersive experience.

3.1. Altered States of Consciousness

The results of the 5D-ASC questionnaire showed an overall mean score of 310.94 (SD = 132.50) out of a possible maximum of 940. The high-immersion group (KAT) had the highest mean score (M = 332.75, SD = 120.62), followed by the medium-immersion (VR) group (M = 327.13, SD = 135.67), and the low-immersion (PC) group (M = 270.71, SD = 137.06).

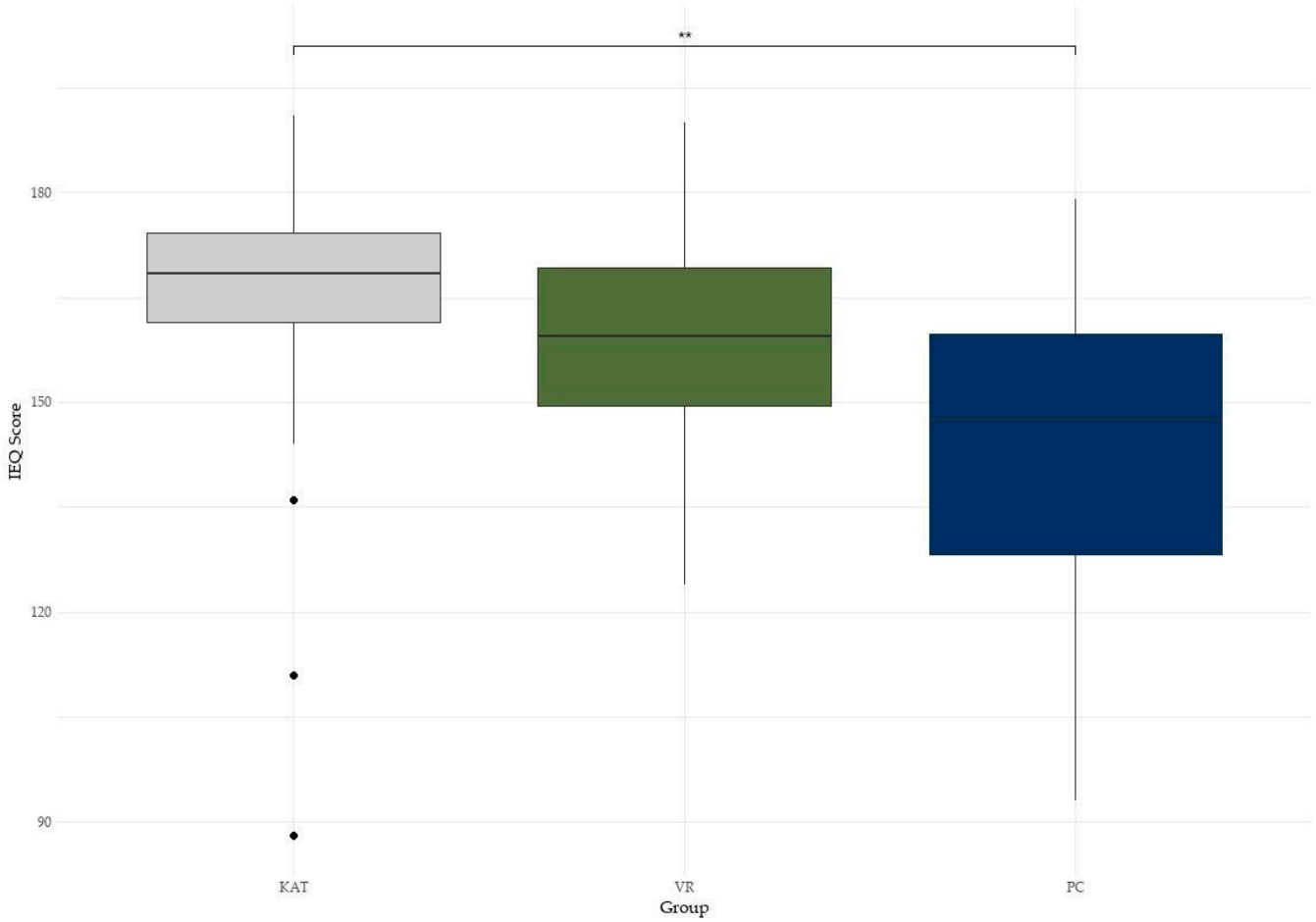


Figure 3. Boxplots showing IEQ scores across experimental conditions (KAT, VR, PC). Immersion scores were significantly higher in the KAT condition compared with PC (p = 0.002), while no differences emerged between VR and PC.

The distribution of the total 5D-ASC scores was not normal (Shapiro–Wilk p = 0.003), although homogeneity of variance was confirmed (Levene's test p = 0.808). Given the right-skewed distribution, a logarithmic transformation was applied, resulting in normally distributed and homoscedastic data (Shapiro–Wilk p = 0.073; Levene p = 0.327). A one-way ANOVA was conducted and did not reveal a statistically significant difference between groups, $F(2, 69) = 2.43$, p = 0.095, $\eta^2 = 0.07$. To further examine the potential influence of cybersickness, a linear model including the CSQ-VR as a covariate was estimated. The effect of the group remained non-significant, $F(2, 68) = 1.49$, p = 0.234, $\eta p^2 = 0.04$. However, the CSQ-VR emerged as a significant predictor, $F(1, 68) = 4.90$, p = 0.030, $\eta p^2 = 0.07$, indicating that higher levels of cybersickness were associated with higher 5D-ASC scores.

Subsequent analyses examined the individual 5D-ASC subscales. Figure 4 provides an overall visual summary of the most relevant subscales, highlighting both the general profile differences across conditions and the pattern of statistical significance. To control for multiple comparisons across the family of ASC subscales, p values were additionally adjusted using the Benjamini–Hochberg false discovery rate (FDR) procedure. Before correction, significant group differences were observed for spiritual experience (uncorrected p = 0.015), disembodiment (uncorrected p = 0.005), positive derealization (uncorrected p = 0.023), positive depersonalization (uncorrected p = 0.005), and altered perception of time and space (uncorrected p = 0.022). After FDR correction, however, only disembodiment (q = 0.039) and positive depersonalization (q = 0.039) remained statistically significant. The effects on spiritual experience, positive derealization, and altered perception of time and

space, therefore, did not survive correction and are interpreted cautiously as exploratory trends rather than robust group differences.

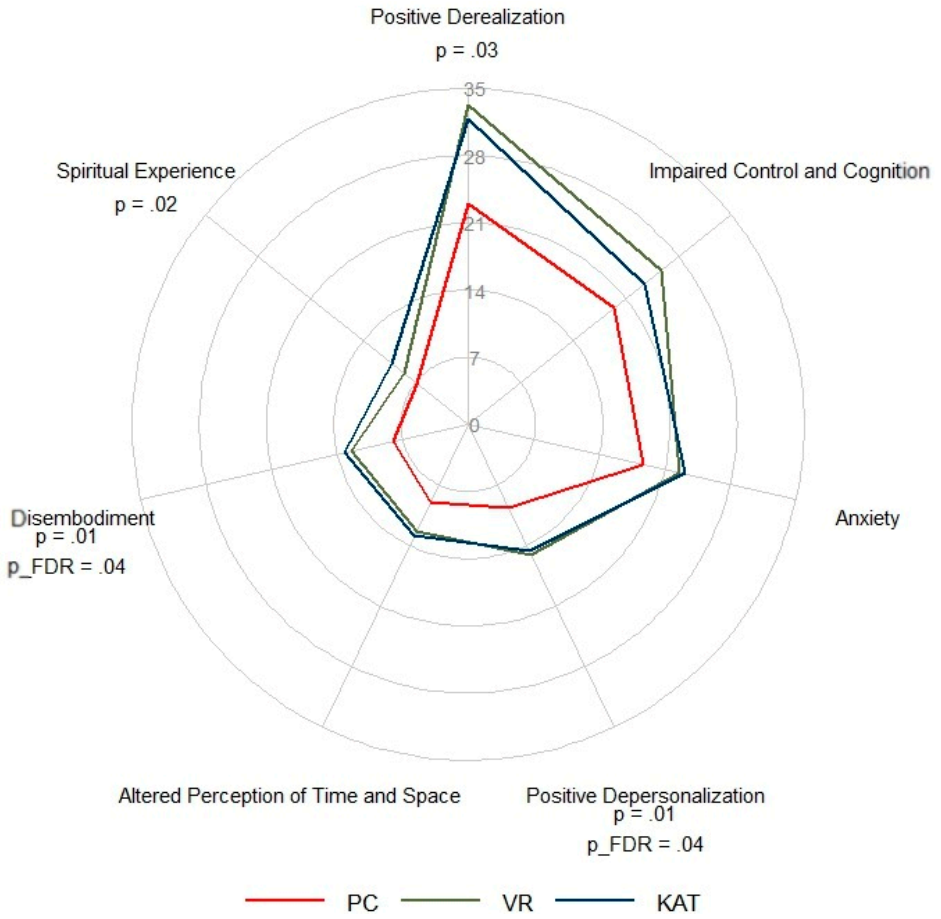


Figure 4. Radar plot showing mean scores for the most relevant 5D-ASC subscales across experimental conditions (PC—red, VR—green, KAT—blue). The figure is intended to provide an overall profile view of ASC-related differences across conditions. Labels indicate which subscales showed nominally significant group differences and which remained significant after FDR correction. The clearest differences were observed in embodiment-related dimensions, especially disembodiment and positive depersonalization.

For the subscales surviving FDR correction, linear models including the CSQ-VR as a covariate were estimated. For disembodiment, log-transformed data met ANOVA assumptions (Shapiro–Wilk $p = 0.062$; Levene's test $p = 0.180$). The model showed a significant effect of group, $F(2, 68) = 4.83$, $p = 0.011$, $\eta p^2 = 0.14$, whereas the CSQ-VR was not a significant predictor ($p = 0.402$, $\eta p^2 = 0.01$). Tukey-adjusted pairwise comparisons of estimated marginal means indicated higher disembodiment in the high-immersion condition (KAT) than in the low-immersion condition (PC; $p = 0.010$, Cohen's d = 0.88), whereas the KAT–VR comparison was not significant ($p = 0.756$) and the PC–VR contrast did not reach significance ($p = 0.069$).

For positive depersonalization, log-transformed data met ANOVA assumptions (Shapiro–Wilk $p = 0.106$; Levene's test $p = 0.400$). The model showed a significant effect of group, $F(2, 68) = 4.92$, $p = 0.010$, $\eta p^2 = 0.14$, whereas the CSQ-VR was not a significant predictor ($p = 0.532$, $\eta p^2 < 0.01$). Tukey-adjusted pairwise comparisons indicated higher scores in both the high-immersion condition (KAT) and the medium-immersion condition (VR) relative to the low-immersion condition (PC; $p = 0.018$, Cohen's d = 0.82, and $p = 0.026$, Cohen's d = 0.79, respectively), whereas KAT and VR did not differ ($p = 0.994$).

Although they did not survive FDR correction, two additional subscales showed uncorrected group effects and are reported here for completeness. For spiritual experience, log-transformed data met ANOVA assumptions (Shapiro–Wilk $p = 0.060$; Levene's test $p = 0.104$), and a significant uncorrected group effect emerged, $F(2, 69) = 4.45$, $p = 0.015$, with Tukey HSD indicating higher scores in KAT than PC ($p = 0.011$). For positive derealization, ANOVA assumptions were violated, so a Kruskal–Wallis test was used, yielding a significant uncorrected effect, $H(2) = 7.52$, $p = 0.023$; post hoc Dunn's tests with Bonferroni adjustment indicated a significant difference between VR and PC ($p = 0.031$). Because neither effect remained significant after FDR correction, these findings are interpreted as exploratory.

The remaining 5D-ASC subscales did not show significant differences between immersion groups after FDR correction (all $q > 0.05$).

3.2. Time Perception

The overall mean of participants' retrospective time estimations was 38.60 min (SD = 13.61). Both the low- and medium-immersion groups showed similar means and standard deviations, 36.54 (SD = 8.29) and 35.26 (SD = 11.54), respectively. In contrast, the high-immersion group (KAT) reported a higher average estimated time (41.51 min), along with greater variability (SD = 16.81) (Figure 5). Although descriptive statistics indicated differences in estimated time across groups, this difference, according to Welch's ANOVA, was not statistically significant, $F(2, 42.88) = 1.08$, $p = 0.35$, $\omega^2 = 0.003$.

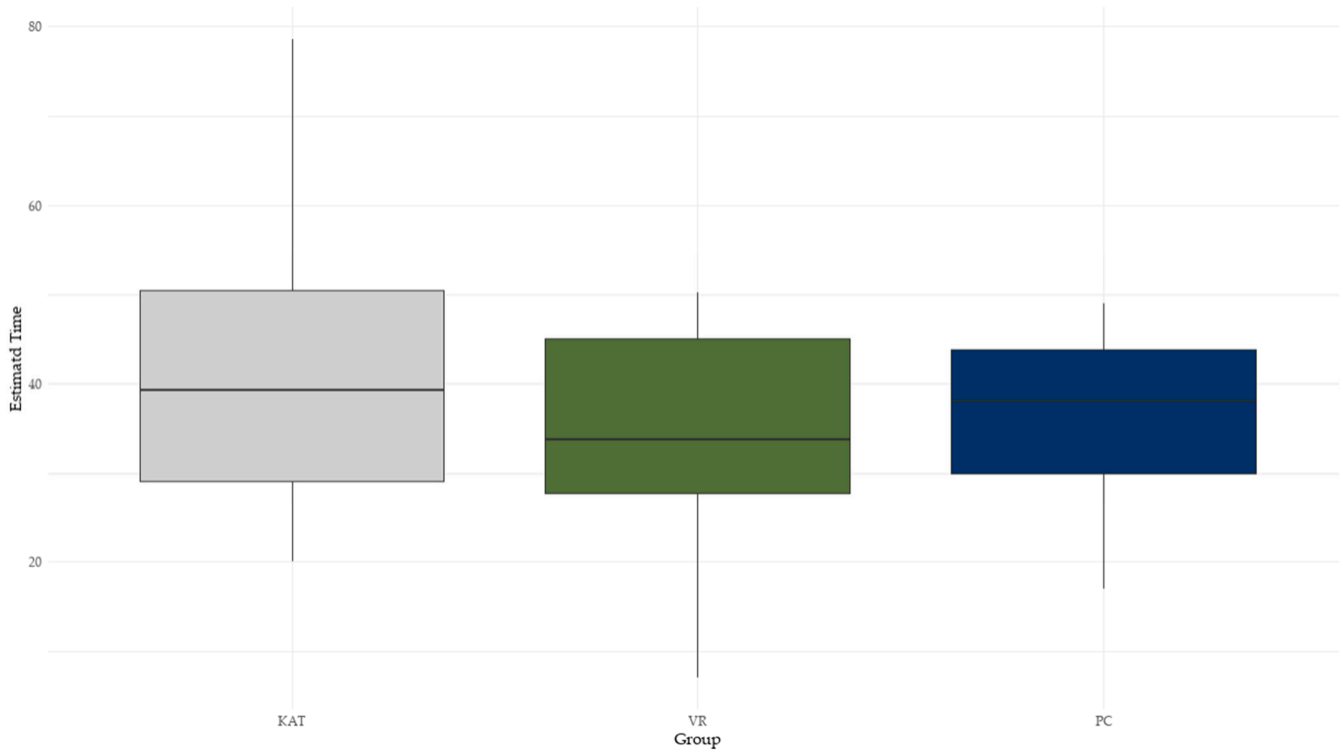


Figure 5. Boxplots showing retrospective time estimations for the 35 min gameplay session across experimental conditions (PC, VR, KAT). No statistically significant differences were observed between groups.

To assess time-estimation accuracy, the absolute error (i.e., the absolute value of the difference between estimated and actual time) was selected because it was independent of the direction of estimation bias. A square-root transformation was applied to normalize the distribution, resulting in data that met the assumptions of normality (Shapiro–Wilk

p = 0.076) and homogeneity of variance (Levene's test p = 0.106). A one-way ANOVA on the transformed absolute error revealed a significant effect of immersion condition, F(2, 69) = 5.269, p = 0.007, η^2 = 0.13 (see Figure 6). To examine the potential influence of cybersickness, a linear model including CSQ-VR as a covariate was estimated. The effect of the condition remained significant, F(2, 68) = 5.00, p = 0.009, ηp^2 = 0.13, whereas the CSQ-VR was not a significant predictor (p = 0.983, ηp^2 < 0.001).

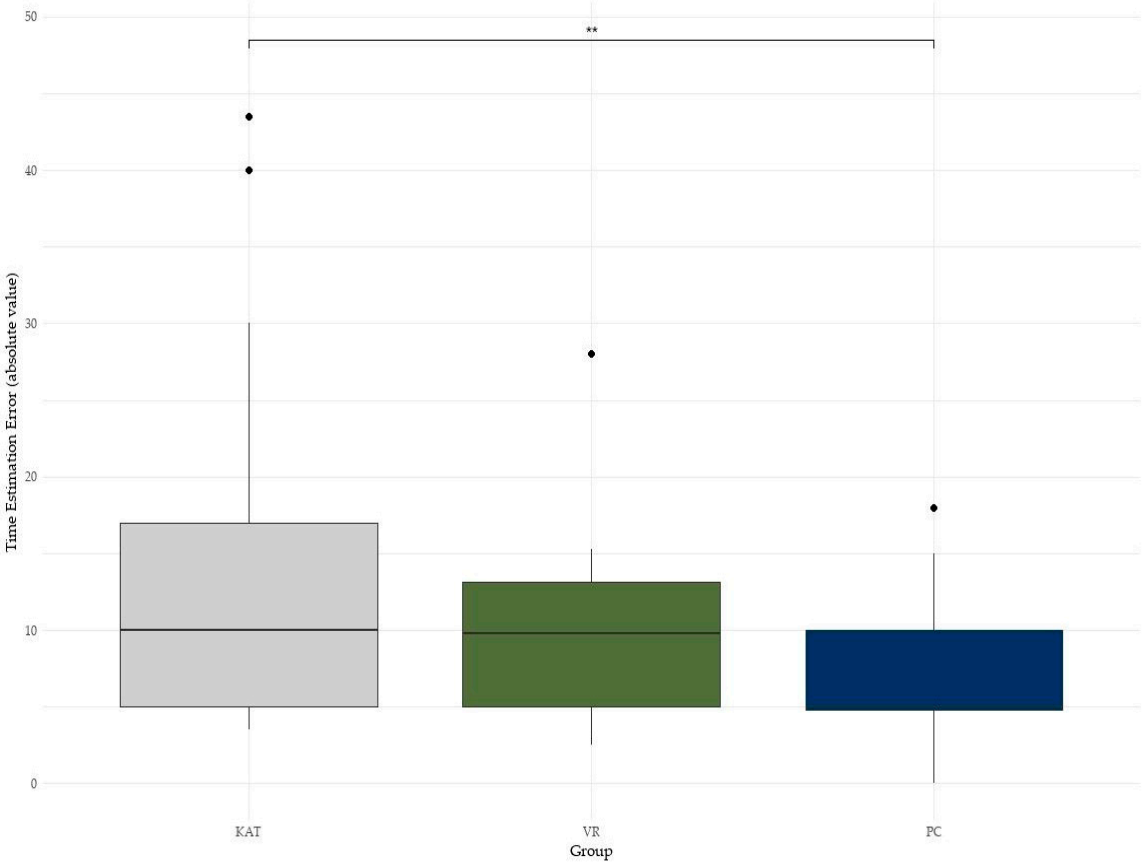


Figure 6. Boxplots showing absolute error in retrospective time estimation across immersion conditions (PC, VR, KAT). Absolute error represents the deviation from the actual gameplay duration (35 min), irrespective of under- or overestimation. Participants in the KAT condition showed significantly greater estimation errors than those in the PC condition (p = 0.005).

Tukey's HSD post hoc test indicated that participants in the high-immersion condition (KAT) had significantly greater estimation errors than those in the low-immersion condition (p = 0.005, Cohen's d = 0.85), while no differences were found between the other conditions.

Although the signed retrospective time-estimation error did not differ significantly between groups, it is reported in Figure 7 for exploratory completeness.

Beyond time-estimation accuracy, the modified version of the STSS questionnaire included two additional items to assess the perceived passage of time: (1) how frequently participants thought about time and (2) how fast time seemed to pass. Both were rated on a 10-point Likert scale.

For both items, tests revealed no significant differences between the three immersion conditions.

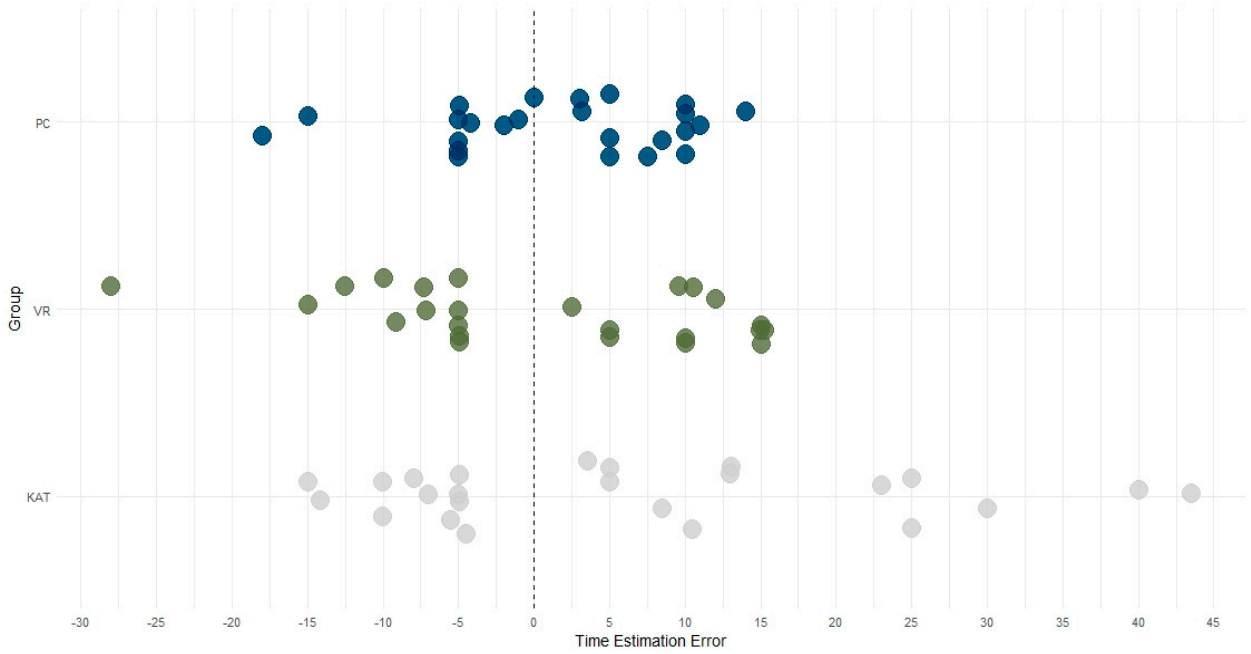


Figure 7. Scatterplot of signed retrospective time-estimation error across immersion conditions (PC, VR, KAT). Signed error was computed as estimated duration − actual gameplay duration (35 min), where negative values indicate underestimation and positive values indicate overestimation. The dashed vertical line marks zero errors.

3.3. Cognitive Flexibility

Cognitive flexibility was assessed using two tasks: the Stroop task and the AUT.

First, descriptive statistics were computed for participants' accuracy in the Stroop task (see Table 5).

Table 5. Mean accuracy rates in the Stroop task by experimental condition (PC, VR, KAT) and trial congruency (congruent, incongruent). Values represent the proportion of correct responses.

Condition	Congruency	Mean Accuracy
PC	Incongruent	0.934
	Congruent	0.962
VR	Incongruent	0.902
	Congruent	0.941
KAT	Incongruent	0.951
	Congruent	0.964

The Stroop effect was then calculated for each participant by computing the difference between the average reaction time (RT) for incongruent trials and that for congruent trials (see Figure 8).

$$\text{Stroop effect} = \text{RT}_{\text{incongruent}} - \text{RT}_{\text{congruent}}$$

Group-level means and standard deviations of RTs were calculated both overall and by congruency condition, as shown in Tables 6 and 7.

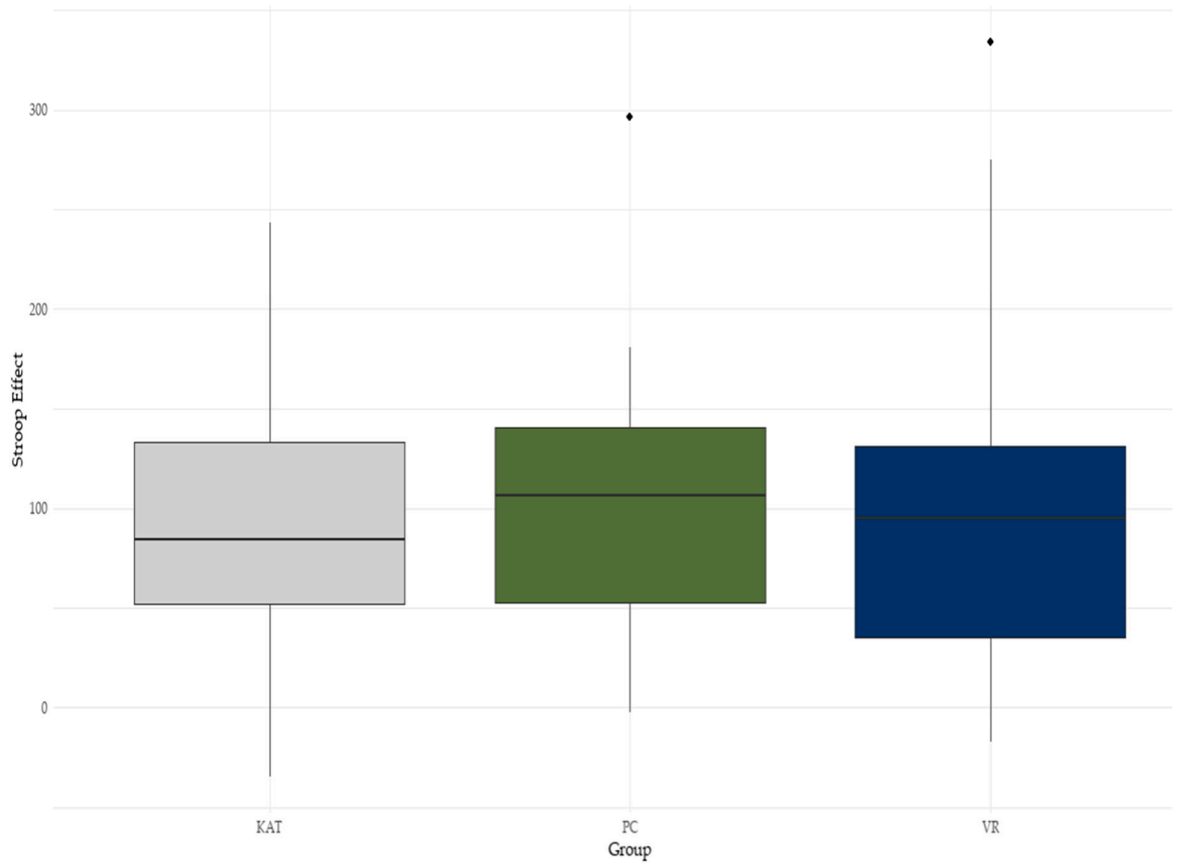


Figure 8. Boxplots showing the Stroop effect across immersion conditions (PC, VR, KAT), calculated as the difference between RTs for incongruent and congruent trials. No significant differences were observed between conditions.

Table 6. Overall mean RTs (in ms) by experimental condition (PC, VR, KAT). Values represent mean RTs across all trials, regardless of congruency.

Condition	Mean (SD)
PC	783.98 (283.25)
VR	790.47 (312.78)
KAT	787.31 (306.92)

Table 7. Mean RTs (in ms) by experimental condition (PC, VR, KAT) and trial congruency. Number of trials and standard deviations are reported for each condition.

Condition	Congruency	Number of Trials	Mean RT (SD)
PC	Incongruent	1977	805.03 (284.51)
	Congruent	663	721.21 (270.10)
VR	Incongruent	1983	814.16 (323.46)
	Congruent	657	718.97 (265.77)
KAT	Incongruent	1984	811.33 (314.85)
	Congruent	656	714.66 (269.03)

To assess the effect of immersion on task accuracy, performance was analyzed using a generalized linear mixed-effects model (GLMM) at the trial level, including experimental condition, congruency, and their interaction as fixed effects and random intercepts and slopes for congruency by participant. A significant main effect of congruency emerged

($\beta = -0.75$, SE = 0.32, $z = -2.36$, $p = 0.018$, OR = 0.47), confirming the expected Stroop effect. However, neither the main effect of condition nor the condition × congruency interaction reached significance (ps > 0.10), indicating that immersion level did not significantly modulate task accuracy.

RTs were analyzed using a linear mixed-effects model (LMM) on log-transformed trial-level RTs with the same fixed and random structure. The Stroop effect was robust ($\beta = -0.135$, SE = 0.017, $t = -7.84$), but no significant main effects or interactions involving condition were observed ($|t| < 1$). These findings indicate that immersion did not influence response speed nor the magnitude of the Stroop effect.

Given that the Stroop task automatically assigned a maximum response time of 2000 milliseconds to trials with missing responses, these trials could artificially inflate mean RTs. To address this, the linear mixed-effects model was re-estimated after excluding RT-capped trials. The results remained consistent, confirming a robust Stroop effect and the absence of significant effects of immersion condition.

Two separate scores were derived from the AUT: the mean creativity score per participant and the total number of responses provided. Descriptive statistics for both scores by group are presented in Table 8.

Table 8. Descriptive statistics for Alternative Uses Task (AUT) performance by experimental condition (PC, VR, KAT), including mean creativity score and mean number of responses per participant.

Condition	Mean Creativity Score	Mean Number of Responses
PC	2.23	19.6
VR	2.43	18.7
KAT	2.43	21.1

Each score was analyzed. Neither the mean score ($p = 0.3043$) nor the number of responses ($p = 0.246$) showed significant group effects. To create a composite flexibility score, the number of responses was multiplied by the participant's average creativity score. However, a one-way ANOVA on this flexibility score also revealed no significant differences among groups, $p = 0.431$.

Correlation analyses revealed several significant positive associations between immersion-related measures (IPQ and IEQ) and the selected 5D-ASC subscales. Specifically:

- IPQ scores and Altered Perception of Time and Space showed significant positive correlations in the low-immersion group ($\rho = 0.741$, $p < 0.001$) and in the medium-immersion group ($\rho = 0.628$, $p = 0.001$).
- IEQ scores and Positive Derealization were positively correlated in all immersion conditions (low: $\rho = 0.767$, $p < 0.001$; medium: $\rho = 0.540$, $p = 0.006$; high: $\rho = 0.458$, $p = 0.025$).
- IPQ scores and Positive Derealization showed significant positive correlations across all groups (low: $\rho = 0.748$, $p < 0.001$; medium: $\rho = 0.471$, $p = 0.020$; high: $\rho = 0.679$, $p < 0.001$).
- IEQ scores and Blissful State were positively correlated in all immersion conditions (low: $\rho = 0.463$, $p = 0.023$; medium: $\rho = 0.415$, $p = 0.044$; high: $\rho = 0.631$, $p = 0.001$).
- IPQ scores and Blissful State showed significant positive correlations in the low- ($\rho = 0.687$, $p < 0.001$) and high- ($\rho = 0.465$, $p = 0.022$) immersion groups.

4. Discussion

The present study investigated whether graded levels of immersion during a continuous videogame experience modulated subjective presence, ASC, time perception, and cognitive flexibility. More specifically, the study tested four hypotheses: that increasing immersion would enhance presence (H1), increase embodiment-related ASC dimensions (H2), increase retrospective time-estimation error (H3), and increase cognitive flexibility (H4). By

keeping the narrative content, duration, and task structure constant and manipulating only the mode of interaction and embodiment (from desktop play to head-mounted VR and VR combined with full-body locomotion), this design enabled a focused examination of how graded immersion-related manipulations were associated with conscious experience and post-experience cognition.

The results supported H1, showing that presence increased with immersion, although not uniformly across all contrasts. Presence, as measured by the IPQ, was selectively enhanced in VR relative to desktop play, whereas immersion, indexed by the IEQ, was highest in the VR plus treadmill condition. This pattern lines up with theoretical distinctions between place illusion (presence) and engagement or absorption (immersion), which are often correlated but not identical [54,55]. Standard VR appears sufficient to establish a compelling sense of "being there," whereas the addition of embodied locomotion further intensifies experiential involvement without necessarily increasing spatial presence per se.

Importantly, prior gaming experience did not account for these differences, indicating that the observed effects primarily reflected the experimental manipulation rather than familiarity or expertise. This suggests that immersion-related changes in conscious experience could emerge even in samples characterized by relative youth and variability in gaming experience.

The results provided partial support for H2. The ASC findings suggest a selective effect of immersion on altered experience. Although the overall 5D-ASC score did not differ significantly between groups, subscale-level analyses indicated that the more immersive conditions were specifically associated with changes in embodiment-related and self-related bodily experience. After correction for multiple comparisons across the ASC subscales, only disembodiment and positive depersonalization remained significant, indicating that the most robust subjective effects were concentrated in the embodiment-related dimensions specified in H2, rather than in a broad intensification of altered consciousness. By contrast, the effects on spiritual experience and positive derealization were significant only before FDR correction and were therefore better interpreted as exploratory trends rather than confirmed group differences. This more selective pattern strengthens the interpretation that immersive gameplay, particularly under conditions of heightened bodily engagement, primarily modulates self-related and embodied aspects of conscious experience. These findings are consistent with prior VR research emphasizing changes in body ownership, agency, and self-location and with recent work suggesting that VR-induced ASCs overlap phenomenologically with psychedelic states along specific dimensions while remaining more constrained and controllable [3,39,40]. The absence of effects on many ASC dimensions underscores an important boundary condition: naturalistic immersive gameplay induces structured and domain-specific alterations in consciousness rather than full-spectrum ASCs. This distinction is critical both theoretically and ethically, particularly when VR is discussed as a non-pharmacological analog of psychedelic experiences [3] or of highly evocative naturalistic settings (such as caves [4]).

The results supported H3, showing that greater immersion was associated with greater retrospective time-estimation errors. A central contribution of the present study, therefore, concerns the relationship between immersion and time perception. While subjective ratings of time passage did not differ reliably across conditions, participants in the highest immersion condition exhibited significantly greater retrospective time-estimation errors. This dissociation between the felt passage of time and accuracy of duration reconstruction is consistent with contemporary models distinguishing experiential and reconstructive components of temporal cognition.

Retrospective time estimation relies primarily on memory encoding, contextual change, and the density of stored events rather than on online temporal monitoring. Full-body

locomotion likely increased sensorimotor engagement and contextual variability, thereby reducing the availability of temporal markers for accurate post hoc reconstruction. From this perspective, an increased estimation error reflects disrupted temporal metacognition rather than a simple acceleration or deceleration of subjective time.

These findings refine common assumptions that immersion straightforwardly makes time "fly." Instead, immersive embodiment appears to impair memory-based duration reconstruction while leaving explicit awareness of temporal flow largely unchanged. This pattern is consistent with attentional and contextual models of retrospective timing and highlights the importance of distinguishing between different components of temporal experience in immersive environments.

The absence of differences in the perceived speed of time is consistent with the view that emotional and experiential factors, rather than the technological medium alone, contribute importantly to temporal distortion. Correlational analyses revealed consistent associations between immersion-related measures and ASC dimensions such as positive derealization and blissful states, suggesting that affective engagement mediated the relationship between immersion and temporal experience.

This interpretation is consistent with prior work showing that enjoyable or engaging experiences compress perceived duration, whereas boredom or frustration produce temporal dilation [34–37]. In immersive videogames, emotional valence and engagement may, therefore, play a more decisive role than immersion level alone, helping to explain inconsistencies in the VR time-perception literature [20,33,47].

Contrary to some expectations derived from the psychedelic and cyberdelic literature [56], H4 was not supported, namely immersion did not produce broad enhancements in cognitive flexibility. Reaction-time-based Stroop interference and divergent thinking measures were unaffected by condition.

The absence of effects on the AUT further indicates that brief, goal-directed immersive gameplay may be insufficient to induce measurable changes in divergent thinking. This contrasts with studies using explicitly psychedelic-like or contemplative VR experiences, which typically involve slower pacing, reduced task demands, and intentional introspection [3,44]. Together, these findings suggest that the cognitive consequences of immersion depend critically on experiential framing, pacing, and intentionality, not immersion alone. Importantly, given the study's sensitivity, the null findings for the AUT and Stroop interferences should be interpreted cautiously, as the design was powered to detect moderate effects, whereas smaller cognitive effects may have gone undetected.

Correlational analyses indicated that higher presence and immersion covaried with greater positive derealization and blissful states; in addition, the IPQ scores were positively associated with altered perception of time and space in the low- and medium-immersion conditions. These findings should be interpreted as correlational rather than causal: they indicate that immersion-related experience covaried with specific ASC dimensions but do not establish that presence or immersion directly produced them. At a theoretical level, this pattern is consistent with models in which presence reflects a shift in attentional and perceptual resources toward the virtual environment, accompanied by a relative attenuation of real-world contextual cues and habitual self-monitoring [18,57].

While the present study does not include neuroscientific measures and therefore cannot directly test neural theories, the findings may nevertheless be considered in relation to broader theoretical accounts of consciousness. From a predictive processing perspective, the present findings are more consistent with a selective rather than global alteration in high-level priors [58]. The strongest effects were concentrated in disembodiment and positive depersonalization, whereas total ASC scores, imagery-related dimensions, and post-experience executive measures showed limited or no change. This pattern suggests

that immersive gameplay primarily affected bodily self-location, embodiment, and environmental anchoring, while leaving broader cognitive organization relatively intact. A similar conclusion applies to the entropic brain framework [41]: the data do not indicate a generalized shift toward a globally altered or unconstrained conscious state, but rather a selective reshaping of specific experiential dimensions. Likewise, from the perspective of the global neuronal workspace theory [42], the findings are more compatible with a relative prioritization of bodily and self-related contents than with a broad change in conscious access.

Taken together, the findings show a differentiated pattern across the four hypotheses. H1 was supported, insofar as presence increased under more immersive conditions. H2 was partially supported, because immersion selectively affected embodiment-related ASC dimensions rather than producing a generalized increase across ASC measures. H3 was supported, as retrospective time-estimation error increased in the most immersive condition. H4 was not supported, since cognitive flexibility measures did not differ significantly across conditions. Overall, this pattern suggests that graded immersion primarily influences presence, embodiment-related experience, and temporal metacognition, while leaving broader post-experience executive functioning comparatively unaffected.

Several limitations warrant consideration. First, the between-subjects design, while minimizing carryover effects, limits sensitivity to subtle cognitive changes. More generally, given the sample size and resulting sensitivity, the study was well suited to detect moderate effects, but smaller effects—especially for null outcomes—cannot be excluded. Second, because attrition due to cybersickness was concentrated in the immersive conditions, especially VR and KAT, and descriptive comparisons suggested that non-completers differed somewhat from completers in baseline characteristics, the present findings are likely to generalize most directly to users who can tolerate immersive VR exposure. Third, the absence of neurophysiological measures precludes direct testing of mechanistic hypotheses derived from predictive processing or entropic brain models. Finally, the findings are necessarily constrained by the characteristics of the specific videogame used. An additional limitation is that the PC condition used a modded NoVR version of the game, whereas the immersive conditions used native VR; although the same gameplay segment and core events were maintained across conditions, subtle differences in interaction dynamics or comfort cannot be fully excluded. Another limitation is that we did not directly measure physical exertion. This is especially relevant for the treadmill condition, in which increased bodily effort may have contributed to the observed time-estimation error, independently of immersion itself. Future studies should include direct indices of exertion, such as perceived effort or heart rate.

Future studies would also benefit from combining immersive manipulations with within-subject designs, additional immersion-related manipulation checks (such as embodiment or agency measures), longitudinal follow-ups, and multimodal measures such as EEG, pupillometry, or autonomic indices. Moreover, comparing different videogames as well as contemplative or non-goal-directed VR experiences may clarify how intention and pacing shape ASC and cognitive outcomes.

5. Conclusions

This study shows that increasing immersion during videogame play enhances presence, selectively modulates embodiment-related dimensions of altered experience, and increases retrospective time-estimation error, without broadly altering executive function or creativity. These findings position immersive VR as a powerful yet constrained tool for experimentally probing altered consciousness, bridging ecological validity with theoretical rigor. Rather than functioning as a digital analog of psychedelic states in general,

immersive gameplay appears to selectively target the structure of self-experience, offering new avenues for research at the intersection of virtual worlds, consciousness science, and cognitive neuroscience. At the same time, these results raise important questions about the temporal dynamics of such effects. Although the altered-state-like changes observed here were measured as short-lived responses to a single session, future research should determine whether some effects persist beyond immediate exposure and whether repeated use of immersive VR leads to habituation, attenuation, or transformation of these responses over time. Clarifying the persistence and adaptability of VR-induced ASC will be important for both theory and the safe and effective use of immersive technologies in research and applied settings.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The datasets generated and analyzed during the current study are not publicly available because participants did not provide explicit written consent for their data to be shared on public repositories. Additionally, the dataset contains demographic information and detailed open-ended textual responses that could potentially compromise participant privacy. Data are available from the corresponding author upon reasonable request. This study was not preregistered.

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Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

ASC	Altered States of Consciousness
AUT	Alternative Uses Task
CSQ-VR	Cybersickness in Virtual Reality Questionnaire
DIAL	Digitally Induced Altered States of Consciousness
IEQ	Immersive Experience Questionnaire
IPQ	Igroup Presence Questionnaire
IRB	Institutional Review Board
PC	Personal Computer
RT	Reaction Time
SD	Standard Deviation
STSS	Subjective Time, Self, and Space
VR	Virtual Reality

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