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The Potential of Virtual Reality for Diagnosing Cognitive Functions in Adolescents with Autism: Empirical Study

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Abstract

Background. Adolescents with autism spectrum disorder often experience significant challenges during traditional cognitive assessments, including social communication difficulties, anxiety in unfamiliar environments, and sensory sensitivities that may compromise diagnostic accuracy. Virtual reality offers a promising alternative that could reduce stress and provide more precise evaluation of cognitive functions. This study compared performance on cognitive tasks across traditional paper-based, digital, and virtual reality environments.

Methods. Twenty-five adolescents with autism spectrum disorder (mean age 15.5 years; 19 males, 6 females) with varying cognitive functioning levels completed five cognitive tasks in three formats: paper-based, digital, and virtual reality. Tasks included Raven's Colored Progressive Matrices, Bourdon attention test, Visual Memory Test, Kohs Block Design Test, and Recognition of Overlapping Figures. Heart rate variability was recorded via electrocardiography during virtual reality immersion to assess psycho-emotional safety. Subjective experiences were evaluated using the Positive and Negative Affect Schedule and Likert-scale questionnaires. Data were analyzed using one-way analysis of variance.

Results. Heart rate variability analysis showed no significant differences across measurement phases (rest, passive virtual reality exposure, active roller coaster simulation), confirming that virtual reality immersion did not adversely affect psycho-emotional state. Performance on Raven's Matrices, Visual Memory Test, and Recognition of Overlapping Figures was comparable across all three formats ($p > 0.05$). However, the Bourdon Test and Kohs Block Test demonstrated significantly longer completion times in virtual reality ($p < 0.05$), attributed to difficulties with controller manipulation. All participants reported predominantly positive emotions and expressed strong interest in future virtual reality experiences.

Conclusions. Virtual reality is a safe and promising tool for cognitive assessment in adolescents with autism spectrum disorder, though tasks requiring precise motor control require adaptation or preliminary training. These findings support the development of virtual reality-based diagnostic models and expand understanding of cognitive processes in varied conditions. The approach shows potential for broader application with other populations with disabilities. Future research should include neurotypical comparison groups and adapt additional assessment tools for virtual reality formats.

Background

Autism spectrum disorder (ASD) refers to a group of complex developmental conditions marked by impaired social interaction and communication, as well as repetitive or stereotyped behavior. Individuals with ASD often experience difficulties in establishing social connections, recognizing visual objects, and using both verbal and nonverbal communication.

ASD also affects cognitive processes on various levels. For instance, adolescents with ASD frequently have difficulties with *joint attention*, which negatively impacts their social interactions (Jyoti, 2020).

Moreover, a combination of generally low mental energy and heightened sensory and emotional sensitivity contributes to an extremely low level of sustained attention. Common signs include rapid mental fatigue (with attention maintained for only a few minutes), difficulties in goal-directed activity, and instability of attention (for example, a teenager may switch from one task sequence to another without focusing on the meaning of the action). These attention processes are closely intertwined with *memory* functions.

Leo Kanner, a pioneer in autism research, was among the first to note the strong mechanical memory of children and adolescents with ASD (Aslanova, 2016): they often demonstrate a remarkable ability to memorize books, long poems, songs, and more. However, their memory is typically selective—they tend to retain emotionally significant events and objects, which makes those emotional experiences more enduring.

People with ASD may show relatively unimpaired performance on memory tasks compared to peers with similar cognitive development but without ASD (Bowler, 2011). Although adolescents with ASD can recall as many items as their neurotypical peers, they often struggle to remember the exact sequence after a single exposure. However, they may use their verbal skills to improve performance in sequential memory tasks (Bowler, 2016).

Adolescents and young people with autism often experience deficits in the spatial component of working memory (Bardyshevskaya, 2003). They may also show impairments in autobiographical memory, facial recognition, as well as prospective and associative memory for names and people. Interestingly, they tend to perform better on associative memory tasks involving animals and sounds (Bordignon, 2015).

In some cases, individuals with ASD may exhibit savant syndrome, marked by extraordinary abilities in one or more areas—such as music, visual arts, mathematical calculations, cartography, design, drawing, sculpting, or computer work—often accompanied by exceptional memory (Semyannikova, 2013; Tokarskaya, 2018).

Another distinctive feature of adolescents with ASD is difficulty in social functioning, which may include challenges with reciprocal interactions and problems with *interpreting or understanding the meaning of emotions* (Barendse, 2018).

Speech development in individuals with ASD can deviate from the norm both quantitatively (delayed speech development, limited vocabulary, sparse speech, and restricted use) and qualitatively (echolalia, disrupted grammar, and difficulty in using speech for communication).

Some children, however, may exhibit early and rapid speech development, which is more typical of Asperger's syndrome. They might recite long passages almost verbatim or use expressions typical of adult speech, yet still struggle to engage in productive dialogue. Understanding spoken language is often hindered by difficulties with interpreting figurative language, implied meanings, and metaphors.

Speech in individuals with ASD is often described as emotionally flat, monotonous, “mechanical,” and limited in terms of pace and volume. When intonation is present, it may sound unusual, exaggerated, or overly elaborate. One of the biggest challenges for people with ASD is recognizing and using intonational stress—that is, emphasizing certain words or phrases within a sentence (Mamokhina, 2017).

The development of verbal and nonverbal communication in individuals with ASD is significantly influenced by the specifics of their *sensory perception*. Even when sensory organs function normally, up to 90% of individuals with ASD exhibit various perceptual peculiarities—most notably in auditory, visual, and tactile processing—as well as reduced sensitivity to pain. These individuals often simultaneously experience both hypo- and hypersensitivity to stimuli. A common characteristic is the lack of selective attention to speech sounds. Difficulties in recognizing emotions in speech produced by human voices are also observed, although this tends to improve when both acoustic variability and voice variability are reduced (Duville, 2024).

Complex forms of sensory self-stimulation are another distinctive feature of perception in adolescents with ASD. Tactile and proprioceptive sensations from their own bodies are particularly significant. In response to persistent sensory discomfort, they often seek specific stimulating experiences by rocking their bodies, jumping, or spinning (Grigorenko, 2018).

Alongside certain limitations, individuals with ASD often exhibit a number of strengths that are closely tied to their willpower. They may show meticulousness, heightened attention to detail, strong visual memory, solid rote memorization skills, and a preference for routine tasks (Tyutyunnikova, 2019). When engaged in tasks that require sustained concentration and mental effort, they typically do not experience fatigue. On the contrary, they often become more immersed and focused as they continue working (Semyannikova, 2013). These characteristics are important to consider when interacting or working with individuals on the spectrum.

Adolescents with ASD often have different cognitive characteristics, experience significant communication challenges, difficulties with eye contact, and anxiety in unfamiliar environments, making traditional diagnostics challenging.

One of the key challenges for researchers is to shed light on how individuals with ASD approach cognitive tasks, as clinical cases of ASD often exhibit, to varying degrees, features associated with other types of atypical psychological development—most commonly, intellectual disability (Morozov S.A., 2016). “There is currently no commonly accepted view on the characteristics of intellectual development in individuals with ASD—opinions vary, sometimes to the point of being mutually contradictory” (Morozov S.A., 2016, p. 11). The need to clarify this issue, therefore, makes the task of assessment and interpretation of results particularly important (Morozov S.A., 2016).

It is important for the assessment process to be comfortable for the child. However, this can be challenging, as the child has to adapt to a new environment, interact with unfamiliar people, and establish effective communication. As a result, their performance may appear significantly lower than

their true abilities—especially when compared to results obtained in familiar or more comfortable settings. Additionally, performance can vary depending on how the material is presented.

Psychological assessment of cognitive functions still largely relies on traditional paper-based test methods, which are typically time-consuming to administer. Researchers often have to enter each data point manually, measure time by hand, and keep track of numerous other variables. Once the diagnostic procedure is complete, the results must be scored and only then interpreted—again, usually by hand. For the test to yield reliable data, it must be conducted under standardized conditions, with consistent instructions and strict timing. This rigidity often leaves room for human error. Moreover, for participants, such testing can be stressful and tedious, which potentially may distort the results due to anxiety or a drop in motivation.

In recent years there has been a growing global interest in developing alternative, automated testing formats to enable maximum standardization. Automation also opens the possibility of testing larger groups at once and doing so remotely, which would facilitate normative research. An additional advantage is the ability to capture various metadata, performance variations across different tasks, and other relevant variables. Adaptivity to each participant's ability level is also key, as it helps reduce unnecessary cognitive load and enhances the overall testing experience. This, in turn, can help maintain attention and motivation, making individuals more willing to participate in research and follow-up assessments. All of the above considerations have stimulated the development of digital testing technologies, but the question of comparability across different presentation formats still remains underexplored and requires further research.

A study examining the academic performance of children aged 7 to 8 across different areas of the curriculum using both paper-based and computerized testing found no significant differences in outcomes. At the same time, most children reported their preference for the computerized version over the traditional one (Sim, 2005). A Russian study explored the feasibility of administering both digital and traditional versions of P. Zelazo's Dimensional Change Card Sort across two participant groups while controlling for transfer effects. They found that digital versions of such tasks correlate well with their paper-based counterparts (Veraksa, 2023). The advantages of the digital format include saving time on instructions and preparing stimulus materials. However, not all assessment tools can be easily digitized, so greater caution is needed when selecting methods for digital adaptation. Digital versions of neuropsychological diagnostic methods developed by T.V. Akhutina demonstrate high reliability (Akhutina, 2017).

Researchers from the Department of Psychology at the University of Virginia have shown that there are assessment tools designed to evaluate cognitive development in adolescents that can be administered digitally without compromising data quality—and, in some cases, even capturing additional metrics (e.g., reaction time) (Vrana, 2017). Moreover, we can now track the administration and scoring process of each subtest, as well as broader clinical skills such as motivating the participant to act; features of

verbal and non-verbal behavior; responses to comments; and questions or non-verbal signals from the participant that are unrelated to the task.

A comparison between the tablet and paper versions of the test for basic mathematical skills (Mathematical Heidelberger Rechen Test, focusing on the arithmetic scales) showed that the modes of administration were comparable for the three arithmetic scales but unsuitable for the graphical counting scale, where tablet results were lower (Hassler Hallstedt, 2018). Arithmetic scales can potentially be transferred to a tablet format with good comparability and consistent test-retest reliability, but caution is needed when adapting graphical scales.

A study assessing executive functions in children with ASD also demonstrated equivalent results when comparing standard and computerized versions of tasks measuring planning and cognitive flexibility (Williams, 2013).

A growing body of research explores the use of virtual reality to support children and adolescents with ASD (Fornasari L., 2011; Wang M., 2014; Lahiri U., 2013; Kuriakose S., 2015; Didehbani N., 2016, among others). However, these studies primarily focus on therapeutic or educational applications rather than diagnostic use. Overall, the results obtained from digital and traditional assessment tools are largely comparable across many parameters. However, not all tools can be seamlessly adapted to a digital format. In cases where the assessment requires specific actions—such as recognizing speech or analyzing drawings—digital methods still fall short of traditional ones (Vrana, 2017). The challenge becomes even greater when working with individuals who have speech impairments or speak unclearly or rapidly. That said, new technologies powered by neural networks, which are increasingly capable of recognizing human speech, offer promising solutions to this problem.

Virtual reality technologies offer valuable opportunities for research, allowing for the design and repetition of experiments that would be dangerous, costly, or unfeasible in real-life conditions. They also enable the collection of precise behavioral data (Mado, 2022; Hakim, 2022). Moreover, VR allows users to interact with virtual objects without involving other people, which is especially important for adolescents with ASD. Given their difficulties with social interaction, communication, and emotion recognition, VR provides a safe, low-pressure environment where they can engage more comfortably.

VR tools used in psychological assessment typically comprise activities designed to closely simulate everyday life tasks—such as face recognition, identifying the location of objects, planning a trip, solving practical problems, or finding symbols on a map. These assessments most often target executive functions, attention, impulsivity, cognitive and motor inhibition, memory, learning capacity, and visuospatial skills (Negut, 2016). However, most psychological tests conducted in VR are not yet standardized. Looking at VR's potential applications in psychological research, authors often describe the virtual environment as an "ideal Skinner box"---a controlled setting capable of presenting a wide range of complex stimuli that are difficult to manage in the real world. This way we can study both cognitive processes (e.g., attention, thinking) and functional behavior (e.g., planning and initiating a sequence of necessary actions). These examples show the difference between stimulus presentation in

virtual reality and traditional experimental procedures: in VR, the participant reacts to stimuli while immersed in a larger, controllable virtual environment. In contrast, traditional experimental contexts may allow for stimulus control, but the surrounding environment often cannot be manipulated (Zborowska, 2024).

In the context of mental disorders, research has primarily focused on anxiety-related conditions (such as specific phobias and post-traumatic stress disorder), followed by the study of psychotic experiences, environmental factors influencing paranoia, and assessments of cognitive and social functioning in individuals with schizophrenia (Freeman, 2017). Another distinct group of studies is dedicated to the diagnosis of symptoms associated with mild cognitive impairment (MCI), Alzheimer's disease, and other age-related conditions. Automated tests offer more precise evaluations of individual cognitive abilities and enable effective monitoring of changes over time (Tan, 2022).

Roberts and his colleagues developed a customizable open-source virtual reality system called PSY-VR, designed to scale psychological testing in a modifiable VR environment (Roberts, 2019). To validate their concept, the researchers compared responses to a typical Flanker task administered in a real-life laboratory with those obtained in a carefully designed virtual lab. The results showed that responses collected in the VR environment were comparable to those from traditional tests, demonstrating the potential of virtual reality for psychological assessment research.

Overall, the most evident advantage of VR is its ability to present stimuli in three dimensions. Additionally, the use of VR helps achieve the following: reduce fear by lowering situational anxiety; make test materials more visually engaging; simplify the work of the examiner by minimizing routine tasks; ensure consistent testing conditions and reduce experimenter effects (thus improving ecological validity and reliability); record additional parameters (not only correct and incorrect answers, but also response times); increase engagement and motivation in children and adolescents through gamification; gain more opportunities for skill training and practice.

Given how quickly the technology is advancing—and how easily it can be integrated with physiological data—VR-based assessment is expected to become a promising tool for psychological evaluation. It offers the possibility of delivering controlled, low-cost assessments on a global scale. However, when designing virtual environments for individuals with ASD, it is important to keep in mind that the effects of VR are still not fully understood, even for typically developing individuals. There is evidence for potential side effects of VR use, such as motion-induced nausea (balance disturbances), light-induced seizures, physical injuries and fatigue from prolonged use, and general physical discomfort (Erik, 2015). Technical issues, cultural considerations, and psychological safety concerns also remain highly relevant (Gandhi, 2018).

Importantly, there are general contraindications for the use of virtual reality such as cardiovascular diseases, signs of epilepsy, a weak vestibular system, and migraines. There are also specific contraindications, including vision impairments that prevent users from following visual instructions in a

VR headset; memory, attention, or speech disorders that hinder effective interaction with a specialist; and severe intellectual disability.

Thus, despite the growing experience in using VR for diagnostic purposes, we need to consider how individual conditions may affect cognitive task performance and to choose appropriate visualization and interaction methods (Bystrova, 2019). Our analysis of research literature highlights several key gaps: limited studies on how individuals with ASD interact with VR; insufficient evidence on the types of environments that best support diagnostic and corrective tasks; and a shortage of diagnostic tools adapted specifically for this population. The rising prevalence of autism spectrum disorder (ASD)---now estimated to affect up to 1.5% of the population and as many as 1 in 68 children (Kim Y. S. et al., 2011) underscores the relevance of this study. Recent CDC data are even more striking: in the U.S., roughly 1 in 36 eight-year-olds is now diagnosed with ASD (Maenner, 2023). These numbers bring pressing challenges—how to ensure accurate diagnosis and support meaningful social integration of ASD children, particularly through education.

Methodology

Study Design and Setting

This was a quasi-experimental within-subjects study designed to compare cognitive task performance across three different presentation formats: traditional paper-based, digital, and virtual reality environments. The research was conducted at the Neurotechnology Research and Education Laboratory of Ural Federal University, named after the first President of Russia, B. N. Yeltsin (Ekaterinburg, Russia). The study protocol was approved by the Institutional Review Board of Ural Federal University. All procedures were conducted in accordance with the Declaration of Helsinki and relevant national regulations regarding research involving human participants. A power analysis was conducted to determine the minimum sample size needed to detect a medium effect size (Cohen's $d = 0.5$) with 80% power at $\alpha = 0.05$, resulting in a required sample of 25 participants, which was met with our final sample of 25 adolescents.

Participants

The sample included 25 adolescents diagnosed with ASD. Of these, one had mild intellectual disability, one had severe intellectual disability, and the remaining participants had typical cognitive functioning. The group consisted of 19 males and 6 females, with an average age of 15.5 years. All participants volunteered to take part in the study, had no history of epileptic activity, and met the necessary health criteria. Recruitment was carried out through an autonomous non-profit organization that supports individuals with ASD. Before the start of the study, the purpose, objectives, and procedures were thoroughly explained to the participants' parents. They were then asked to sign an informed consent form, agreeing to their child's participation and to the use of anonymized data collected during the study.

Parental consent and adolescent assent were obtained for all participants prior to enrollment in the study.

Materials and Equipment

Traditional Format

Printed test sheets, a pen, and Kohs blocks were used for paper-based administration.

Digital Format

Tasks were administered via computer or laptop. The Recognition of Overlapping Figures, Bourdon Test, and Visual Memory Test were completed using a Word document. Raven's Colored Progressive Matrices test was administered via the "Psychological Tests Online" website. Since a digital version of the Kohs Block Test was not available, this task was omitted in the digital format.

Virtual Reality Format: The stimulus materials consisted of cognitive task simulators specifically developed using the Unity cross-platform game development environment. The visual content was delivered through an HTC Vive VR headset. The setup included two controllers, two tracking stations, a computer, and a battery pack for the headset's autonomous operation. The custom VR simulator integrated the Bourdon correction test and Koos Cubes tasks, designed specifically for this study to parallel the traditional versions as closely as possible. Additional pre-existing simulators from the SteamVR platform were used for the physiological assessment phase: *Vermillion -- VR Painting* (for passive exposure) and *Epic Roller Coasters* (for active stimulation). These simulators were selected because they do not require mandatory use of handheld controllers, which would have interfered with physiological data collection.

Physiological Monitoring

Heart rate variability was recorded using electrocardiography (ECG) with three clip electrodes ("clamp" type) placed on the left and right wrists, with one serving as the ground. The NVX36 digital DC EEG amplifier transmitted data from the electrodes to the computer, and NeoRec software was used for data recording and subsequent processing.

Subjective Experience Measures

The Positive and Negative Affect Schedule (PANAS) and a Likert-scale questionnaire were administered to assess participants' subjective experiences during VR immersion.

Procedures

The study consisted of four stages:

Stage 1: **Physiological and Subjective Response Assessment**. Participants' responses to VR immersion were assessed using heart rate sensors, PANAS, and the Likert questionnaire. This stage involved three steps: first, participants' physical state at rest was measured using sensors for a 5-minute baseline period; second, they were immersed in virtual reality using a VR headset, without movement, using the *Vermillion -- VR Painting* simulator to help them adapt to the environment; and third, they experienced a short virtual roller coaster ride using *Epic Roller Coasters*, which offered a complete VR experience with intense stimulation. Each VR exposure lasted approximately 3–5 minutes. The order of these conditions was fixed for all participants to maintain consistency. After completing each task across all stages of the study, participants were asked about their condition. The adolescents reported feeling well and in a good mood.

Stage 2: Traditional Paper-Based Assessment. Adolescents with ASD performed cognitive tasks using traditional paper-based methods, administered through direct interaction with the researcher. A personalized experimental plan was created for each participant, ensuring a consistent and structured sequence of tasks. The materials used included printed test sheets, a pen, and Kohs blocks. Tasks were administered in the following order: Raven's Colored Progressive Matrices, Bourdon Test, Visual Memory Test, Kohs Block Test, and Recognition of Overlapping Figures. Standardized instructions were read aloud to each participant, and clarification was provided when necessary.

Stage 3: Digital Environment Assessment. Participants completed a digital version of the cognitive tasks on a computer. The sequence of tasks matched that of the previous stage, with the exception of the Kohs Block Test, which was omitted due to lack of digital adaptation. Participants were given brief tutorials on using the computer interface before task commencement. The same timing parameters and scoring criteria were applied as in the traditional format to ensure comparability.

Stage 4: Virtual Reality Assessment. We examined the feasibility of completing cognitive tasks in a VR environment. The sequence of tasks remained the same as in previous stages, with tasks presented through the custom Unity-based VR simulator. Participants received a 10-minute tutorial on using the HTC Vive controllers [1] before beginning the cognitive tasks.

At this stage, the sequence of tasks remained the same as in previous stages: Bourdon Test and Kohs Block Test were presented in VR format, alongside other tasks that had been successfully adapted.

Reward for Participation. As a reward for participation, each respondent was offered the opportunity to play any available virtual reality game from the Steam platform for up to 30 minutes after completing all study procedures. This incentive was consistent across all participants and was not contingent upon performance.

Statistical Analysis

Data were processed and interpreted using analysis of variance (ANOVA). Specifically, one-way repeated measures ANOVA was conducted to compare performance across the three testing formats (traditional,

digital, VR) for each cognitive task. Statistical analyses were conducted using SPSS version 26. Statistical significance was set at $p < 0.05$ for all analyses. Post hoc pairwise comparisons with Bonferroni correction were performed to identify specific differences between testing formats when omnibus ANOVA results were significant. We verified the data met statistical requirements and applied corrections where appropriate. For follow-up group comparisons, we adjusted our analysis to control for multiple comparisons. Heart rate variability data were analyzed using similar ANOVA procedures to compare across the three measurement phases (rest, passive VR, active VR). Effect sizes were calculated using partial eta-squared (η^2) values, with 0.01, 0.06, and 0.14 representing small, medium, and large effects respectively.

Results

Physiological Data Analysis Results

To process the data, we employed ANOVA; however, the recordings from two participants had to be excluded due to poor quality that made analysis impossible. No significant differences in heart rate variability were found across the three measurement phases for each participant (p-value > 0.05). The mean deviation across the three phases ranged from 0.725 to 0.759, and the standard deviation ranged from 0.061 to 0.078. Post hoc analysis also revealed no significant differences between the conditions in pairwise comparisons, with all p-values exceeding 0.05.

The absence of significant differences in heart rate variability (HRV) across the three stages—resting state, *Vermillion–VR Painting*, and *Epic Roller Coasters* --- indicates that immersion in VR did not affect the psycho-emotional state of adolescents with ASD. Thus, we can make a conclusion that VR is a safe method for this population (Fig. 3).

The effect size for the overall ANOVA model was small ($\eta^2 = 0.03$), suggesting minimal practical significance of VR exposure on autonomic arousal. It should be noted that the stimuli featured high-quality graphics, which may have contributed to the lack of differences in emotional response.

Interestingly, the average HRV value for *Epic Roller Coasters* was slightly elevated. This could be attributed to the nature of the simulation—a roller coaster ride is inherently stimulating, increasing adrenaline, heart rate, and consequently, HRV. However, no negative emotions or complaints of discomfort were reported, even during this more intense VR experience. Nonetheless, the inclusion of such emotionally charged elements in research procedures should be approached with caution.

Cognitive Function Assessment Results Across Three Environments

Bourdon Test Results. The results showed statistically significant differences in task completion time across the three different versions for each participant (p-value < 0.05). The ANOVA revealed a

significant main effect of testing format, F(2, 46) = 4.86, p = 0.010, η^2 = 0.17, indicating a medium to large effect.

Table 1
– ANOVA results for the *Bourdon Test*

Analysis of variance						
Source of variation	*SS*	*Df*	*MS*	**F**	*P-Value*	*F Critical*
Between groups	720,212744	2	360,1064	**4,863209**	0,010445	3,123907449
Within groups	5331,38921	72	74,04707			
Total	6051,60195	74				

Post hoc comparisons revealed that the VR format took significantly longer than the traditional format (p = 0.008(, while the digital format did not differ significantly from either traditional or VR formats after Bonferroni correction (p > 0.05). The analysis revealed significant differences in completion time between two specific stages—namely, the traditional version and the VR version—for each participant (p-value < 0.05).

Kohs Block Test Results. The presence of statistically significant differences in completion time for the Kohs Block Test was also observed, F (1, 23) = 8.82, p = 0.005, η^2 = 0.28, representing a large effect size. Post hoc analysis indicated significantly longer completion times in the VR format compared to the traditional format (p < 0.01).

Table 2
– ANOVA results for the *Kohs Block Test*

Source of variation	***SS***	***df***	***MS***	***F***	***P-Value***	***F Critical***
Between groups	1351,5320	1,0000	1351,5320	**8,8184**	0,0046	4,0427
Within groups	7356,579383	48	153,2620705			
Total	8708,111423	49				

The mean completion time in VR (M = 187.4 seconds, SD = 31.2) was approximately 40% longer than in the traditional format (M = 134.2 seconds, SD = 22.8). These findings can be explained by participants' need to adapt to using VR controllers, which can add extra time during task performance. This outcome indicates that our initial assumption—that this method would be well-suited for assessing cognitive functions in virtual reality—was incorrect. To address this issue, participants should be given more time to practice tasks in both VR and possibly in digital environments.

Recognition of Overlapping Figures, Visual Memory Test, and Raven's Colored Progressive Matrices Results revealed no significant differences in the number of correct answers across the three stages of data collection for each participant (all p-values > 0.05). For the Recognition of Overlapping Figures, F(2,

46) = 0.87, p = 0.43, η^2 = 0.04; for Visual Memory Test, F(2, 46) = 1.12, p = 0.33, η^2 = 0.05; for Raven's Matrices, F(2, 46) = 0.45, p = 0.64, η^2 = 0.02, all indicating small and non-significant effects. Mean accuracy rates across formats were consistently high (85–92% correct), suggesting stable performance regardless of presentation modality. It can therefore be concluded that VR immersion did not affect the performance of cognitive tasks by adolescents with ASD. Thus, the use of digital and VR versions of these methods is both appropriate and promising, on par with traditional formats. The results also suggest consistency across the different methods.

Questionnaire Results. The final phase of the study's first stage involved a subjective assessment of VR experience, using the PANAS scale and the Likert questionnaire. Due to emotional impairments commonly observed in individuals with ASD, participants completed the PANAS scale selectively and with the assistance of their parents.

Overall, the results show a predominance of positive emotional responses (selected items included: enthusiastic, joyful, energetic, interested, attentive). Most respondents reported experiencing these emotions to a "significant" or "very strong" degree. Only two participants reported negative emotions (scared, nervous), and only to a "slight" degree.

The Likert scale results were quite clear: all 25 respondents chose the answer "I really liked it and would like to try it again." Twenty participants answered positively to the question "Did you like the visuals and graphics you saw?" Five participants responded to the same question with "It was good, I liked it."

In addition, after the study was completed, we asked each respondent what they liked and disliked during the process. Overall, adolescents with ASD enjoyed being in the VR environment the most; some expressed an understanding that virtual reality is not the same as real life and described it as an interesting game. Some participants said that they found it easy to complete the tasks in all formats, although more time was needed to adapt to VR technologies. Others reported that they did not notice any difference when completing tasks across the three formats.

Thus, the survey showed that adolescents with ASD had a positive experience in virtual reality and all of them said they would like to try it again.

Discussion

Interpretation of Key Findings. The primary objective of this study was to evaluate the feasibility and effectiveness of virtual reality as a diagnostic tool for cognitive assessment in adolescents with ASD. Our findings provide mixed but promising support for this application. The absence of significant changes in autonomic arousal, as measured by heart rate variability, across resting state, passive VR exposure, and active VR stimulation, is a critical finding. This suggests that VR immersion does not induce undue psycho-emotional stress in this population, addressing a primary concern regarding the safety of VR-based assessment tools for individuals with sensory sensitivities and anxiety vulnerabilities. This finding aligns with previous research suggesting that controlled VR environments

can be well-tolerated by individuals with ASD (Newbutt et al., 2020). The slight increase in HRV during the roller coaster simulation, while not statistically significant, warrants cautious interpretation and suggests that dynamic, high-stimulation VR scenarios should be introduced gradually.

The cognitive performance data reveal a nuanced picture. For tasks measuring visual perception, reasoning, and visual memory (Raven's Matrices, Recognition of Overlapping Figures, Visual Memory Test), performance was statistically equivalent across traditional, digital, and VR formats. This consistency is crucial, as it demonstrates that the core cognitive constructs being measured remain stable regardless of presentation modality, supporting the construct validity of VR-based adaptations. This cross-modal stability is consistent with findings from Roberts et al. (2019), who demonstrated comparable results between real-world and VR-based psychological testing paradigms. These findings suggest that for certain cognitive domains, VR can serve as a viable alternative to traditional assessment methods, potentially increasing engagement without compromising measurement integrity.

Challenges with Motor-Dependent Tasks. In contrast, the Bourdon Test and Kohs Block Test demonstrated significantly prolonged completion times in the VR environment. This discrepancy appears to be related to the motor demands of VR controller manipulation rather than cognitive processing differences per se. Participants required additional time to coordinate their movements in the three-dimensional virtual space, which introduced a confounding motor component that is absent in paper-and-pencil or simple digital point-and-click versions. This finding highlights a critical consideration for future VR test development: tasks requiring fine motor control and precise spatial manipulation may require extensive practice trials to separate motor learning effects from cognitive processing speed. Our initial hypothesis that VR would enhance or at least not impede performance on spatial tasks (like Kohs Blocks) was not supported, likely because the interface created a dual-task scenario (motor coordination + cognitive problem-solving) that increased cognitive load.

Positive User Experience and Clinical Implications. The uniformly positive subjective responses across all participants, including those with mild intellectual disabilities, are encouraging. The high degree of enjoyment and interest in repeat VR exposure suggests that this modality may improve compliance and reduce test-taking anxiety in clinical settings. This is particularly relevant for longitudinal assessments where participant motivation is essential for reliable data collection. The fact that even participants with intellectual disabilities could successfully complete VR tasks after brief training suggests that VR accessibility may be broader than anticipated, though individual customization will remain necessary. The clinical implication is that VR assessment batteries could be developed with built-in practice modules to familiarize users with the interface before formal testing begins, thereby reducing motor-related confounds.

Limitations .Several limitations must be acknowledged. *First*, the sample size of 25 participants, while adequate for detecting medium to large effects, limits generalizability and precludes subgroup analyses based on cognitive functioning level or specific ASD presentation. *Second*, the heterogeneous cognitive profiles of participants (ranging from severe intellectual disability to typical cognitive functioning) may

have introduced variability that masked subtle effects, though we attempted to control for this through within-subjects design. *Third*, the absence of a neurotypical control group prevents us from determining whether the observed effects (particularly the motor slowing in VR) are specific to ASD or represent a general learning curve phenomenon that would be observed in any population new to VR technology. *Fourth*, potential practice effects, despite counterbalancing attempts, could have influenced performance improvements across formats, though the consistent ordering (traditional → digital → VR) may have actually disadvantaged the VR condition by introducing fatigue effects. *Fifth*, the reliance on parent-assisted completion of affect measures may have introduced reporting bias, though this was necessary given the emotional recognition challenges common in ASD. *Sixth*, we did not control for prior gaming or technology experience, which could have moderated the speed of VR adaptation. *Seventh*, the VR environments, while designed to be sensory-friendly, were not individually customized to each participant's specific sensory profile, which may have affected performance in ways not captured by our general HRV measures. *Finally*, the study examined short-term VR exposure only; the effects of longer assessment sessions remain unknown.

Strengths and Future Directions. This study possesses several notable strengths. The within-subjects design controls for individual differences in cognitive ability, while the inclusion of multiple cognitive domains provides a comprehensive evaluation of VR's potential. The simultaneous assessment of physiological arousal and subjective experience offers a multi-modal validation of VR safety and acceptability. The successful engagement of participants across the cognitive functioning spectrum demonstrates real-world feasibility.

Future research should prioritize several areas. First, replication with larger, more homogeneous samples and inclusion of neurotypical controls is essential to establish normative parameters. Second, development of standardized practice protocols for VR motor control is needed to separate interface learning from cognitive processing. Third, investigation of individually-tailored VR environments that match specific sensory profiles could optimize performance. Fourth, exploration of eye-tracking and other embedded metrics could enhance the diagnostic yield beyond traditional accuracy measures. Fifth, examination of VR's utility for tracking cognitive changes over time in intervention studies would establish its value for outcome measurement. Finally, development of a standardized VR cognitive assessment battery specifically validated for ASD populations, with robust psychometric properties and clinical cut-offs, remains the ultimate goal toward which this research contributes.

Conclusion

The study revealed that virtual reality is an effective and promising technology for working with adolescents with ASD. However, it requires methodological refinement and rigorous evaluation of its effectiveness. Some methods, such as the Bourdon Test and Kohs Block Test, may not be well-suited for diagnostic use in virtual reality, as it is difficult to accurately account for task completion time—an issue that partly challenges our initial hypothesis. However, this limitation can be addressed by providing participants with preliminary training in using VR controllers.

The results of the Recognition of Overlapping Figures, Raven's Colored Progressive Matrices, and Visual Memory Test in both digital and VR formats were consistent with those obtained in the traditional versions of these methods. Therefore, these tools can be considered appropriate for diagnostic work with adolescents with ASD. The lack of significant changes in ECG readings among adolescents with ASD during VR immersion suggests that VR does not negatively affect their psycho-emotional state. This finding supports our conclusion that the method is safe for this group and confirms our second hypothesis.

In addition, survey responses reflect a generally positive impression of the VR experience. Notably, even participants with mild intellectual disabilities were able to successfully complete tasks in the VR environment, which points to the broader potential of this approach. The simulator developed as part of this study can be used for future research with other participant groups. The successful development and initial validation of this VR assessment platform provides a foundation for creating more comprehensive, ecologically valid diagnostic tools that may ultimately improve clinical care and educational planning for individuals with ASD.

Declarations

Contribution of the authors. The authors contributed equally to collecting empirical data, processing data, and writing the article.

Conflict of interest statement. The authors declare that there is no conflict of interest.

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Author Contribution

The authors contributed equally to collecting empirical data, processing data, and writing the article. L.V.T., R.V.U., and N.K. designed the study methodology and contributed equally to empirical data collection, data processing, and manuscript preparation. L.V.T. supervised the research and provided expertise in autism spectrum disorder assessment. R.V.U. coordinated participant recruitment and conducted clinical evaluations. N.K. developed the VR simulators, performed statistical analyses, and served as corresponding author. All authors reviewed, edited, and approved the final manuscript. Statement on the use of AI: During the preparation of this work, the authors used KIMI.AI to translate the text from Persian to English and modify the English text. After using this service, the authors review and edit the content if necessary and take full responsibility for the content of the publication.

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39. Contribution of the authors. The authors contributed equally to collecting empirical data, processing data, and writing the article.

Footnotes

1. HTC Vive controllers are handheld, motion-tracked input devices that enable precise interaction with virtual environments by translating users’ hand movements and button inputs into real-time actions within VR systems.

Figures

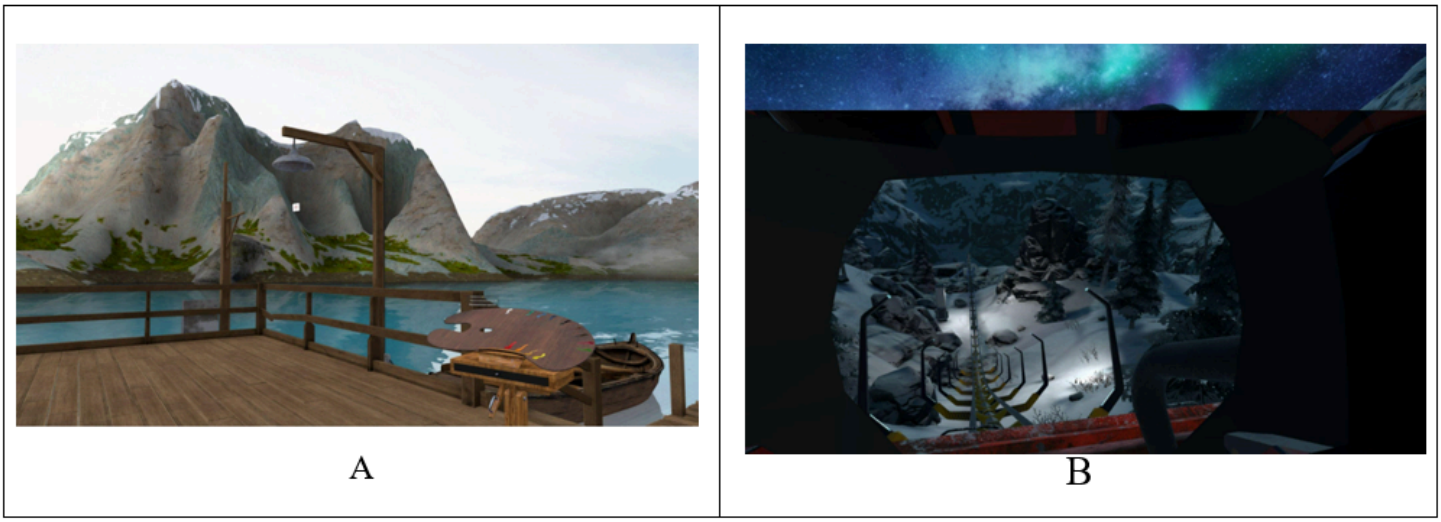


Figure 1

A – screenshot from the *Vermillion – VR Painting* simulator, “Veranda” location, mountain view; B – screenshot from *Epic Roller Coasters*, view of the “coaster.”

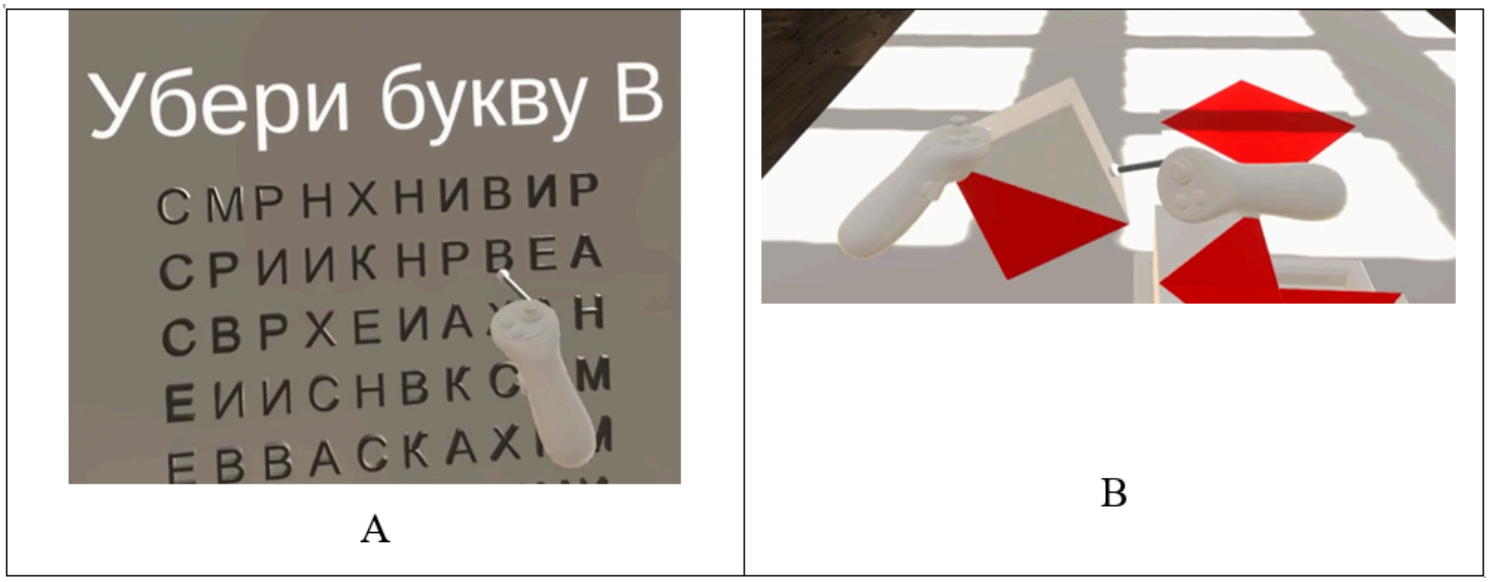


Figure 2

A – screenshot of the Bourdon Test; B – screenshot of the Kohs Block Test.

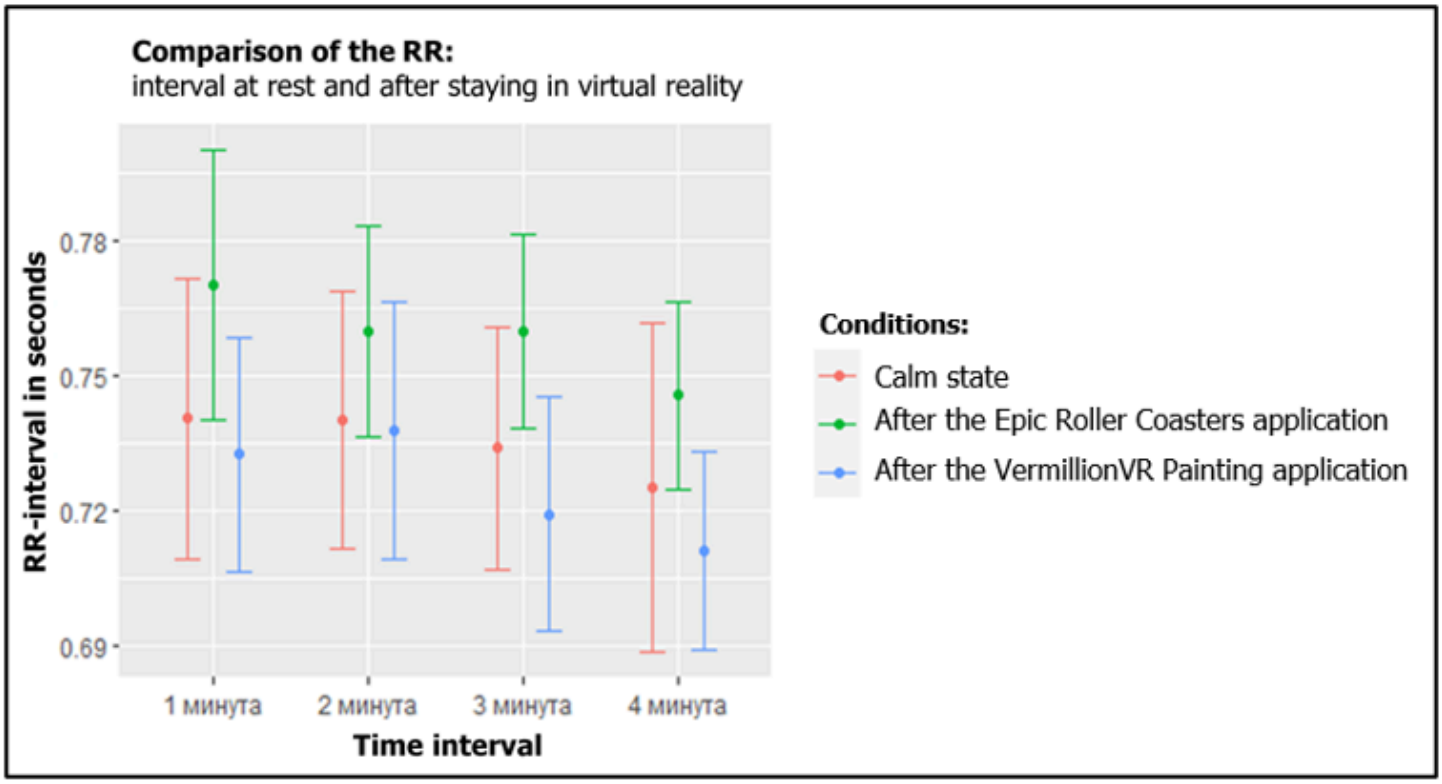


Figure 3

Graphical representation of ANOVA results for heart rate variability across three measurement phases.