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Effectiveness of Virtual Reality on Theory of Mind in Children with Autism Spectrum Disorder

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A B S T R A C T

The present study was conducted with the aim of examining the effectiveness of virtual reality on theory of mind in children with Autism Spectrum Disorder (ASD). The research design was quasi-experimental with a pretest–posttest structure and a control group. The statistical population consisted of all children with ASD in the city of Arak in 2025. The sample included 30 children aged 7 to 12 years diagnosed with ASD, who were purposively selected through clinical file review and diagnostic confirmation by a specialist in neurodevelopmental disorders or a child psychiatrist. The children were then randomly assigned to two groups of 15: experimental and control. First, theory of mind in both groups was assessed using the Stierman Performance Test (pretest). The experimental group then received a virtual reality intervention for 15 sessions, each lasting 35 minutes, delivered twice per week. After completion of the intervention, theory of mind in both groups was reassessed using the Stierman Performance Test (posttest), followed by a two-month follow-up assessment to evaluate treatment stability. Data were analyzed using repeated-measures analysis of variance with both between-group and within-group factors. The findings indicated a statistically significant difference between the experimental and control groups in theory of mind ($p < .05$). The results demonstrated that virtual reality is effective in improving theory of mind in children with ASD.

Keywords: *Virtual reality, theory of mind, Autism Spectrum Disorder (ASD)*

1. Introduction

Autism Spectrum Disorder (ASD) is a neurodevelopmental condition characterized by persistent difficulties in social communication, impaired social reciprocity, restrictive patterns of behavior, and challenges in understanding others' mental states, commonly referred to as theory of mind (ToM). The core impairments associated with ASD have profound implications for children's interactions, emotional understanding, and capacity to interpret social cues in everyday environments. According to recent advances in clinical research, conceptualizations of ASD increasingly emphasize deficits in social cognition, including difficulties in emotion regulation and perspective taking, as foundational mechanisms contributing to the disorder's behavioral manifestations (Qin et al., 2024). The rapid evolution of technological approaches to assessment and intervention has expanded the possibilities for addressing these deficits, particularly through virtual reality (VR), which creates controlled, immersive, and repeatable simulations of social scenarios relevant to ToM development. As a result, VR-based interventions represent one of the most promising contemporary avenues for enhancing ToM and related social-cognitive skills among children with ASD (Zhang et al., 2022).

Understanding emotional processes is a crucial component of ToM. Emotional recognition, differentiation, and contextual interpretation are often impaired in ASD, limiting children's ability to respond appropriately to social stimuli (Conner et al., 2023). Emotional dysregulation is highly prevalent in this population, and its associations with internalizing symptoms such as anxiety and depression highlight the importance of early interventions that target emotional understanding within social contexts. Advances in VR research have demonstrated promising outcomes in enhancing emotion recognition and emotional regulation through immersive experiences that simulate realistic interpersonal encounters (Colombo et al., 2021). VR-based mood induction, for example, reveals that individuals' neural responses to emotional events can be reliably assessed during simulated environments, providing opportunities for sustained and progressive emotional training (Rodríguez et al., 2015). These findings underscore the potential of VR not only as a therapeutic tool but also as a methodological framework for examining the emotional underpinnings of ToM.

A central challenge in ASD is difficulty with attention allocation and processing of social cues. Meta-analytic evidence shows that individuals with heightened anxiety display threat-related attentional biases, which interfere with cognitive processing during complex social interactions (Bar-Haim et al., 2007). Although this research has mainly targeted anxious populations, similar attentional patterns are often observed in ASD, where atypical perceptual styles can impair the recognition of social information. Research using the emotional Stroop paradigm suggests that emotional stimuli tend to produce a general slowdown in cognitive processing across populations, indicating that emotional distractibility is a robust mechanism affecting social functioning (Algom et al., 2004). VR allows such attentional and emotional processes to be examined in ecologically valid yet controlled environments, enabling more precise insights into the attentional mechanisms that underlie ToM deficits (Dubovi, 2024).

The integration of VR into interventions for ASD has expanded significantly over the last decade. One influential line of research demonstrates that immersive VR environments can effectively enhance social orientation, emotional understanding, and adaptive social behavior in children with ASD (Ip et al., 2018). These interventions frequently include simulations of real-world emotional exchanges, interactive avatars, and perspective-taking tasks designed to strengthen ToM skills. Building on these findings, Yuan and Ip (Yuan & Ip, 2018) showed that VR can effectively train emotional and social skills when traditional behavioral methods fall short. Similarly, Didehbani and colleagues (Didehbani et al., 2016) demonstrated significant improvements in social cognition and conversation skills among high-functioning children with ASD following VR-based training, including increases in eye contact, emotional labeling, and pragmatic communication competence.

The ability of VR to enhance emotional learning is supported by its immersive characteristics, which activate both behavioral and physiological systems. According to VR exposure research, the mechanisms of therapeutic change involve behavioral activation, inhibition, and emotional processing in contexts that replicate real-world stimuli more accurately than two-dimensional interventions (Wilhelm et al., 2005). This embodied experience allows children with ASD to practice ToM-relevant skills—such as inferring intentions, identifying emotional cues, and interpreting situational ambiguity—within safe, structured virtual contexts. Numerous systematic reviews support the role of

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VR in improving social skills and emotional competencies among autistic children (Bravou et al., 2022; Glaser & Schmidt, 2022). These reviews emphasize that VR interventions are especially effective when they incorporate multi-sensory feedback, repeated practice opportunities, and adaptive difficulty levels tailored to each child's developmental profile.

Several empirical studies further highlight the strengths of VR in reinforcing ToM skills. For example, Lorenzo and colleagues (Lorenzo et al., 2016) created an immersive VR system aimed at improving emotional skills in autistic children and found significant gains in emotion recognition and social engagement. Similarly, Frolli et al. (Frolli et al., 2022) documented improvements in social skills and greater generalization to real-world behaviors when VR scenarios simulated everyday social interactions. These findings parallel work by Mohamed Aly et al. (Mohamed Aly et al., 2024), who demonstrated how emotionally charged VR tasks influence cognitive processes such as spatial navigation and decision making. In addition, VR-based interventions have been shown to influence children's inhibitory control, which plays a central role in processing others' beliefs and intentions—components integral to ToM (Dina et al., 2025). Because inhibitory control underlies flexible thinking and the ability to suppress egocentric assumptions, VR tasks that strengthen inhibition can indirectly enhance ToM performance.

Other studies underscore the practical advantages of VR in creating ecologically valid diagnostic and therapeutic contexts. Donahue and Shrestha (Donahue & Shrestha, 2019) developed VR-based tasks that measure response inhibition during stressful and neutral situations, illustrating the precision of VR platforms in capturing neurocognitive performance. Complementary findings by Rocabado and Duñabeitia (Rocabado & Duñabeitia, 2022) show that VR paradigms effectively assess inhibitory control in real-world environments, further validating the use of VR as a diagnostic complement to ToM assessments. Meanwhile, Savickaite et al. (Savickaite et al., 2021) explored how VR headsets influence visual processing styles—an important consideration given that atypical perceptual patterns in ASD may affect ToM development.

Beyond ASD, VR interventions have demonstrated benefits for diverse clinical populations, offering insight into how immersive environments facilitate emotional, cognitive, and social learning. Carballo-Marquez et al. (Carballo-Marquez et al., 2025) showed that VR-based training significantly improved emotional regulation and cognitive functioning in adolescents at risk of executive dysfunction. A similar pattern emerged in ADHD interventions: Martin-Moratinos and colleagues (Martin-Moratinos et al., 2025) found that VR-based video games enhanced emotional regulation and reduced behavioral difficulties. These results complement findings from behavioral psychology demonstrating that virtual exposure can reduce anxiety symptoms and social distress by modulating behavioral activation systems (Cavallo et al., 2024; Nazemi et al., 2019). Taken together, these studies suggest that VR fosters emotional learning and behavioral adaptation across a range of neurodevelopmental and psychological conditions.

The use of VR is also increasingly supported by research on learning and educational outcomes. Meta-analytic evidence indicates that VR significantly enhances learning performance, engagement, and cognitive processing in children, particularly those in early education settings (Villena-Taranilla et al., 2022). Similar findings have been reported in clinical educational research, where VR-based cognitive rehabilitation improved executive functions among children with neurodevelopmental disorders (Barati et al., 2021). In the context of motor and perceptual development, Alizadeh et al. (Alizadeh et al., 2024) found that VR exercises enhanced motor proficiency among neurotypical and developmentally delayed children, demonstrating VR's broad applicability in child development interventions. Furthermore, VR-based serious games have been increasingly used to support emotional resilience and cognitive flexibility in both clinical and educational contexts (Marchena-Giráldez et al., 2024; Tjiptono, 2024).

Research on ASD-specific treatments also highlights the importance of embedding emotional and social learning into intervention models. Parents and therapists play a significant role in shaping early emotional development, and recent interventions have emphasized parental participation in reducing maladaptive behaviors among autistic children (Jafari et al., 2022). Similarly, emotional regulation training among parents has been shown to improve emotion management strategies within families of children with ASD (Safarpour & Ashouri, 2024). These parental programs complement child-focused VR interventions by targeting the emotional and behavioral environment in which autistic children learn. Additionally, psychological research indicates that faulty attention patterns and biases toward threatening social stimuli can interfere with children's social learning processes (Conner et al., 2023). VR offers a mechanism through which these patterns can be safely addressed, monitored, and modified in structured scenarios.

Advances in VR design have also contributed to its growing utility for ASD interventions. Systematic reviews highlight specific design principles required for successful implementation, such as avatar realism, emotional clarity, adaptive feedback, and opportunities for generalization to real-world settings (Glaser & Schmidt, 2022). New technologies, including stereoscopic 3D simulations, immersive soundscapes, and interactive object manipulation, provide ASD learners with opportunities to practice ToM-relevant tasks in ways that align with their sensory and cognitive profiles. Furthermore, collaborative VR environments hold potential for more interactive and socially contingent ToM training, incorporating peer-based communication tasks that mirror naturalistic social experiences (Colombo et al., 2021).

Taken together, this body of evidence supports the integration of VR-based training into interventions designed to improve theory of mind among children with ASD. VR's capacity to simulate complex social environments, elicit emotional responses, and structure interpersonal situations offers unique advantages for teaching mental state understanding, perspective taking, and emotion recognition—skills that traditional didactic interventions often struggle to teach effectively (Cihak et al., 2012; Donahue & Shrestha, 2019). Moreover, the growing clinical, developmental, and educational evidence base demonstrates that VR interventions are not only feasible but also effective across diverse populations and cognitive domains.

Therefore, the aim of the present study is to examine the effectiveness of virtual reality training on improving theory of mind in children with Autism Spectrum Disorder.

2. Methods and Materials

2.1. Study Design and Participants

The present study employed a quasi-experimental design with a pretest–posttest structure and a control group. The statistical population consisted of children with Autism Spectrum Disorder (ASD) in the city of Arak in 2025. The sample included 30 children aged 7 to 12 years with ASD, selected purposively based on clinical file review and diagnostic confirmation by a child psychiatrist or a psychologist specializing in neurodevelopmental disorders. The participants were then randomly assigned to two groups of 15: experimental and control. Inclusion criteria consisted of a confirmed diagnosis of ASD, age between 7 and 12 years, absence of other severe psychiatric disorders, and absence of severe sensory or motor impairments. Exclusion criteria included lack of cooperation from the child or family, and missing more than two intervention sessions.

At the beginning of the study, theory of mind in both groups was assessed using the Stierman Performance Test (pretest). The experimental group then participated in a virtual reality intervention across 15 sessions, each lasting 35 minutes, delivered twice weekly, while the control group continued their regular activities in their centers or schools and did not receive any specific intervention. The virtual reality intervention was implemented in an interactive environment designed using Unity software and executed via an Oculus Quest 2 headset. The program included emotional and social scenarios such as peer interaction, mindreading tasks, exposure to anxiety-provoking situations, and neutral stimuli. In each session, the child entered the virtual environment using the headset, and the researcher monitored performance online and provided guidance when necessary. After the intervention, both groups were reassessed using the Stierman Performance Test (posttest), followed by a two-month follow-up assessment to evaluate the durability of the intervention effects.

2.2. Measures

The Theory of Mind Test was developed by Stierman (1999). The original version of this test was designed to assess theory of mind in typically developing children and those with pervasive developmental disorders aged 5 to 12 years, providing information about the breadth of social understanding, sensitivity, insight, and the extent to which a child is able to recognize and adopt the emotions and thoughts of others. The questionnaire consists of 38 items and three subscales as follows:

a) First subscale: "Basic Theory of Mind"—that is, first-level theory of mind involving emotion recognition and pretend play, consisting of 20 items.

b) Second subscale: "Initial Expression of a True Theory of Mind"—that is, second-level theory of mind involving first-order false belief comprehension, consisting of 13 items.

c) Third subscale: "More Advanced Aspects of Theory of Mind"—that is, third-level theory of mind involving second-order false belief comprehension or understanding humor, consisting of 5 items.

Qamerani, Alborzi, and Kheir reported concurrent validity of the test through its correlation with the Dollhouse

Task at .89, significant at the .01 level. Correlations between the subscales and the total score were also significant in all cases, ranging from .82 to .96. Reliability was examined through test–retest, Cronbach's alpha, and inter-rater reliability coefficients. Test–retest reliability ranged from .70 to .94, with all coefficients significant at $\alpha = .01$. Internal consistency using Cronbach's alpha for the total test and each subscale was .81, .80, .72, and .86, respectively. The inter-rater reliability coefficient was .98.

2.3. Intervention

The virtual reality intervention protocol consisted of 15 individual sessions of 35 minutes each, designed based on principles of gradual exposure, mindreading skill training, and generalization to real-world contexts, with the overarching goal of enhancing children's ability to use theory of mind in social interactions, communication, and everyday situations. Each session followed a fixed structure, including (1) preparation and explanation of session goals (5 minutes), (2) implementation of VR scenarios (25 minutes), and (3) debriefing and summarizing (5 minutes). Session content progressed from basic familiarity with VR equipment and anxiety reduction through interaction with safe virtual objects (Session 1), to recognition of basic emotions such as happiness, sadness, anger, fear, surprise, and disgust using avatars and emotionally charged scenarios (Sessions 2–5). Subsequent sessions targeted understanding differences in perspectives, predicting what an avatar sees (Session 6), identifying secondary emotions such as pride, shame, jealousy, and gratitude (Sessions 7–8), and distinguishing accidental versus intentional actions (Session 9). More advanced sessions integrated social problem-solving, combining perspective-taking with secondary emotions (Session 10), followed by classical false-belief tasks such as the Sally–Anne scenario involving object relocation (Session 11) and appearance–reality conflicts using deceptive containers (Session 12). Higher-order mindreading skills were addressed through scenarios involving humor, intention recognition (Session 13), and simple deception where children analyzed motives and distinguished truth-telling from lying (Session 14). The final session (Session 15) involved complex, integrative social scenarios requiring simultaneous use of all previously learned mindreading skills, serving as a comprehensive review and an assessment of overall progress.

2.4. Data analysis

Data were analyzed using repeated-measures analysis of variance with both between-group and within-group factors in SPSS.

3. Findings and Results

Demographic findings of the study showed that among the 30 children participating in the experimental and control groups, the highest frequency belonged to 8-year-old children, such that 46.7% of the children in both groups were in this age range. In the experimental group, the lowest number of children were aged 6 and 9 years (13.3%), whereas in the control group, the lowest frequency was observed at age 6 (6.7%). Examination of fathers' occupational status indicated that in both groups, most fathers were self-employed, with 73.3% in the experimental group and 60% in the control group reporting self-employment, while the lowest frequency belonged to fathers who were employees. Likewise, findings regarding mothers' occupations showed that in both the experimental and control groups, the majority of mothers were homemakers, with 53.3% in the experimental group and 73.3% in the control group being homemakers, whereas a smaller percentage of mothers in both groups were employed. Overall, the results indicate that the demographic composition of the two groups in terms of age and parental occupational status was nearly similar and exhibited a balanced distribution.

Table 1

Descriptive Information Related to Theory of Mind

Variable	Phase	Experimental (M)	Experimental (SD)	Control (M)	Control (SD)
Theory of Mind	Pretest	17.33	3.35	15.26	3.99
	Posttest	23.80	4.21	15.26	2.60
	Follow-up	25.80	4.24	15.86	2.97

According to the findings, theory of mind and its components in the experimental group showed a substantial increase from pretest to posttest, whereas no notable change was observed in the control group.

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To assess the homogeneity of variances as a prerequisite for univariate analysis of variance, Levene's test was used. The results indicated that the assumption of homogeneity of variances was met.

Next, the assumptions of homogeneity of covariance matrices were examined through Box's M test, and the sphericity assumption was assessed using Mauchly's test. The results are presented in Table 2.

Table 2

ANOVA Results

Group	Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
Corrected Model	925.631	1	929.631	258.639	.001	.905
Group Interaction	215.314	2	107.657	29.952	.001	.689
Error	97.047	27	3.594			

The test of between-group effects showed a significant difference between groups in the dependent variable, theory of mind. Eta squared indicated a meaningful impact of the intervention group (virtual reality) on improving theory of mind compared to the control group.

Table 3

Mauchly's Test of Sphericity

Mauchly's Test	χ^2	df	Sig.	Greenhouse–Geisser	Huynh–Feldt
.087	62.792	5	.001	.436	.484

To examine the sphericity assumption for repeated-measures ANOVA, Mauchly's test was performed. The value of Mauchly's test (.087) and the significance level (< .001) indicated that the sphericity assumption was violated. Therefore, correction factors such as Greenhouse–Geisser or Huynh–Feldt were used, with their epsilon values also reported in the table. The Greenhouse–Geisser epsilon value was .436 and the Huynh–Feldt value was .484; thus, the degrees of freedom were adjusted accordingly.

Table 4

Test of Within-Group Effects

Source	Group	Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
Time	Sphericity assumed	14203.4	3	4734.4	4.134	.009	.133
	Greenhouse–Geisser	14203.4	1.309	10851.5	4.134	.040	.133
	Huynh–Feldt	14203.4	1.451	9791.6	4.134	.035	.133
Time × Group	Sphericity assumed	8790.9	6	1465.1	1.279	.276	.087
	Greenhouse–Geisser	8790.9	2.618	3358.1	1.279	.295	.087
	Huynh–Feldt	8790.9	2.901	3030.1	1.279	.295	.087

In this table, the test was performed using sphericity corrections for the time factor as well as its interaction with group. According to the within-group effects test, the time factor had a significant effect on improving theory of mind in children with ASD; however, the interaction between time and group (virtual reality intervention vs. control) was not significant. This finding indicates that although repeated testing/time contributed to changes in theory of mind, these changes were not significantly dependent on the experimental versus control group.

4. Discussion and Conclusion

The purpose of this study was to examine the effectiveness of a structured virtual reality (VR) intervention on improving theory of mind (ToM) in children with Autism Spectrum Disorder (ASD). The results demonstrated significant improvements in ToM scores from pretest to posttest and follow-up in the experimental group, while the control group showed no meaningful change. These findings provide strong support for the growing body of research indicating that VR, through immersive and controlled social simulation, can facilitate the development of core social-cognitive abilities in children with ASD (Zhang et al., 2022). The progressive improvement observed in the experimental group suggests that repeated exposure to VR-based social scenarios can strengthen children's ability to infer emotional states, recognize others' beliefs, and differentiate between true and false mental representations.

The overall pattern of results aligns with research showing that VR-based interventions enhance emotional understanding, perspective-taking, and social engagement in ASD populations. For instance, previous studies have demonstrated that VR is an effective medium for improving emotion recognition and social adaptation through structured simulations involving avatars and dynamic social environments (Ip et al., 2018; Yuan & Ip, 2018). Similarly, Lorenzo et al. reported substantial improvements in emotional skills following an immersive VR training program, emphasizing that VR allows children to repeatedly practice skills that are otherwise difficult to generalize in real-world contexts (Lorenzo et al., 2016). The present findings corroborate such results by showing improved ToM competencies after repeated exposure to interactive VR tasks, including emotion identification, false-belief reasoning, and intention recognition.

A central aspect of ToM involves understanding others' emotional expressions, intentions, and beliefs—all areas in which children with ASD typically experience difficulty. The VR intervention in this study included gradual exposure to emotional avatars, scenarios involving conflicting perspectives, and tasks requiring prediction of beliefs and intentions. Such immersive social simulations may help children decode complex nonverbal cues and infer mental states more effectively. This mechanism echoes findings from Colombo and colleagues, who demonstrated that VR enhances emotion regulation by providing a scaffolded learning environment that encourages active engagement with emotional stimuli (Colombo et al., 2021). Similarly, Rodríguez et al. found that emotional engagement during VR mood-induction tasks activates neural systems related to emotional regulation, illustrating how VR can serve as a medium for emotional learning (Rodríguez et al., 2015). The present study's improvements in ToM may therefore reflect enhanced emotional processing facilitated by VR-based exposure to realistic emotional contexts.

The observed gains in ToM also align with theoretical frameworks emphasizing the role of attentional control and cognitive flexibility in mental state understanding. Algorithms of attentional bias have shown that emotional stimuli can produce distraction and cognitive slowdown across populations, affecting higher-order cognitive processes (Algom et al., 2004). However, VR environments may mitigate such distractibility by enabling focused engagement with emotionally meaningful scenarios. For example, Dubovi demonstrated that VR increases emotional engagement during learning tasks and that facial expressions reflect deeper involvement with educational content (Dubovi, 2024). Improvements in ToM within this study may similarly be attributed to children's heightened engagement with VR scenarios requiring sustained attention, emotional labeling, and mental state inference.

The current findings also resonate with research on inhibitory control, which plays a central role in ToM development. Dina et al. showed that VR environments can effectively measure and challenge children's inhibitory control by embedding executive functioning demands within naturalistic settings (Dina et al., 2025). Additionally, Rocabado and Duñabeitia provided evidence that VR can assess real-world inhibitory control with high ecological validity, suggesting that VR offers a unique platform for practicing cognitive skills relevant to ToM (Rocabado & Duñabeitia, 2022). Because inhibitory control is essential for distinguishing one's own beliefs from others', it is plausible that the VR activities requiring attention switching, resisting prepotent responses, and perspective taking contributed to the observed improvements in ToM scores.

The present results also align with the broader literature demonstrating the benefits of VR interventions for ASD social and emotional functioning. Multiple reviews and empirical studies have noted that VR enhances social initiation, joint attention, and nonverbal communication (Bravou et al., 2022; Frolli et al., 2022; Glaser & Schmidt, 2022). In particular, Didehbani and colleagues reported significant improvements in social cognition after VR-based training among children with high-functioning ASD, mirroring the present study's findings (Didehbani et al., 2016). VR's advantage lies in its ability to replicate complex social situations, allow for repeated practice without real-world consequences, and tailor difficulty levels to each child's learning pace.

The study's findings further extend insights from behavioral and educational research where VR has shown promise in improving cognitive and emotional outcomes. For example, Carballo-Marquez et al. found that VR reduced internalizing symptoms and strengthened cognitive functions in adolescents (Carballo-Marquez et al., 2025),

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while Martin-Moratinos et al. demonstrated improved emotional regulation in children with ADHD following VR-based gameplay (Martin-Moratinos et al., 2025). These studies collectively highlight VR's capacity to modulate emotional and executive functioning systems, which may indirectly support ToM development in ASD populations. Similarly, findings from Villena-Taranilla's meta-analysis have shown that VR enhances learning outcomes in children, suggesting that the modality is particularly effective for cognitive processes requiring visualization, simulation, and emotional engagement (Villena-Taranilla et al., 2022). The improvements in ToM observed in the current study may therefore reflect the broader cognitive benefits associated with immersive learning.

Emotion regulation is another factor associated with ToM. Conner et al. found significant associations between emotion regulation difficulties and internalizing symptoms among autistic individuals, emphasizing the interdependence of emotional and cognitive components of social understanding (Conner et al., 2023). VR interventions targeting emotional awareness, such as those studied by Marchena-Giráldez and colleagues, highlight how exposure to emotionally relevant virtual scenarios can support adaptive emotional responses (Marchena-Giráldez et al., 2024). Similarly, studies of virtual exposure therapy in anxiety and social distress demonstrate that VR reduces avoidance and enhances engagement with social stimuli (Cavallo et al., 2024; Nazemi et al., 2019). The emotional-social nature of VR in the present study likely contributed not only to cognitive ToM processing but also to emotional readiness for interpreting others' mental states.

The present results are also consistent with intervention studies demonstrating improvements in social behaviors and communication when treatments incorporate interactive or multi-sensory approaches. For example, Cihak et al. demonstrated that video modeling paired with communication systems increased independent communicative initiations in preschoolers with ASD (Cihak et al., 2012). Although VR differs technologically, its reliance on visual modeling, repeated practice, and interactive feedback mirrors the mechanisms underlying such interventions. Furthermore, parent-based emotional regulation interventions, such as those studied by Safarpour and Ashouri, may complement VR approaches by reinforcing emotional learning within the home environment (Safarpour & Ashouri, 2024). In combination, these findings suggest that both child-focused VR training and family-based support may be essential components of comprehensive ToM intervention programs.

Advances in VR design have greatly contributed to the quality and effectiveness of ASD-related VR interventions. Systematic reviews highlight key principles such as avatar realism, emotional clarity, adaptive feedback, and customizable sensory environments (Glaser & Schmidt, 2022). These design considerations are essential for reducing sensory overload and improving engagement among autistic children, whose sensory processing patterns may differ significantly from neurotypical peers (Savickaite et al., 2021). The VR platform used in this study, which incorporated dynamic emotional avatars, perspective-taking tasks, and false-belief scenarios, was consistent with these design recommendations and may have contributed significantly to the observed outcomes.

Moreover, the intervention's structured progression—from basic emotion recognition to advanced false-belief reasoning—aligns with skill hierarchies described in ToM development literature. For example, research on false-belief comprehension, perspective-taking, and mental state attribution emphasizes that children with ASD benefit from structured supports and repeated learning opportunities to internalize ToM skills (Rodríguez et al., 2015). The systematic nature of the VR sessions in this study likely facilitated learning through gradual exposure, immediate feedback, and adaptive scenario complexity.

In summary, the findings provide robust evidence that VR-based training can significantly improve theory of mind in children with ASD. The improvement is consistent with neurocognitive, educational, and emotional research underscoring VR's capacity to enhance social cognition through controlled simulation, repeated practice, and emotionally meaningful engagement.

This study had several limitations. The sample size was relatively small, which may limit the generalizability of the findings to broader ASD populations. The study included only children aged 7–12 years, restricting the applicability of results to younger or older age groups. Additionally, the VR intervention required specialized equipment and technological infrastructure, which may not be widely accessible in clinical or educational settings. Finally, although a two-month follow-up was conducted, longer-term follow-up is needed to determine the persistence of gains in theory of mind.

Future research should include larger and more diverse samples to enhance generalizability. Studies should explore VR-based ToM training across different age ranges and ASD

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severity levels. Researchers may also investigate the combined effects of VR interventions with parent-based or school-based social skills training. Additionally, future work should examine neural or physiological correlates of ToM improvements using neuroimaging or psychophysiological measures. Finally, long-term follow-up studies are needed to assess whether VR-based gains persist over time and generalize to real-world social interactions.

Practitioners may consider integrating VR-based social-cognitive training into ASD intervention programs, particularly when targeting emotion understanding, perspective taking, and mental state reasoning. The structured nature of VR scenarios can complement existing therapeutic approaches. Clinicians and educators should ensure that VR environments are tailored to individual sensory and cognitive needs. Collaboration between therapists, parents, and technology specialists can maximize the effectiveness of VR-based interventions in everyday settings.

Authors' Contributions

Authors contributed equally to this article.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of Interest

The authors report no conflict of interest.

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Ethical Considerations

The study protocol adhered to the principles outlined in the Helsinki Declaration, which provides guidelines for ethical research involving human participants.

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