



A Systematic Literature Review of Virtual Reality for Teaching Individuals with Autism Spectrum Disorder

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Article History:

Received: Aug 15th 2025

Revised: Sept 12th 2025

Accepted: Nov 30th 2025

Keywords: *Individuals with ASD, interventions, therapeutic, virtual reality*

Abstract: *This systematic literature review explores the application and efficacy of virtual reality as a tool for teaching and improving skills in individuals with autism spectrum disorder (ASD). Considering the heterogeneity of ASD and the importance of early intervention, it is imperative to identify effective, innovative therapeutic approaches. A comprehensive search of existing literature and research databases, including PubMed, PsycINFO, IEEE Xplore, Scopus and EBSCOhost, was undertaken, and 704 articles were identified as relevant. We evaluated these studies, establishing their eligibility, and eight met the inclusion criteria. This review synthesised studies highlighting the potential of virtual reality to address the unique needs of individuals with ASD, including social skills training, emotional and cognitive development and the management of specific phobias. It reveals how virtual reality simulations offer a safe and controlled environment for practice and learning, supporting the development of essential skills for social interaction and daily functioning. With its structured and individualised approach, virtual reality technology emerges as a promising intervention that caters to the diverse requirements of the ASD population. The review calls for further research to optimise virtual reality tools for broader clinical applications, aiming for more inclusive and accessible interventions for individuals with ASD.*



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Introduction

Autism spectrum disorder (ASD) is a complex and heterogeneous neurodevelopmental disorder characterised by deficits in social communication, impaired social interaction and restricted, repetitive patterns of behaviour¹. Early

¹ Lord et al. (2020). Autism spectrum disorder. *Nature Reviews Disease Primers*, 6(1), 5.

detection and intervention are crucial for improving developmental outcomes in children with ASD^{2 3 4}. The mean age at diagnosis of ASD is around 5 years, indicating a need for earlier identification⁵. Screening and surveillance help detect developmental delays and any signs of ASD symptoms, allowing for timely intervention and effective management of the condition. This is especially important because early detection and intervention can significantly improve the long-term outcomes for individuals with ASD⁶.

Individuals with ASD face significant challenges when it comes to social interactions, including initiating and sustaining conversations and understanding implicit social rules. This can lead to profound feelings of social isolation and extreme anxiety, especially in individuals on the 'higher functioning' end of the spectrum who have relatively normal verbal abilities. Studies by Ghaziuddin et al.⁷ and Howlin⁸ have found that these individuals are more likely to have insight into their disorder and a heightened awareness of how they differ from others. It is crucial to recognise the severity of these issues and provide the necessary support to help individuals with ASD overcome these challenges and lead fulfilling lives.

Neuroimaging studies have revealed differences in brain anatomy and functioning in individuals with ASD, highlighting the neurobiological basis of the disorder⁹. Moreover, the implementation of specialised interventions for young children with ASD is a global clinical and research priority¹⁰. Virtual reality (VR) has shown promise in improving social skills, cognition and functioning in children and adolescents with ASD¹¹. VR

<https://doi.org/10.1038/s41572-019-0138-4>

² Dawson et al. (2010). Randomized, Controlled Trial of an Intervention for Toddlers With Autism: The Early Start Denver Model. *Pediatrics*, 125(1), e17–e23. <https://doi.org/10.1542/peds.2009-0958>

³ Koegel, L. K., Koegel, R. L., Ashbaugh, K., & Bradshaw, J. (2014). The importance of early identification and intervention for children with or at risk for autism spectrum disorders. *International Journal of Speech-Language Pathology*, 16(1), 50–56. <https://doi.org/10.3109/17549507.2013.861511>

⁴ Whitehouse et al. (2021). Effect of Preemptive Intervention on Developmental Outcomes Among Infants Showing Early Signs of Autism. *JAMA Pediatrics*, 175(11), e213298. <https://doi.org/10.1001/jamapediatrics.2021.3298>

⁵ van 't Hof et al. (2021). Age at autism spectrum disorder diagnosis: A systematic review and meta-analysis from 2012 to 2019. *Autism*, 25(4), 862–873. <https://doi.org/10.1177/1362361320971107>

⁶ Casseus, M. (2022). Prevalence of co-occurring autism spectrum disorder and attention deficit/hyperactivity disorder among children in the United States. *Autism*, 26(6), 1591–1597. <https://doi.org/10.1177/13623613221083279>

⁷ Ghaziuddin, M., Ghaziuddin, N., & Greden, J. (2002). Depression in persons with autism: implications for research and clinical care. *Journal of Autism and Developmental Disorders*, 32(4), 299–306. <https://doi.org/10.1023/A:1016330802348>

⁸ Howlin, P. (1998). Psychological and Educational Treatments for Autism. *Journal of Child Psychology and Psychiatry*, 39(3), S0021963097002138. <https://doi.org/10.1017/S0021963097002138>

⁹ Ecker, C. (2017). The neuroanatomy of autism spectrum disorder: An overview of structural neuroimaging findings and their translatability to the clinical setting. *Autism*, 21(1), 18–28. <https://doi.org/10.1177/1362361315627136>

¹⁰ Colombi, C., Narzisi, A., Ruta, L., Cigala, V., Gagliano, A., Pioggia, G., Siracusano, R., Rogers, S. J., & Muratori, F. (2018). Implementation of the Early Start Denver Model in an Italian community. *Autism*, 22(2), 126–133. <https://doi.org/10.1177/1362361316665792>

¹¹ Kandalaf, M. R., Didehbani, N., Krawczyk, D. C., Allen, T. T., & Chapman, S. B. (2013). Virtual reality social cognition training for young adults with high-functioning autism. *Journal of autism and*

simulations can also aid in social skills training by allowing individuals with ASD to practise social interactions in a safe and controlled manner. These simulations can include scenarios like initiating conversations, making eye contact or interpreting social cues, all within a supportive virtual space. Studies have indicated that immersive VR is a promising tool for improving the skills of students with ASD¹².

VR has been gaining in popularity in interventions for children with ASD, with the potential to support and promote the learning of new social skills^{13 14} and has been proposed as a tool to help develop and improve emotional skills in students with autism¹⁵. A study by Zhao et al.¹⁶ revealed that VR can also effectively enhance cognitive abilities and social communication skills in children with ASD. This research highlights VR's potential as an innovative approach to address the unique challenges faced by individuals with ASD. Meindl et al.'s study¹⁷ demonstrated that VR can be a promising tool for reducing blood draw phobia in adults diagnosed with ASD, indicating that it can potentially address specific phobias in this population effectively.

Moreover, VR provides practical and innovative clinical tools for measuring and intervening in social-communicative impairments in individuals with ASD¹⁸. It has been highlighted that VR makes cognitive programmes accessible to children with autism, providing structured and individualised activities while addressing their weaknesses and building on their strengths¹⁹. It has also been explored to address auditory hypersensitivity in individuals with ASD, indicating its potential to cater to specific sensory sensitivities associated with the condition²⁰.

developmental disorders, 43(1), 34–44. <https://doi.org/10.1007/s10803-012-1544-6>

¹² Dechsling et al. (2022). Virtual and Augmented Reality in Social Skills Interventions for Individuals with Autism Spectrum Disorder: A Scoping Review. *Journal of Autism and Developmental Disorders*, 52(11), 4692–4707. <https://doi.org/10.1007/s10803-021-05338-5>

¹³ Feng, S., Wang, X., Wang, Q., Fang, J., Wu, Y., Yi, L., & Wei, K. (2018). The uncanny valley effect in typically developing children and its absence in children with autism spectrum disorders. *PLOS ONE*, 13(11), e0206343. <https://doi.org/10.1371/journal.pone.0206343>

¹⁴ Grynspan, O., Weiss, P. L. (Tamar), Perez-Diaz, F., & Gal, E. (2014). Innovative technology-based interventions for autism spectrum disorders: A meta-analysis. *Autism*, 18(4), 346–361. <https://doi.org/10.1177/1362361313476767>

¹⁵ Lorenzo, G., Lledó, A., Pomares, J., & Roig, R. (2016). Design and application of an immersive virtual reality system to enhance emotional skills for children with autism spectrum disorders. *Computers & Education*, 98, 192–205. <https://doi.org/10.1016/j.compedu.2016.03.018>

¹⁶ Zhao et al. (2022). Virtual reality technology enhances the cognitive and social communication of children with autism spectrum disorder. *Frontiers in Public Health*, 10. <https://doi.org/10.3389/fpubh.2022.1029392>

¹⁷ Meindl et al. (2019). Reducing blood draw phobia in an adult with autism spectrum disorder using low-cost virtual reality exposure therapy. *Journal of Applied Research in Intellectual Disabilities*, 32(6), 1446–1452. <https://doi.org/10.1111/jar.12637>

¹⁸ Lorenzo et al. Design and application, 192–205.

¹⁹ Wang, M., & Reid, D. (2013). Using the Virtual Reality-Cognitive Rehabilitation Approach to Improve Contextual Processing in Children with Autism. *The Scientific World Journal*, 2013, 1–9. <https://doi.org/10.1155/2013/716890>

²⁰ Johnston, D., Egermann, H., & Kearney, G. (2020). SoundFields: A Virtual Reality Game Designed to Address Auditory Hypersensitivity in Individuals with Autism Spectrum Disorder. *Applied Sciences*, 10(9),

In addition, VR has been used to teach safety skills to children with ASD, indicating its potential for training programmes in this population²¹. VR has also been proposed as a tool to facilitate improvements in social communication skills for adolescents with autism²². One of the key advantages is VR's ability to provide a structured and controlled learning environment. This controlled setting is essential for individuals with ASD, who often thrive in predictable and manageable environments that help reduce anxiety and enhance focus during learning experiences. VR is effective in treating specific phobias in individuals with ASD, demonstrating its potential to address anxiety-related symptoms^{23 24}.

VR technology has proved valuable in creating immersive environments that simulate real-life scenarios. This approach has been widely studied and has shown promising results in helping individuals with ASD improve their social and communication abilities^{25 26}. Moreover, VR has been identified as a valuable tool for raising awareness about autism and promoting understanding among the neurotypical population²⁷. It has also been explored to address auditory hypersensitivity in individuals with ASD, indicating its potential to cater to specific sensory sensitivities associated with the condition²⁸.

Method

Search Strategy

Multiple academic databases were searched to identify relevant studies on the effectiveness of VR interventions for teaching individuals with ASD. The preferred reporting items for systematic reviews and meta-analyses (PRISMA) determined the

2996. <https://doi.org/10.3390/app10092996>

²¹ Strickland, D. C., McAllister, D., Coles, C. D., & Osborne, S. (2007). An Evolution of Virtual Reality Training Designs for Children With Autism and Fetal Alcohol Spectrum Disorders. *Topics in Language Disorders*, 27(3), 226–241. <https://doi.org/10.1097/01.TLD.0000285357.95426.72>

²² Lahiri, U., Trewyn, A., & Warren, Z. (2012). Dynamic Eye gaze and its Potential in Virtual Reality Based Applications for Children with Autism Spectrum Disorders. *Autism - Open Access*, 01(01). <https://doi.org/10.4172/2165-7890.1000101>

²³ Maskey et al. (2019). A Randomised Controlled Feasibility Trial of Immersive Virtual Reality Treatment with Cognitive Behaviour Therapy for Specific Phobias in Young People with Autism Spectrum Disorder. *Journal of Autism and Developmental Disorders*, 49(5), 1912–1927. <https://doi.org/10.1007/s10803-018-3861-x>

²⁴ Meindl et al. (2019). Reducing blood draw phobia. 1446–1452.

²⁵ López-Carral et al. (2022). *A Virtual Reality System for the Simulation of Neurodiversity* (pp. 523–531). https://doi.org/10.1007/978-981-16-2380-6_46

²⁶ Newbutt, N., Bradley, R., & Conley, I. (2020). Using Virtual Reality Head-Mounted Displays in Schools with Autistic Children: Views, Experiences, and Future Directions. *Cyberpsychology, Behavior, and Social Networking*, 23(1), 23–33. <https://doi.org/10.1089/cyber.2019.0206>

²⁷ López-Carral et al. (2022). *A VR System for Neurodiversity*. 523–531.

²⁸ Johnston et al. Soundfields. 2996.

screening criteria^{29 30 31 32 33 34}. The search terms were carefully selected to capture articles focusing on the intersection of VR technology and ASD education. Specifically, we used combinations of keywords such as "virtual reality" or "VR" with "autism spectrum disorder" or "ASD", along with terms related to education, teaching and interventions. The search was limited to studies published in English within the last ten years to ensure the inclusion of recent research. A comprehensive search was conducted using databases such as PubMed, PsycINFO, IEEE Xplore, Scopus, and *EBSCOhost* to retrieve relevant literature. This approach aimed to gather a diverse range of studies that examine the use of VR in educational settings for individuals diagnosed with ASD.

Study Selection Process

The process involved thoroughly screening potentially relevant articles identified through the database search. Initially, titles and abstracts were reviewed to assess their alignment with the inclusion criteria, which specified empirical studies evaluating VR interventions for individuals with ASD. Articles meeting these criteria were then put through a full-text review to determine their eligibility for inclusion in the systematic literature review. This phase involved a detailed assessment of each article's content to ensure that it provided relevant data on using VR technology for teaching individuals with ASD. Two reviewers conducted the selection process independently, with any discrepancies resolved through discussion or consultation with a third reviewer, where needed. The goal was to identify and select studies that contribute valuable insights into the effectiveness and implications of VR interventions in ASD education, thereby ensuring the reliability and comprehensiveness of the systematic review.

Data Extraction

During the data extraction phase, relevant information was systematically gathered from the selected studies. This involved extracting critical details from each included article, such as study characteristics (e.g., authors, publication year, study

²⁹ Ghafari, M., Baigi, V., Cheraghi, Z., & Doosti-Irani, A. (2016). Correction: The Prevalence of Asymptomatic Bacteriuria in Iranian Pregnant Women: A Systematic Review and Meta-Analysis. *PLOS ONE*, 11(10), e0165114. <https://doi.org/10.1371/journal.pone.0165114>

³⁰ Jacob, U. S., Edozie, I. S., & Pillay, J. (2022a). Strategies for enhancing social skills of individuals with intellectual disability: A systematic review. *Frontiers in Rehabilitation Sciences*, 3. <https://doi.org/10.3389/fresc.2022.968314>

³¹ Jacob, U. S., Edozie, I. S., & Pillay, J. (2022b). Strategies for enhancing social skills of individuals with intellectual disability: A systematic review. *Frontiers in Rehabilitation Sciences*, 3. <https://doi.org/10.3389/fresc.2022.968314>

³² Jacob, U. S., & Pillay, J. (2022a). Instructional strategies that foster reading skills of learners with intellectual disability: A scoping review. *Cypriot Journal of Educational Sciences*, 17(7), 2222–2234. <https://doi.org/10.18844/cjes.v17i7.7589>

³³ Jacob, U. S., & Pillay, J. (2022b). Instructional strategies that foster reading skills of learners with intellectual disability: A scoping review. *Cypriot Journal of Educational Sciences*, 17(7), 2222–2234. <https://doi.org/10.18844/cjes.v17i7.7589>

³⁴ Jacob, U. S., & Pillay, J. (2022b). Instructional strategies that foster reading skills of learners with intellectual disability: A scoping review. *Cypriot Journal of Educational Sciences*, 17(7), 2222–2234. <https://doi.org/10.18844/cjes.v17i7.7589>

design), participant demographics (e.g., age, gender, ASD diagnosis), details of the VR intervention (e.g., type of VR technology used, duration of intervention, content), educational outcomes assessed (e.g., academic performance, social skills development, behaviour changes), and any reported benefits or challenges associated with the VR interventions. The extracted data was organised and compiled in a structured format to facilitate subsequent analysis and synthesis of findings. This comprehensive data extraction process aimed to capture essential information from the selected studies and provide a basis for evaluating the effectiveness and potential limitations of VR interventions for teaching individuals with ASD.

Identifying studies via databases and registers follows a systematic approach to ensure that only relevant and high-quality research is included in the review. Initially, records were gathered from multiple academic databases, including Scopus, EBSCOhost, PubMed, IEEE Xplore, and PsycINFO, resulting in 704 identified studies. Duplicate records, records flagged as ineligible by automatic tools, and other studies excluded for various reasons were removed, resulting in 454 studies being screened.

Studies were examined based on predefined inclusion criteria at the screening stage, and 78 records were excluded because of language constraints. This left 376 reports, which were then sought for retrieval. However, 83 reports could not be accessed due to paywall restrictions, missing links, or the unavailability of full-text articles. The remaining 293 reports were assessed for eligibility, with further exclusions based on document type, source type, and publication stage. Consequently, only eight studies met all the necessary criteria and were included in the final review. This structured approach (illustrated in Figure 1) ensured that the selection process remained rigorous and objective, ultimately focusing only on studies that would contribute meaningfully to this literature review.

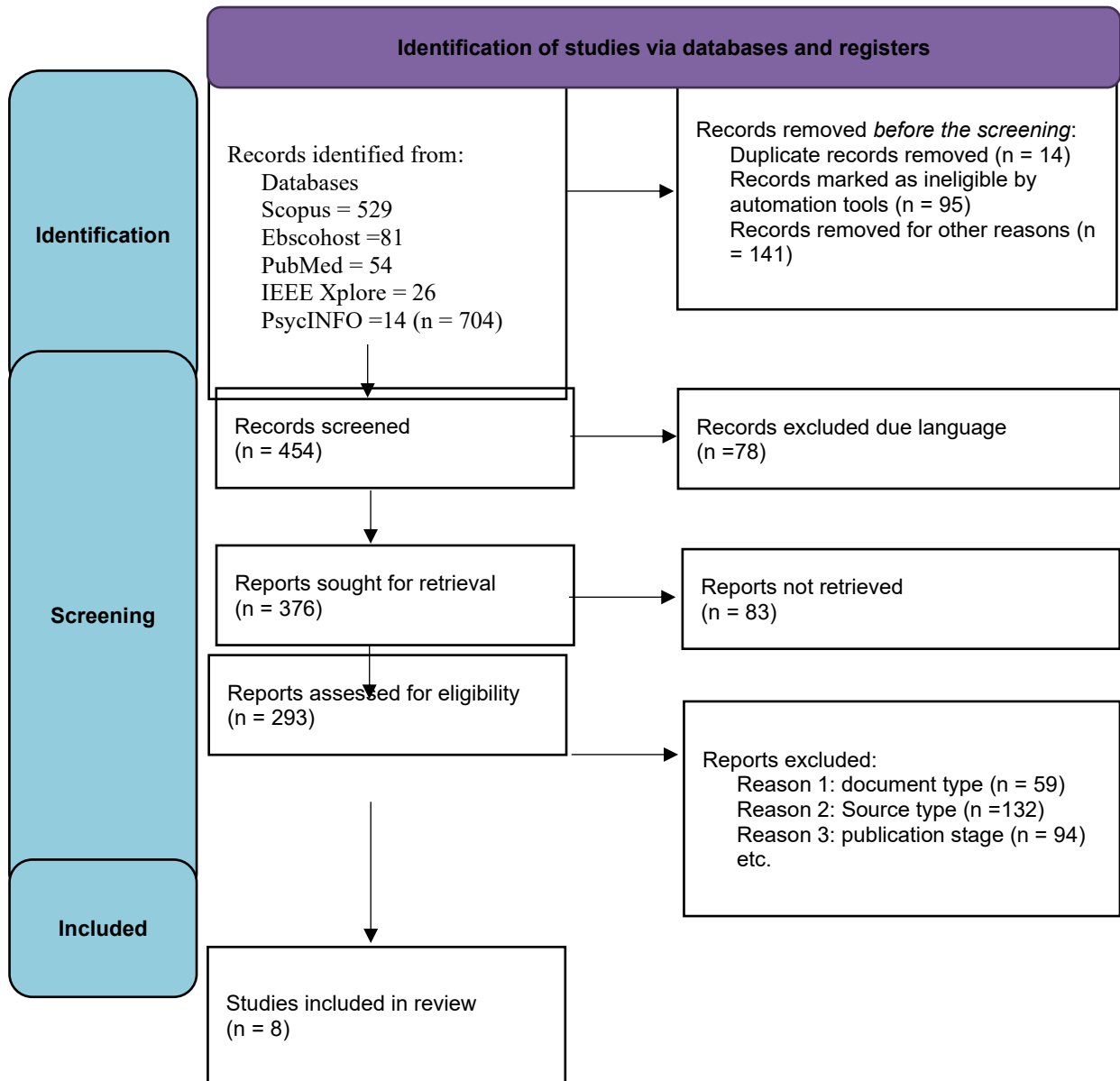


Figure 1. Flowchart of the systematic literature review

Quality Assessment

The included studies were subjected to a thorough review of their methodological soundness and overall reliability. This process aimed to assess the validity and trustworthiness of the research findings obtained from each study. Critical aspects considered during the quality assessment included study design, sample size, participant selection criteria, use of appropriate control groups or comparison conditions, outcome measures and statistical analyses employed. Studies demonstrating robust methodologies with clear research objectives, well-defined procedures and appropriate data analysis techniques were regarded more favourably in terms of quality. Conversely,

studies with methodological limitations, such as small sample sizes, lack of control groups or unclear reporting of procedures, were considered lower in quality and reliability. The quality assessment was conducted using established evaluation tools or criteria specific to the study designs identified in the systematic review, ensuring a methodical and transparent approach to appraising the included studies. This critical appraisal process helped determine the overall strength of evidence. It informed the interpretation of findings in the context of the systematic literature review on VR interventions for individuals with ASD.

Data Synthesis

The data synthesis phase involved a comprehensive analysis and integration of findings from the included studies. Key outcomes, themes and trends identified across the selected literature were summarised and interpreted using a narrative synthesis approach. This process involved examining the reported effectiveness of VR interventions for teaching individuals with ASD and the specific applications and educational outcomes associated with these interventions. The synthesised data was used to generate insights into the overall impact of VR technology on teaching those with ASD, highlighting both the benefits and challenges observed in the literature.

Subgroup analyses were performed to explore outcome variations based on different types of VR interventions or participant characteristics. The narrative synthesis also addressed gaps in the existing research, identifying areas for further investigation and improvement. By synthesising the findings from diverse studies, this process provided a coherent and evidence-based overview of current knowledge regarding VR interventions for individuals with ASD in educational settings. This comprehensive analysis contributed to a deeper understanding of the potential implications and future directions for research and practice in this critical study area.

Ethical Approval

This review only involved analysing published data; therefore, ethical approval was not required.

Result

Table 1 shows the methodological details of the selected articles on using VR for teaching individuals with ASD.

Table 1: Participants, instruments, description of interventions and design

Authors	Participants	Instrument(s)	Description of intervention	Design	Duration	Data Analysis
Lorenzo et al. (2016) ³⁵	40	Emotional Script (Teachers)	10 Social situations were presented to elicit emotional behaviour on IVRS and real-life situations	Mixed	40 weeks	Descriptive
Ip et al. (2018) ³⁶	94	Raven's Progressive Matrices (RPM), Childhood Autism Spectrum Test (CAST). Psychoeducational Profile (PEP) (Teachers & parents)	4-side immersive VR environment	Cross-sectional	14 weeks	Mixed repeated measures ANOVA
Zhao et al. (2022a) ³⁷	120	Autism Behavior Checklist (ABC), Childhood Autism Rating Scale (CARS), and Clancy	Exposure to 3D models with moving objects in real natural movement	Cross-sectional	8 weeks	Two-way analysis of variance (ANOVA)

³⁵ Lorenzo et al. Immersive virtual reality system, 192–205.

³⁶ Ip et al. (2018). Enhance emotional and social adaptation skills for children with autism spectrum disorder: A virtual reality enabled approach. *Computers & Education*, 117, 1–15. <https://doi.org/10.1016/j.compedu.2017.09.010>

³⁷ Zhao, J.-Q., Zhang, X.-X., Wang, C.-H., & Yang, J. (2022a). Effect of cognitive training based on virtual reality on the children with autism spectrum disorder. *Current Research in Behavioral Sciences*, 2, 100013. <https://doi.org/10.1016/j.crbeha.2020.100013>

		Autism Behavior Scale (CABS) (Research team)				
(Zhao et al. (2022b)) ³⁸	34	(PEP-3) (Caregivers, researchers, clinicians, and therapists)	VR technology was added to the rehabilitation training offered to the control group	Quasi-Experimental	12 weeks	Paired and independent t-test
Ke et al. (2022) ³⁹	8	Social Communication Questionnaire (SCQ) (Researcher)	The use of innovative technologies for social skills training	Cross-sectional	4 weeks	Paired-test
Herrero and Lorenzo (2020) ⁴⁰	6	Non-verbal Communication Questionnaire & Social and Emotional Reciprocity (Teachers, parents & researchers)	The training was given to improve on the symptoms identified using DSM-V	Quasi-Experimental	4 weeks	Descriptive statistics
Yuan and Ip (2018) ⁴¹	72	PEP-3 (VR Technologists)	VR training, children enter the CAVE and	Quasi-Experimental	not provided	Mixed repeated measures

³⁸ Zhao et al. (2022b). Virtual reality technology enhances the cognitive and social communication of children with autism spectrum disorder. *Frontiers in Public Health*, 10. <https://doi.org/10.3389/fpubh.2022.1029392>

³⁹ Ke, F., Moon, J., & Sokolikj, Z. (2022). Virtual Reality–Based Social Skills Training for Children With Autism Spectrum Disorder. *Journal of Special Education Technology*, 37(1), 49–62. <https://doi.org/10.1177/0162643420945603>

⁴⁰ Herrero, J. F., & Lorenzo, G. (2020). An immersive virtual reality educational intervention on people with autism spectrum disorders (ASD) for the development of communication skills and problem solving. *Education and Information Technologies*, 25(3), 1689–1722. <https://doi.org/10.1007/s10639-019-10050-0>

⁴¹ Yuan, S. N. V., & Ip, H. H. S. (2018). Using virtual reality to train emotional and social skills in

					navigate the design VRE with guidance and support				ANOVA
Hu and Han (2019) ⁴²	337	WISC-IV & CARS-2	&	Leap Motion-aided technology	Motion-VR	Multiple probe design	not provide	d	Descriptive statistics

A total of 711 participants were included across the studies. Hu and Han’s⁴³ study had the highest number of participants, with 337, and Herrero and Lorenzo’s⁴⁴ study had the lowest, with six participants. The difference between the highest and lowest number of participants was 331 (98.22%). The studies used different research design types: three studies used a quasi-experimental design^{45 46 47}, while those by Ip et al.⁴⁸, Ke et al.⁴⁹ and Zhao et al.⁵⁰ used cross-sectional designs. Hu and Han⁵¹ and Lorenzo et al.⁵² used mixed and multiple probe designs, respectively.

In the selected studies, various data analysis techniques were used to explore the effectiveness of interventions to elicit emotional and behavioural responses. This was done mainly in populations with autism or related conditions. Herrero and Lorenzo⁵³, Hu and Han⁵⁴ and Lorenzo et al.⁵⁵ used descriptive statistics to summarise and visually represent data to understand trends, variations or patterns in the data. Although descriptive statistics cannot infer causality or relationships, they are essential for establishing a basic understanding of the data characteristics. In contrast, more sophisticated statistical methods, such as the mixed repeated measures ANOVA employed by Ip et al.⁵⁶ and Yuan and Ip⁵⁷, allowed for a nuanced examination of the

children with autism spectrum disorder. *London Journal of Primary Care*, 10(4), 110–112. <https://doi.org/10.1080/17571472.2018.1483000>

⁴² Hu, X., & Han, Z. R. (2019). Effects of gesture-based match-to-sample instruction via virtual reality technology for Chinese students with autism spectrum disorders. *International Journal of Developmental Disabilities*, 65(5), 327–336. <https://doi.org/10.1080/20473869.2019.1602350>

⁴³ Hu & Han. Gesture-based VR. 327–336.

⁴⁴ Herrero & Lorenzo. Immersive VR. 1689–1722.

⁴⁵ Herrero & Lorenzo. Immersive VR. 1689–1722.

⁴⁶ Yuan & Ip. Using Virtual Reality. 110–112.

⁴⁷ Zhao et al. Virtual Reality Technology. 1–8.

⁴⁸ Ip et al. Enhance Emotional skills. 1–15

⁴⁹ Ke et al. VR-based Social Skills Training. 49–62.

⁵⁰ Zhao et al. Cognitive training based on VR. 1–5.

⁵¹ Hu & Han. Gesture-based VR. 327–336.

⁵² Lorenzo et al. (2016). Immersive virtual reality system, 192–205.

⁵³ Herrero & Lorenzo. Immersive VR. 1689–1722.

⁵⁴ Hu & Han. Gesture-based VR. 327–336.

⁵⁵ Lorenzo et al. (2016). Immersive virtual reality system, 192–205.

⁵⁶ Ip et al. Enhance Emotional skills. 1–15.

⁵⁷ Yuan & Ip. Using Virtual Reality. 110–112.

interventions' effects across different groups and time points. This method is particularly suited to controlled settings, offering insights into both the direct impact of the intervention and variations among participants.

Similarly, the two-way analysis of variance (ANOVA) used by Zhao et al.⁵⁸ extends this analytical depth by testing the influence of two independent variables and their interactions on a dependent variable. This is crucial for understanding the intervention impacts' multifaceted nature, where multiple factors influence outcomes. In addition, paired and independent t-tests, as seen in Zhao et al.⁵⁹, are used to compare mean differences within the same group over time or between two distinct groups. These tests are particularly valuable for pre-post comparisons between the same individuals or between experimental and control groups, offering a detailed view of the intervention's efficacy. The study by Ke et al.⁶⁰ uses a paired test, possibly the comparative sample t-test, to assess change over time within a small sample size. This approach, similar in purpose to the paired t-test mentioned earlier, is used to assess the direct effects of an intervention over a period within the same group of individuals.

Table 2: Nature of Intervention and Participants

Authors	Type of Intervention	Age (years)	Gender	Participants
Lorenzo et al. (2016)	Immersion VR	7-12	M=29 F=11	Children
Ip et al. (2018)	VR-enabled	6-12	M= 86 F=8	Children
Zhao et al. (2022a)	Cognitive training based on VR	2-7	M= 88 F=32	Children
(Zhao et al. (2022b)	VR rehabilitation on cognition, imitation, and social interaction	3-5	M=25 F=9	Children
Ke et al. (2022)	Desktop VR-based learning environment for social skills training	10-14	M=7 F=1	Children & teenagers
Herrero and Lorenzo (2020)	Immersive VR educational intervention	8-15	M=3 F= 3	Children & teenagers
Yuan and Ip (2018)	VR learning environment	6-10	M=64 F=8	Children
Hu and Han (2019)	Gesture-based environment	VR 6-7	M=179 F=158	Children

⁵⁸ Zhao et al. Cognitive training based on VR. 1-5.

⁵⁹ Zhao et al. Virtual Reality Technology. 1-8.

⁶⁰ Ke et al. VR-based Social Skills Training. 49-62.

In Table 2, the interventions described across the studies primarily focus on employing VR in various contexts, ranging from immersive VR and VR-enabled environments to specific applications in cognitive training, rehabilitation, cognition, imitation and social interaction, and VR-based learning environments for social skills training and educational interventions. The adoption of VR as therapy was in the form of immersion VR⁶¹, VR-enabled educational activities⁶², cognitive training based on VR⁶³, VR rehabilitation on cognition, imitation, and social interaction⁶⁴, desktop VR-based learning environments for social skills training⁶⁵, immersive VR educational intervention⁶⁶, VR learning environments⁶⁷ and gesture-based VR environments⁶⁸.

Participants in the included studies ranged in age from two to 15 years. Specifically, Zhao et al.⁶⁹ targeted children aged two to seven years, while the oldest participants were found in Herrero and Lorenzo’s study⁷⁰ (15 years old) and in Ke et al.’s study⁷¹, which had an age range of between 10 and 14 years. There were 430 male participants and 230 females. The study by Hu and Han⁷², involved 179 male and 158 female participants, while the difference in the number of male and female participants was 12. In contrast, Ke et al.⁷³, included seven male and one female participant. In all studies except one (Herrero & Lorenzo, 2020), there were significantly more male than female participants, reflecting a notable disparity in gender distribution across studies.

Table 3: Intervention Administration and Result

Instrument	Description of intervention	Duration	Agent	Result
Lorenzo et al. (2016)	Ten social situations were presented to elicit emotional behaviour on IVRS and real-life situations	40 weeks	Teachers	There was a significant improvement in the children's emotional competencies compared to the

⁶¹ Lorenzo et al. (2016). Immersive virtual reality system, 192–205.

⁶² Ip et al. Enhance Emotional skills. 1–15.

⁶³ Zhao et al. Cognitive training based on VR. 1–5.

⁶⁴ Zhao et al. Virtual Reality Technology. 1–8.

⁶⁵ Ke et al. VR-based Social Skills Training. 49–62.

⁶⁶ Herrero & Lorenzo. Immersive VR. 1689–1722.

⁶⁷ Yuan & Ip. Using Virtual Reality. 110–112.

⁶⁸ Hu & Han. Gesture-based VR. 327–336.

⁶⁹ Zhao et al. Virtual Reality Technology. 1–8.

⁷⁰ Herrero & Lorenzo. Immersive VR. 1689–1722.

⁷¹ Ke et al. VR-based Social Skills Training. 49–62.

⁷² Hu & Han. Gesture-based VR. 327–336.

⁷³ Ke et al. VR-based Social Skills Training. 49–62.

					control group.
Ip et al. (2018)	4-side immersive virtual reality environment (a.k.a., half-CAVE)	14 weeks	Teachers and parents		There is a significant improvement in the project's primary measures of children's emotional expression and regulation and social-emotional reciprocity but not in other secondary measures.
Zhao et al. (2022a)	Exposure to 3D models with moving objects in real natural movement	8 weeks	Research team		It significantly improved the typical symptoms (social communication disorder, speech retardation, narrow interest, and rigid behaviour) of children with ASD
(Zhao et al. (2022b)	VR technology was added to the rehabilitation training offered to the control group	12 weeks	Caregivers, researchers, clinicians, and therapists		Children in both groups exhibited improved abilities in cognition, imitation, and social interaction after the intervention. However, different post-intervention scores were recorded between the intervention and control groups.
Ke et al. (2022)	The use of innovative technologies for social skills training	4 weeks	Researcher		Increased level of successful social skills performance

						from the baseline to the intervention phase
Herrero & Lorenzo (2020)	The training was given to improve on the symptom identified using DSM-V	4 weeks	Teachers, parents and researchers			The adaptation levels and the improvements obtained suggest that IVR in the presented format aligns with the sensory preferences and visuospatial strength of children with ASD.
Yuan and Ip (2018)	VR training, children enter the CAVE navigate the VRE with guidance and support.	n/a	VR Technologists			Children from the training group scored higher on emotional expression and regulation than before the training.
Hu and Han (2019).	Leap Motion-aided VR technology	n/a	Researcher			Participants acquired the target match-to-sample skills and maintained the acquired skills at a high level for up to 12 weeks.

Table 3 describes the interventions used in the selected articles. These focused on exposure to social situations in a VR environment^{74 75}, training in specific skills in a VR

⁷⁴ Lorenzo et al. (2016). Immersive virtual reality system, 192-205.

⁷⁵ Zhao et al. Virtual Reality Technology. 1-8.

environment^{76 77 78 79 80} and using VR to aid the development of desirable skills^{81 82}. The intervention period for the studies in the selected articles ranges from 2 weeks to 10 months. In two studies (25%), the intervention lasted four weeks. Four studies reported intervention durations of 8, 12, 14 and 40 weeks, respectively, while the remaining two studies did not specify the duration.

The intervention agents in the studies in the selected articles were teachers, parents, therapists, technologists and research teams. A significant improvement was reported in participants' emotions^{83 84 85}, social skills^{86 87 88 89}, stability⁹⁰, and sensory preferences and visuospatial strength^{91 92}.

Discussion

The exploration of VR and cognitive training interventions across various studies reveals their significant potential to support emotional and social development among children, including those with ASD. The consistent positive outcomes across different settings, methodologies, and participant demographics underscore the value of these technologies. However, a holistic approach is needed to fully realise their impact. This includes technological advancements, professional training, personalised intervention strategies and research on their long-term efficacy.

Integration in Mainstream and Special Education

The versatility demonstrated by VR and cognitive training applications, as shown in these studies, suggests they could become integral parts of mainstream and special education curricula. For instance, Herrero and Lorenzo⁹³ and Lorenzo et al.⁹⁴ depict scenarios where emotional intelligence and social skills are enhanced. This indicates an opportunity to reinforce empathy, emotional understanding and social interaction skills

⁷⁶ Herrero & Lorenzo. Immersive VR. 1689–1722.

⁷⁷ Ke et al. VR-based Social Skills Training. 49–62.

⁷⁸ Yuan & Ip. Using Virtual Reality. 110–112.

⁷⁹ Zhao et al. Cognitive training based on VR. 1–5.

⁸⁰ Zhao et al. Virtual Reality Technology. 1–8.

⁸¹ Hu & Han. Gesture-based VR. 327–336.

⁸² Ip et al. Enhance Emotional skills. 1–15.

⁸³ Ip et al. Enhance Emotional skills. 1–15.

⁸⁴ Lorenzo et al. (2016). Immersive virtual reality system, 192–205.

⁸⁵ Yuan & Ip. Using Virtual Reality. 110–112.

⁸⁶ Hu & Han. Gesture-based VR. 327–336.

⁸⁷ Ke et al. VR-based Social Skills Training. 49–62.

⁸⁸ Zhao et al. Cognitive training based on VR. 1–5.

⁸⁹ Zhao et al. Virtual Reality Technology. 1–8.

⁹⁰ Hu & Han. Gesture-based VR. 327–336.

⁹¹ Herrero & Lorenzo. Immersive VR. 1689–1722.

⁹² Zhao et al. Cognitive training based on VR. 1–5.

⁹³ Herrero & Lorenzo. Immersive VR. 1689–1722.

⁹⁴ Lorenzo et al. Immersive virtual reality system, 192–205.

among children with ASD, which could aid in furthering the integration and inclusive education of these children. Moreover, the studies had varying participant age ranges, from two to seven years⁹⁵ to 10 to 14 years⁹⁶. Despite age differences, the interventions showed positive outcomes. This suggests that VR and cognitive training tools are versatile and can be effectively used across various developmental stages.

Customisation and Personalisation

The diversity of interventions – ranging from immersive VR experiences to gesture-based learning – points towards customisation. Children with ASD often have distinct needs and sensitivities. VR's ability to adapt to these, providing individualised learning paths (as seen in Zhao et al.⁹⁷, can significantly enhance these children's learning experiences and outcomes. Using technology to personalise educational and therapeutic interventions could thus represent a significant stride forward in special needs education. Lorenzo et al.⁹⁸ observed a significant enhancement in emotional competencies through VR immersion. Similarly, Ke et al.⁹⁹ reported increased social skills performance in a desktop VR-based learning environment. This indicates that immersive and non-immersive VR technologies can effectively train emotional and social skills.

Long-term Impact and Retention

While most studies reported positive outcomes within their respective durations, ranging from 4 to 40 weeks, few explored the long-term retention of skills acquired through VR and cognitive training. Hu and Han¹⁰⁰ note that participants maintained acquired skills for up to 12 weeks post-intervention. This suggests an area for future research, emphasising longitudinal studies to understand how enduring these benefits are. In addition, it suggests what factors contribute to sustained success.

Barrier Reduction in Access to Interventions

Despite its advanced capabilities, VR technology is becoming increasingly accessible and affordable. This accessibility could significantly reduce the barriers to effective emotional and social skill development interventions, especially in under-resourced areas or communities. Furthermore, as technology advances, the potential for even more immersive, interactive and engaging learning experiences promises to enhance the efficacy of these interventions further. Zhao et al.¹⁰¹ specifically noted improvements in typical ASD symptoms, such as social communication disorders and speech retardation, through cognitive training based on VR. This suggests that targeted VR interventions can directly impact core ASD symptoms. This provides a compelling

⁹⁵ Zhao et al. Virtual Reality Technology. 1–8.

⁹⁶ Ke et al. VR-based Social Skills Training. 49–62.

⁹⁷ Zhao et al. Virtual Reality Technology. 1–8.

⁹⁸ Lorenzo et al. Immersive virtual reality system, 192–205.

⁹⁹ Ke et al. VR-based Social Skills Training. 49–62.

¹⁰⁰ Hu & Han. Gesture-based VR. 327–336.

¹⁰¹ Zhao et al. Virtual Reality Technology. 1–8.

argument for incorporating technology-driven methods into treatment and education plans for ASD.

Professional Training and Implementation

The promising results reported across these studies also highlight the need to adequately train educators, therapists and professionals in using these technologies to their full potential. As Herrero and Lorenzo¹⁰² and Ip et al.¹⁰³ suggest, VR interventions require technological infrastructure and skilled professionals who can guide and support children through these experiences. Professional development programmes must evolve alongside technological development to equip stakeholders with the necessary skills.

Conclusion

The systematic literature review highlights the significant potential of VR as a transformative tool in the education and therapy of individuals with ASD. Comparatively, the choice of data analysis technique across these studies reflects the alignment with the study design and objectives, where inferential statistics are carefully selected based on the specific hypotheses being tested. Techniques like mixed ANOVA and two-way ANOVA provide detailed insights into interaction effects, not just across time but also across conditions or factors, enriching our understanding of how interventions work in complex settings. Through various studies, VR has demonstrated its efficacy in improving social communication skills. It has also reduced phobias, enhanced cognitive abilities and provided safe environments for social interactions.

VR's immersive nature allows for a controlled, structured and individualised learning experience tailored to the unique needs and sensitivities of individuals with ASD. This technology addresses the core challenges these individuals face and opens new avenues for their empowerment and inclusion in society. Future research should focus on longitudinal studies to further understand the long-term benefits and impacts of VR interventions and on innovative VR applications that could support individuals with ASD in more engaging and impactful ways. In addition, considerations around accessibility, affordability, and the integration of VR into existing therapeutic frameworks will be critical to the widespread adoption and success of VR interventions for ASD. As we move forward, VR holds significant promise as a complementary tool in the multifaceted approach to supporting individuals with ASD, with the potential to enhance their personal development and quality of life.

Limitations

The review of the use of VR interventions for individuals with ASD encountered

¹⁰² Herrero & Lorenzo. Immersive VR. 1689–1722.

¹⁰³ Ip et al. Enhance Emotional skills. 1–15.

several limitations that could impact the interpretation and generalisability of the findings. One of the limitations is the inherent variability in study designs and methodologies across the included literature. The diversity in VR technologies, intervention protocols, outcome measures and participant characteristics may introduce challenges in comparing and synthesising findings across studies. In addition, the availability of high-quality randomised controlled trials (RCTs) specifically focusing on VR interventions for ASD education was limited. Most studies in this area rely on smaller sample sizes or quasi-experimental designs, which could affect the strength of evidence and the ability to draw definitive conclusions about the effectiveness of VR interventions.

Furthermore, language bias is a significant concern, as the review only included studies published in English. This exclusion of non-English language studies may have potentially overlooked valuable research conducted in other languages, leading to a partial representation of the available evidence. Finally, the rapidly evolving nature of VR technology and its applications in ASD education may limit the long-term relevance of the review's findings. New studies and advancements in VR interventions for ASD are likely to emerge beyond the scope of this review, necessitating ongoing monitoring and updates to maintain relevance. Acknowledging these limitations is essential for interpreting the review's results accurately and understanding the scope of the existing evidence base. Despite these challenges, the systematic review provided a comprehensive synthesis of the current knowledge on VR interventions for individuals with ASD and identified areas for future research and development in this field.

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