The Effectiveness of Different Virtual Reality Technologies on Social and Communication Skills in Children with Autism Spectrum Disorder: A Systematic Review and Network Meta-Analysis of Randomized Controlled Trials

Lin Wang, Dan Li, Xiuyan Gao, Jin Zhao, Yajun He, Ningning Fu, Shaolong Liu, XiuMei Bu

Submitted to: JMIR Pediatrics and Parenting
on: August 22, 2025

Table of Contents

The Effectiveness of Different Virtual Reality Technologies on Social and Communication Skills in Children with Autism Spectrum Disorder: A Systematic Review and Network Meta-Analysis of Randomized Controlled Trials

Lin Wang[1*]; Dan Li[2*]; Xiuyan Gao[1]; Jin Zhao[3]; Yajun He[4]; Ningning Fu[1]; Shaolong Liu[1]; XiuMei Bu[1]

[1] School of Nursing Liaoning University of Traditional Chinese Medicine Liaoning Province CN
[2] Liaoning University of Traditional Chinese Medicine Liaoning Province CN
[3] Liaoning Provincial Health and Wellness Service Center Liaoning Province CN
[4] Liaoning Provincial Nursing Association Liaoning Province CN
[*]these authors contributed equally

Corresponding Author:
XiuMei Bu

School of Nursing
Liaoning University of Traditional Chinese Medicine
Liaoning University of Traditional Chinese Medicine, No. 79, Chongshan Road, Huanggu District
Liaoning Province
CN

Abstract

Background: Autism spectrum disorder (ASD) is characterized by core impairments in social interaction and communication, with limited effective interventions to address these challenges. Traditional therapies such as behavioral training and pharmacotherapy often face limitations in ecological validity and side-effect profiles. Virtual reality (VR) technology has emerged as a promising alternative, leveraging immersive and interactive environments to simulate real-world social scenarios. However, the comparative effectiveness of different VR modalities remains unclear. This knowledge gap hinders clinical decision-making and the adoption of VR technologies in ASD intervention, highlighting the need for systematic evaluation to clarify the efficacy of various VR approaches.

Objective: This study aimed to evaluate the effectiveness of different virtual reality (VR) technologies in improving social and communication skills in children with Autism Spectrum Disorder (ASD) and to determine the optimal intervention program through a network meta-analysis (NMA).

Methods: A systematic search was conducted in PubMed, Embase, Cochrane Library, Web of Science, EBSCOhost, CNKI, VIP, Wanfang databases for randomized controlled trials (RCTs) from January 1990 to 26 February, 2025. The overall risk of bias of the included literature was summarized using the revised Cochrane risk of bias tool for randomized trials (RoB-2). Based on the frequency theory framework, statistical analysis was conducted using STATA 18.0. The quality of evidence was evaluated using the confidence in the network meta-analysis (CINeMA) framework.

Results: A total of 11 RCTs (n = 718) were included. The network evidence diagram showed that eight techniques constitute the main comparison nodes. Compared with conventional care, HMD significantly improved social communication deficits (SMD = 8.17, 95% CI: 2.60, 13.74), with the highest SUCRA value (82.6%), making it the optimal intervention. The risk of bias in the included literature is relatively low, and the overall quality of evidence is moderate.

Conclusions: As an immersive VR technology, HMD can effectively improve the social ability of children with ASD and is recommended as a first-line supplementary intervention. Further studies are needed to expand the sample size. Clinical Trial: This study is registered in PROSPERO international system evaluation platform registered (CRD420250654696).

(JMIR Preprints 22/08/2025:82814)
DOI: https://doi.org/10.2196/preprints.82814

Preprint Settings

1) Would you like to publish your submitted manuscript as preprint?

✓ **Please make my preprint PDF available to anyone at any time (recommended).**

Please make my preprint PDF available only to logged-in users; I understand that my title and abstract will remain visible to all users.

Only make the preprint title and abstract visible.

No, I do not wish to publish my submitted manuscript as a preprint.

2) If accepted for publication in a JMIR journal, would you like the PDF to be visible to the public?

✓ **Yes, please make my accepted manuscript PDF available to anyone at any time (Recommended).**

Yes, but please make my accepted manuscript PDF available only to logged-in users; I understand that the title and abstract will remain v

Yes, but only make the title and abstract visible (see Important note, above). I understand that if I later pay to participate in <a href="http

No. Please do not make my accepted manuscript PDF available to anyone. I understand that if I later pay to participate in <a href="https:/

Original Manuscript

The Effectiveness of Different Virtual Reality Technologies on Social and Communication Skills in Children with Autism Spectrum Disorder: A Systematic Review and Network Meta-Analysis of Randomized Controlled Trials

Author: Lin Wang[a 1], Dan Li[a 1], Xiuyan Gao[a], Jin Zhao[b], Yajun He[c], Ningning Fu[a], Shaolong Liu[a], Xiumei Bu[a]

Corresponding author: Xiumei Bu, Liaoning University of Traditional Chinese Medicine, No. 79, Chongshan Road, Huanggu District, 110847 Shenyang, Liaoning, China.1366319241@qq.com.

Affiliations:
[a] Liaoning University of Traditional Chinese Medicine, Shenyang, Liaoning, China
[b] Liaoning Provincial Health and Wellness Service Center, Shenyang, Liaoning, China
[c] Liaoning Provincial Nursing Association, Shenyang, Liaoning, China

[1] Lin Wang and Dan Li should be considered joint first author

Abstract

Background: Autism spectrum disorder (ASD) is characterized by core impairments in social interaction and communication, with limited effective interventions to address these challenges. Traditional therapies such as behavioral training and pharmacotherapy often face limitations in ecological validity and side-effect profiles. Virtual reality (VR) technology has emerged as a promising alternative, leveraging immersive and interactive environments to simulate real-world social scenarios. However, the comparative effectiveness of different VR modalities remains unclear. This knowledge gap hinders clinical decision-making and the adoption of VR technologies in ASD intervention, highlighting the need for systematic evaluation to clarify the efficacy of various VR approaches.

Objective: This study aimed to evaluate the effectiveness of different virtual reality technologies in improving social and communication skills in children with Autism Spectrum Disorder and to determine the optimal intervention program through a network meta-analysis (NMA).

Methods: A systematic search was conducted in PubMed, Embase, Cochrane Library, Web of Science, EBSCOhost, CNKI, VIP, Wanfang databases for randomized controlled trials (RCTs) from January 1990 to 26 February, 2025. The overall risk of bias of the included literature was summarized using the revised Cochrane risk of bias tool for randomized trials (RoB-2). Based on the frequency theory framework, statistical analysis was conducted using STATA 18.0. The quality of evidence was evaluated using the confidence in the network meta-analysis (CINeMA) framework.

Results: A total of 11 RCTs (n = 718) were included. The network evidence diagram showed that eight techniques constitute the main comparison nodes. Compared with conventional care, HMD significantly improved social communication deficits (SMD = 8.17, 95% CI: 2.60, 13.74), with the highest SUCRA value (82.6%), making it the optimal intervention. The risk of bias in the included literature is relatively low, and the overall quality of evidence is moderate.

Conclusions: As an immersive VR technology, HMD can effectively improve the social ability of children with ASD and is recommended as a first-line supplementary intervention. Further studies are needed to expand the sample size.

Registration: This study is registered in PROSPERO international system evaluation platform registered (CRD420250654696).

Keyword: Autism Spectrum Disorder, Virtual Reality, Social Communication Skills, Network Meta-Analysis, Children

Introduction

Autism Spectrum Disorder (ASD), commonly referred to as autism, is a neurodevelopmental disorder that originates in early childhood. Its primary characteristics include impairments in social interaction and communication, repetitive patterns of behavior, and restricted interests or activities[1]. The global prevalence of autism is on the rise[2]. According to the 2023 report from the US Centers for Disease Control and Prevention, by 2020, the prevalence of ASD among 8-year-old children was approximately 1 in 36 (4% for boys and 1% for girls), which is higher than the estimation of the ADDM network from 2000 to 2018[3]. A multi-stage convenience cluster sampling study in China indicates that the estimated prevalence of ASD among children aged 6-12 in China is 0.70%, equivalent to approximately 700,000 children[4]. One of the core symptoms of ASD is social impairment, which manifests as a lack of early social interest and motivation compared to peers, ultimately affecting their ability to engage socially[5]. Even when they exhibit social interest, they often lack the necessary social skills for appropriate interaction with others[6]. This leads to difficulties in effectively communicating and interacting with others, hindering their ability to maintain normal social relationships, which further impacts their language skills and mental health[7]. Therefore, it is essential to identify effective and sustainable measures to enhance social and communication skills among individuals with ASD.

Although current medical research has made certain progress, the exact cause of the disease has not been fully clarified. Existing studies suggest that the disorder may be caused by the interaction of multiple factors, such as genetic susceptibility[8], environmental exposure[9], and abnormal changes in the neurodevelopmental process. Due to the complexity of its pathogenesis, there is currently no specific treatment strategy targeting the cause[10]. Currently, clinical practice primarily employs comprehensive treatment, encompassing drug therapy, behavioral modification, educational training, and physical therapy[11,12]. However, traditional treatments still have some limitations. For example, behavioral training relies heavily on the therapeutic room environment and lacks ecological validity in real-world social scenarios, making it difficult to transfer skills[13]. Second-generation antipsychotic drugs (such as risperidone) can alleviate aggressive behavior but cannot improve core symptoms and carry the risk of metabolic syndrome[14]. In addition, autism is characterized by a high disability rate and currently lacks an effective cure. Its management primarily involves long-term, intensive professional rehabilitation interventions aimed at enhancing the overall abilities of children with autism. Nevertheless, these interventions impose significant economic burdens, demand substantial time commitments from caregivers, and exert considerable psychological pressure[15]. Moreover, they present formidable challenges for the allocation of social public resources, the establishment of professional service systems, and ensuring their long-term sustainability.

Since the 1990s, numerous empirical studies have systematically explored the feasibility and effectiveness of utilizing virtual reality for training and intervention in ASD individuals[16]. VR technology is capable of integrating the real and virtual worlds, replicating diverse scenarios via algorithms, generating immersive experiences, and enabling human-computer interaction through controllers, thereby embodying the characteristics of immersion, interactivity, and imagination[17]. Over the past two decades, VR has been extensively applied in medicine and has garnered increasing attention in clinical cognitive rehabilitation[18]. Relevant research indicates that VR not only enhances the life skills of ASD patients[19], but also improves their cognitive abilities[20], emotional regulation and recognition skills[21], as well as social and communication competencies[22]. Studies demonstrate that VR technology exhibits unique advantages in addressing core symptoms in children with ASD through mechanisms such as neuroplastic remodeling, behavioral reinforcement learning, and multimodal compensation[23].

Current VR intervention studies encompass desktop-based, augmented reality, immersive, and hybrid technologies[24], with intervention content spanning areas such as social communication and emotional cognition[25]. However, the effects of different types and application contexts of VR technologies on the social and communicative abilities of individuals with ASD remain ambiguous, and there is a paucity of comparative analyses across these approaches. This study seeks to comprehensively assess the efficacy of various virtual reality interventions for children with autism by integrating direct and indirect evidence. It aims to compare and quantitatively rank the effectiveness of different VR applications, thereby addressing the central question of "which VR approach is most effective." The findings will provide practical, reliable intervention strategies for ASD rehabilitation and offer robust scientific guidance for technology development and policy formulation.

Methods

This systematic review was conducted in accordance with the Preferred Reporting Items (PRISMA) statement for Systematic Reviews and meta-Analyses and the PRISMA extension of the NMA guidelines[26], the details of which can be found in **Supplement 1.** This study is registered in PROSPERO international system evaluation platform registered (No. CRD420250654696).

Search strategy and inclusion and exclusion criteria

The selection and search strategies for eligible studies were constructed based on the PICOS (Population/Patient, Intervention, Comparator, Outcome, and Study Design) framework. We systematically retrieved data from eight electronic databases (PubMed, Embase, Cochrane Library, Web of Science, EBSCOhost, CNKI, VIP, Wanfang) from 1990 to 26 February, 2025. To ensure no eligible literature was overlooked, we also examined the reference lists of earlier systematic reviews[27–31]and the included studies as supplementary sources. Only articles in Chinese and English were included in the search, and the comprehensive strategy can be found in Supplement 2. Following a thorough search of numerous databases, duplicate publications were discarded. Titles and abstracts were then screened, and full texts were assessed according to the inclusion/exclusion criteria. The screening and selection process was independently conducted by two evaluators (L.W and XY.G). Any differences are determined through consultation by a third evaluator (XM.B).

Table 1 displays the specific selection criteria. Overall, if a study meets the following conditions, it is considered to be eligible: (1) The trial design is a randomized controlled trial aiming to evaluate the effectiveness of any VR intervention on children with autism; (2) Recruitment of children diagnosed with ASD is based on clinical assessments or the criteria from the DSM-5 or other recognized diagnostic standards (such as the Autism Diagnostic Observation Schedule, 2nd Edition, or the International Classification of Diseases, 10th Edition); (3) Participants in the control group underwent non-VR interventions, non-drug treatments, or routine nursing care, while those in the experimental group were exposed to VR interventions; (4) At least one outcome related to social or communication function is reported in the outcome indicators. If a study (1) is a re-published article; (2) cannot obtain the full text or has a high risk of bias (such as an unrigorous trial design, lack of participant data, etc.); (3) is a review, observational study, case report, letter to the editor or conference abstract will be excluded.

Outcome

The primary outcome was social and communication skills. The efficacy was expressed as the change in the overall social and communication symptom assessment score after VR intervention (data before and after the intervention).

Data extraction

Two independent reviewers (NN.F and SL.L) extracted relevant information in a standard manner, including bibliographic data (author, publication year, country/region), participant characteristics (age, gender, sample size), intervention components (category, frequency, duration), and immediate post-intervention primary outcome measures. In cases where studies used two or more measurements for the same outcome indicator, the task most commonly utilized was included. If a single task had multiple raw scores, the higher-quality results were preferred. The formula from the Cochrane Handbook was used to calculate the changes in mean and standard deviation relative to the baseline when they were not fully reported[32]. We reached out to the corresponding author via email to gather more information if any data was missing. The Cochrane risk of bias tool for randomized trials[33]was used to assess the methodological quality of the included randomized controlled trials. The evidence quality of social and communication abilities was evaluated within the framework of Network Meta-Analysis Confidence Interval Meta-Analysis (CINeMA)[34].

Data Analysis

The data analysis was conducted jointly by two researchers (L.W and D.L). All the measures of outcome in this study were continuous variables. In order to mitigate the effect of baseline variations, the alteration in mean and standard deviation pre- and post-intervention was used for effect size pooling. Because the evaluation tools and units used in individual studies were slightly different, standardized mean difference (SMD) was used as the effect scale to calculate the combined effect size, in which no 0 in the 95% confidence interval (CI) indicated that the difference was significant.

Network meta-statistics were performed using the random-effects-model of the frequentist framework of Stata 18.0 software to compare relative effectiveness by direct and indirect comparisons. The Network package was used to draw the network evidence map. If there was a closed loop between studies, the node splitting method was used for consistency check, and if there was inconsistency, the inconsistency model was used[35]. Treatment rankings were established using SUCRA, which reflects the effectiveness of each intervention. Higher values denote better effects[36]. Additionally, heterogeneity was tested using the I^2 value. When $P \geq 0.05$ and $I^2 \leq 50\%$, studies were considered homogeneous, leading to the adoption of a fixed-effect model, whereas significant heterogeneity, with $P < 0.05$ and $I^2 > 50\%$, necessitated a random-effect model. We used a method of eliminating articles from the literature individually to perform sensitivity analyses, aiming to assess the robustness of our findings and identify potential heterogeneity sources. A meta-regression analysis was carried out to examine how sample size, intervention duration, and dosage impacted the initial analysis. Subgroup analysis was done considering the duration, frequency, length, and intensity of the intervention. The funnel plot adjusted was used to evaluate the effect of small-scale studies[37].The test level α=0.05.

Results

The retrieval of the system identified 1198 records from the electronic database. Once duplicates were eliminated, the titles and summaries of the bar records were reviewed, and 125 full-text articles were obtained to assess their eligibility. Another 134 records determined from the reference list of the relevant systematic review were also screened as qualified. The method used for literature screening is presented in **Figure 1**. Finally, a total of 11 studies [38–48]were included in this review, involving 718 children with ASD.

Research characteristics

Table 2 summarizes the details of each included study. Among them, all 11 studies employed formal diagnostic criteria to diagnose ASD. In terms of intervention forms, the experimental group involved eight virtual technology intervention methods, namely: digital platform, head-mounted display, VR glasses, MR, CAVE, H-CAVE, desktop VR, and magic skill training. Among them, HMD (n = 3) was the most commonly used VR intervention method, followed by the digital platform. All studies reported the assessment of outcome variables after the intervention. In parallel, 11 studies mentioned the duration of the intervention, the duration of the word intervention ranging from the shortest 15 minutes to the longest 60 minutes; the frequency of the intervention varying from once a week to five times a week; and the duration of the intervention ranging from once to six months.

Risk of Bias Assessment

Two researchers (J.Z. and YJ.H) respectively evaluated the risk of bias in each study.

The assessment of domain level and overall risk of bias is presented in Supplement 3. Among the five dimensions, one study was low risk, seven had some concerns, and three were high risk, primarily due to the open-label design and randomization process.

Assessment of quality of evidence

The quality of evidence for each comparison was rated as high, moderate, low, or very low. The limited number of included studies increased the risk of reporting bias. Regarding the effectiveness of VR interventions in enhancing social and communication functions, the evidence quality ranged from very low to low (evaluation details in **Supplement 8**). This downgrading was primarily due to concerns regarding risk of bias within studies, imprecision, and heterogeneity.

Pairwise meta-analyses

Results from the pairwise meta-analysis of 11 RCTs are presented in **Figure 2**. Children with ASD in the VR intervention group showed a significantly greater improvement in social function relative to the control group (SMD=1.26, 95%CI: 0.67-1.84). This indicates that VR interventions are effective in improving social and communication skills for children with ASD.

Network Evidence Diagram

The effective rates were reported in all 11 studies, as shown in **Figure 3**. In the relationship among the intervention measures, the points represent the intervention methods of virtual reality technology adopted, with each point assigned the total number of participants in each study. The edges are assigned the standard errors. The lines between the points represent the direct comparison between the two intervention forms. The absence of a direct connecting line between two interventions indicates that no head-to-head comparison trials were available. Consequently, comparative effectiveness estimates for these pairs were derived solely through indirect comparison analysis. Furthermore, as the network geometry did not form any closed loops of evidence, assessment of inconsistency between direct and indirect evidence was not applicable.

The influence of different intervention forms on the social and communication abilities of Autism Spectrum Disorder

Table 3 presents the comparative effects of eight different treatments. When compared to conventional care, a statistically significant difference was observed in HMD (SMD = 8.17, 95% CI: 2.60, 13.74). In contrast, no statistically significant differences were detected among the various intervention measures. **Table 4** shows the treatment ranking of SUCRA for various intervention measures. HMD (SUCRA = 82.6%) may be the most effective. The ranking plits is shown in **Supplement 4**.

Other analyses

Meta-regression did not indicate the significant effects of region, intervention form, intervention duration and intervention cycle on social and communication skills. Meanwhile, subgroup analysis showed significant heterogeneity among different regions and different intervention form groups. The research results are presented in **Supplement 5**. The source of this heterogeneity might be due to the insufficient sample size of the included original studies. Furthermore, in a single intervention, a treatment course of more than 40 minutes showed significant heterogeneity, which might be attributed to methodological differences, individual differences among participants, and publication bias, etc. **In Supplement 6**, the sensitivity analysis demonstrated that excluding studies with a high risk of bias generally yielded results consistent with the original findings. The funnel plot of **Supplement 7** shows that the scattered points are mainly located at the top of the funnel and present bilateral symmetry, indicating that the studies using the Social Functioning Assessment Scale as the outcome measurement have the least publication bias. However, three studies were located outside the funnel and were rather scattered, indicating that there might be a certain degree of publication bias, which could be due to the small sample size and low accuracy.

Discussion

This study conducted a network meta-analysis by including 11 randomized controlled trials to systematically evaluate the effectiveness of various virtual reality technologies in improving the social and communication skills of children with ASD, and ranked the effectiveness of different interventions through quantitative comparison. The results indicate that head-mounted displays (HMDs) demonstrate a significant advantage over conventional care and other VR technologies in addressing social communication deficits, making them a promising first-line supplementary intervention. As the first NMA study focusing on differences in VR intervention forms, its quantitative comparison framework significantly enhances the evidence strength compared to traditional qualitative reviews, despite the limited number of included studies and relatively low quality of evidence.

The advantages of HMD are not only reflected in the statistical differences of therapeutic indicators, but also stem from the targeted intervention mechanism of HMD technical characteristics for the core defects of ASD. The therapeutic effects of HMD align with the conclusions of Bradley and Newbutt's [49] systematic review, which highlights the potential of individuals with ASD to use VR-HMD technology for social skills training, daily living skill acquisition, and generalization of these skills to real-world contexts. HMD leverages its 3I characteristics (immersion, interaction, and imagination)[50] to construct controllable virtual social scenarios, offering opportunities for practicing dynamic and realistic social interactions[51].

Unlike traditional interventions constrained by venue resources and participant motivation, HMD enhances accessibility and flexibility through customizable virtual environments. For instance, a pilot study[52] demonstrated an acceptance rate of 86% among individuals with ASD, with no influence of IQ level on willingness to use or immersive experience.

Compared with previous studies, the innovation of this research lies in its integration of VR technology classifications through a network meta-analysis and the clear identification of HMD's priority. Unlike early foundational studies[53] that confirmed VR efficacy without technology differentiation, we quantified HMD superiority through SUCRA rankings and identified a dose-effect relationship between immersion level and therapeutic outcomes. Specifically, desktop VR ranked second (SUCRA = 77.9%, SMD = 7.65, 95% CI: 0.63, 14.66), aligning with reports of its suitability for older/high-functioning ASD children due to lower sensory demands[54] and validated social interaction benefits[55].Conversely, Augmented Reality (AR) exhibited unstable effects (SMD = 6.14, 95% CI: -3.11, 15.39), attributable to environmental noise-induced sensory overload—consistent with Kandalaft [56]. The CAVE system’s fixed-space constraints (SUCRA = 30.4%) further limit personalized interventions for heterogeneous ASD needs. Thus, HMDs demonstrate superior clinical utility via flexibility and customizability. Notably, the H-CAVE system (SUCRA = 40.5%) mitigated traditional CAVE limitations by balancing immersion with environmental awareness, potentially benefiting ASD sensory regulation. However, our social interaction-focused results diverge from Cheng[57], where CAVE excelled in emotion recognition tasks, suggesting task-dependent efficacy. Mixed Reality (MR) underperformed (SUCRA = 28.9%), likely due to current emphasis on static object interactions over dynamic social scenarios. Consequently, future work should prioritize MR for complex social rule training.

Despite compelling evidence of HMD's clinical utility for ASD interventions, its real-world implementation faces dual challenges. Although concerns regarding adverse effects[52]persist, empirical data indicate comparable anxiety levels in children with ASD using HMDs versus monitor-based interventions[58], suggesting potential underestimation of HMD's clinical acceptability. Critically, studies confirm high engagement and adaptability to HMD technology among ASD populations[49]. Nevertheless, pragmatic barriers—particularly equipment costs and specialized training requirements—constrain broad implementation, especially in resource-limited settings. To advance clinical translation while mitigating these barriers, we propose integrating HMDs as advanced reinforcement tools with cost-effective mobile VR for initial adaptation training. Concurrently, clinicians must address risks of overgeneralization, including resistance to enclosed HMD environments or excessive reliance on virtual interactions. Thus, intervention frameworks should incorporate a structured "virtual-to-real transition" phase, systematically fading virtual cues while escalating real-world social engagement.

This study indicates that virtual reality-based therapeutic interventions can be integrated into the multimodal framework of personalized treatment for individuals with ASD, particularly addressing the contextual learning requirements of children with ASD. In regions where budgets permit, priority should be given to acquiring medical-grade HMD systems. Future research should focus on three key areas: First, enhancing sample diversity by including subgroups from varied cultural backgrounds and across the spectrum of ASD severity to validate the generalizability of HMD applications. Second, employing multimodal assessments, such as electroencephalography (EEG) and eye-tracking, to elucidate the underlying mechanisms of HMD effects. Third, investigating the synergistic potential between HMD technology and behavioral therapies, potentially leveraging the Naturalistic Developmental Behavioral Intervention (NDBI) framework proposed by Boyd[59], wherein VR scenarios could serve as a "preparatory platform" for naturalistic teaching contexts.

Limitations

Firstly, while the inclusion of 11 RCTs satisfied the minimum node connectivity requirement for NMA, some comparison groups were based on only one study. This limitation may compromise statistical power and result in unstable effect size estimates. Future research should prioritize increasing the density of evidence through multi-center collaborations or individual patient data meta-analyses (IPD-MA). Secondly, approximately half of the studies exhibited a risk of bias, with 27%

classified as high risk. However, sensitivity analyses indicated that excluding high-risk studies did not significantly alter the stability of the effect estimates. To enhance the overall quality of evidence, future studies should focus on improving the transparency and rigor of reporting randomization processes, protocol adherence, and outcome measurements. Lastly, significant heterogeneity across studies was observed, likely attributable to variations in patient characteristics and inconsistencies in VR intervention protocols. Although a random-effects model was employed to assess consistency, subgroup analyses and meta-regression failed to fully elucidate the sources of heterogeneity. Therefore, future investigations should emphasize more comprehensive data collection strategies to refine analytical approaches and better address these discrepancies.

Conclusion

This NMA presents a comprehensive analysis of all existing VR technologies to date aimed at alleviating social and communication impairments in children with ASD and evaluates their therapeutic effects. Our findings suggest that HMDs are the most promising intervention for improving social and communication skills in individuals with ASD.

In addition, future treatment plans for children with ASD could be refined by leveraging the preliminary findings of this NMA, focusing on the development of hybrid models that integrate virtual reality technology with conventional therapeutic approaches.

Acknowledgments

The authors have nothing to report.

Conflict of Interest Statement

The authors declare no conflicts of interest.

Funding

The author declares that there is no funding.

References

1. Guha M. Diagnostic and statistical manual of mental disorders: DSM-5. Reference Reviews Emerald Publishing; 2014;28(3):36–37.
2. Lord C, Elsabbagh M, Baird G, Veenstra-Vanderweele J. Autism spectrum disorder. Lancet Elsevier; 2018 Dec 14;392(10146):139–154. Available from: http://link.springer.com/10.1007/978-3-319-98414-8_11
3. Maenner MJ. Prevalence and characteristics of autism spectrum disorder among children aged 8 years—autism and developmental disabilities monitoring network, 11 sites, United States, 2020. MMWR Surveill Summ 2016 Apr 1;65(3):1–23. Available from: http://www.cdc.gov/mmwr/volumes/65/ss/ss6503a1.htm
4. Zhou H, Xu X, Yan W, Zou X, Wu L, Luo X, Li T, Huang Y, Guan H, Chen X. Prevalence of autism spectrum disorder in China: a nationwide multi-center population-based study among children aged 6 to 12 years. Neurosci Bull Springer; 2020 June 30;36(9):961–971. Available from: https://link.springer.com/10.1007/s12264-020-00530-6
5. Neuhaus E, Webb SJ, Bernier RA. Linking social motivation with social skill: The role of emotion dysregulation in autism spectrum disorder. Dev Psychopathol Cambridge University Press; 2019 Apr 8;31(3):931–943. Available from: https://www.cambridge.org/core/product/identifier/S0954579419000361/type/journal_article
6. Chan N, Fenning RM, Neece CL. Prevalence and phenomenology of anxiety in preschool-aged children with autism spectrum disorder. Research on Child and Adolescent Psychopathology Springer; 2022 Sept 1;51(1):33–45. Available from: https://link.springer.com/10.1007/s10802-022-00964-8
7. Matson JL. Handbook of social behavior and skills in children. Springer; 2017. Available from: http://link.springer.com/10.1007/978-3-319-64592-6 ISBN:978-3-319-64591-9
8. de la Torre-Ubieta L, Won H, Stein JL, Geschwind DH. Advancing the understanding of autism disease mechanisms through genetics. Nat Med Nature Publishing Group US New York; 2016 Apr;22(4):345–361. Available from: https://www.nature.com/articles/nm.4071
9. Kuodza GE, Kawai R, LaSalle JM. Intercontinental insights into autism spectrum disorder: a synthesis of environmental influences and DNA methylation. Environ Epigenet Oxford University Press UK; 2024;10(1):dvae023. Available from: https://academic.oup.com/eep/article/doi/10.1093/eep/dvae023/7884223
10. Eissa N, Al-Houqani M, Sadeq A, Ojha SK, Sasse A, Sadek B. Current enlightenment about etiology and pharmacological treatment of autism spectrum disorder. Front Neurosci Frontiers Media SA; 2018 May 16;12:304. Available from: http://journal.frontiersin.org/article/10.3389/fnins.2018.00304/full
11. Genovese A, Butler MG. Clinical assessment, genetics, and treatment approaches in autism spectrum disorder (ASD). Int J Mol Sci Multidisciplinary Digital Publishing Institute; 2020 July 2;21(13):4726. Available from: https://www.mdpi.com/1422-0067/21/13/4726

12. Hyman SL, Levy SE, Myers SM, Kuo DZ, Apkon S, Davidson LF, Ellerbeck KA, Foster JE, Noritz GH, Leppert MO. Identification, evaluation, and management of children with autism spectrum disorder. Pediatrics American Academy of Pediatrics; 2021 Apr 7;145(1):855–925. Available from: https://publications.aap.org/aapbooks/book/678/chapter/8184867/Identification-Evaluation-and-Management-of
13. Williams BF, Williams RL. Effective programs for treating autism spectrum disorder: Applied behavior analysis models. Routledge; 2010. ISBN:0-203-85503-5
14. Wong CM, Aljunied M, Chan DKL, Cheong JMY, Chew B, Chin CH, Choo SHT, Chua AHL, Foo MTS, Goh TJ. 2023 clinical practice guidelines on autism spectrum disorder in children and adolescents in Singapore. Ann Acad Med Singapore Academy of Medicine, Singapore; 2024 Apr 29;53(4):241–252. Available from: https://annals.edu.sg/2023-clinical-practice-guidelines-on-autism-spectrum-disorder-in-children-and-adolescents-in-singapore/
15. Rogge N, Janssen J. The economic costs of autism spectrum disorder: A literature review. J Autism Dev Disord Springer; 2019 Apr 11;49(7):2873–2900. Available from: http://link.springer.com/10.1007/s10803-019-04014-z
16. Parsons S, Cobb S. State-of-the-art of virtual reality technologies for children on the autism spectrum. Technology and students with special educational needs Routledge; 2011. p. 355–366. Available from: http://www.tandfonline.com/doi/abs/10.1080/08856257.2011.593831
17. Rauschnabel PA, Felix R, Hinsch C, Shahab H, Alt F. What is XR? Towards a framework for augmented and virtual reality. Comput Hum Behav Elsevier; 2022 Aug;133:107289. Available from: https://linkinghub.elsevier.com/retrieve/pii/S074756322200111X
18. He D, Cao S, Le Y, Wang M, Chen Y, Qian B. Virtual reality technology in cognitive rehabilitation application: bibliometric analysis. JMIR Serious Games JMIR Publications Toronto, Canada; 2022 Oct 19;10(4):e38315. Available from: https://games.jmir.org/2022/4/e38315
19. Adjorlu A, Høeg ER, Mangano L, Serafin S. Daily living skills training in virtual reality to help children with autism spectrum disorder in a real shopping scenario. 2017 IEEE International Symposium on Mixed and Augmented Reality (ISMAR-Adjunct) Nantes, France: IEEE; 2017. p. 294–302. Available from: http://ieeexplore.ieee.org/document/8088509/
20. Didehbani N, Allen T, Kandalaft M, Krawczyk D, Chapman S. Virtual reality social cognition training for children with high functioning autism. Comput Hum Behav Elsevier; 2016 Sept;62:703–711. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0747563216303089
21. Farashi S, Bashirian S, Jenabi E, Razjouyan K. Effectiveness of virtual reality and computerized training programs for enhancing emotion recognition in people with autism spectrum disorder: a systematic review and meta-analysis. International Journal of Developmental Disabilities Taylor & Francis; 2022 Apr 18;70(1):110–126. Available from:

https://www.tandfonline.com/doi/full/10.1080/20473869.2022.2063656
22. Herrero JF, Lorenzo G. 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 Springer; 2019 Nov 18;25(3):1689–1722. Available from: http://link.springer.com/10.1007/s10639-019-10050-0
23. Zhang M, Ding H, Naumceska M, Zhang Y. Virtual reality technology as an educational and intervention tool for children with autism spectrum disorder: current perspectives and future directions. Behavioral Sciences MDPI; 2022 May 10;12(5):138. Available from: https://www.mdpi.com/2076-328X/12/5/138
24. Šlosar L, Voelcker-Rehage C, Paravlić AH, Abazovic E, de Bruin ED, Marusic U. Combining physical and virtual worlds for motor-cognitive training interventions: position paper with guidelines on technology classification in movement-related research. Front Psychol Frontiers Media SA; 2022 Dec 14;13:1009052. Available from: https://www.frontiersin.org/articles/10.3389/fpsyg.2022.1009052/full
25. Mittal P, Bhadania M, Tondak N, Ajmera P, Yadav S, Kukreti A, Kalra S, Ajmera P. Effect of immersive virtual reality-based training on cognitive, social, and emotional skills in children and adolescents with autism spectrum disorder: A meta-analysis of randomized controlled trials. Res Dev Disabil Elsevier; 2024 Aug;151:104771. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0891422224001033
26. Hutton B, Salanti G, Caldwell DM, Chaimani A, Schmid CH, Cameron C, Ioannidis JP, Straus S, Thorlund K, Jansen JP. The PRISMA extension statement for reporting of systematic reviews incorporating network meta-analyses of health care interventions: checklist and explanations. Ann Intern Med American College of Physicians; 2015 June 2;162(11):777–784. Available from: https://www.acpjournals.org/doi/10.7326/M14-2385
27. Baragash RS, Al-Samarraie H, Alzahrani AI, Alfarraj O. Augmented reality in special education: A meta-analysis of single-subject design studies. European Journal of Special Needs Education Taylor & Francis; 2019 Dec 20;35(3):382–397. Available from: https://www.tandfonline.com/doi/full/10.1080/08856257.2019.1703548
28. Denizli-Gulboy H, Genc-Tosun D, Gulboy E. Evaluating augmented reality as evidence-based practice for individuals with autism spectrum disorder: a meta-analysis of single-case design studies. International Journal of Developmental Disabilities Taylor & Francis; 2021 Sept 8;69(4):472–486. Available from: https://www.tandfonline.com/doi/full/10.1080/20473869.2021.1972741
29. Sandgreen H, Frederiksen LH, Bilenberg N. Digital interventions for autism spectrum disorder: a meta-analysis. J Autism Dev Disord Springer; 2020 Nov 10;51(9):3138–3152. Available from: https://link.springer.com/10.1007/s10803-020-04778-9
30. Xu F, Gage N, Zeng S, Zhang M, Iun A, O'Riordan M, Kim E. The use of digital interventions for children and adolescents with autism Spectrum disorder—a

Meta-analysis. J Autism Dev Disord Springer; 2024 Sept 26;1–17. Available from: https://link.springer.com/10.1007/s10803-024-06563-4
31. Zhang Q, Wu R, Zhu S, Le J, Chen Y, Lan C, Yao S, Zhao W, Kendrick KM. Facial emotion training as an intervention in autism spectrum disorder: A meta-analysis of randomized controlled trials. Autism Res Wiley Online Library; 2021 July 19;14(10):2169–2182. Available from: https://onlinelibrary.wiley.com/doi/10.1002/aur.2565
32. Chandler J, Cumpston M, Li T, Page MJ, Welch V. Cochrane handbook for systematic reviews of interventions. Hoboken: Wiley 2008 Sept 22;4. Available from: https://onlinelibrary.wiley.com/doi/book/10.1002/9780470712184
33. Sterne JA, Savović J, Page MJ, Elbers RG, Blencowe NS, Boutron I, Cates CJ, Cheng H-Y, Corbett MS, Eldridge SM. RoB 2: a revised tool for assessing risk of bias in randomised trials. Br Med J British Medical Journal Publishing Group; 2019 Aug 28;366:l4898. Available from: https://www.bmj.com/lookup/doi/10.1136/bmj.l4898
34. Nikolakopoulou A, Higgins JP, Papakonstantinou T, Chaimani A, Del Giovane C, Egger M, Salanti G. CINeMA: an approach for assessing confidence in the results of a network meta-analysis. PLoS Med Public Library of Science San Francisco, CA USA; 2020 Apr 3;17(4):e1003082. Available from: https://dx.plos.org/10.1371/journal.pmed.1003082
35. Dias S, Welton NJ, Caldwell DM, Ades AE. Checking consistency in mixed treatment comparison meta-analysis. Stat Med Wiley Online Library; 2010 Mar 8;29(7–8):932–944. Available from: https://onlinelibrary.wiley.com/doi/10.1002/sim.3767
36. Salanti G, Ades AE, Ioannidis JP. Graphical methods and numerical summaries for presenting results from multiple-treatment meta-analysis: an overview and tutorial. J Clin Epidemiol Elsevier; 2011 Feb;64(2):163–171. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0895435610001691
37. Egger M, Smith GD, Schneider M, Minder C. Bias in meta-analysis detected by a simple, graphical test. Br Med J British Medical Journal Publishing Group; 1997 Sept 13;315(7109):629–634. Available from: https://www.bmj.com/lookup/doi/10.1136/bmj.315.7109.629
38. Wang Y. Effects of immersive virtual reality technology on social skills in children with autism. Chinese Science and Technology Periodical Database (cited edition). Medicine and Health 2024;(2):0116–0119.
39. Zhao J, Zhang X, Lu Y, Zhou F. Effect of family rehabilitation intervention for core symptoms of children with autism spectrum disorder based on virtual reality technology. CHINESE NURSING RESEARCH 2021;35(23):4214–4217.
40. Voss C, Schwartz J, Daniels J, Kline A, Haber N, Washington P, Tariq Q, Robinson TN, Desai M, Phillips JM. Effect of wearable digital intervention for improving socialization in children with autism spectrum disorder: a randomized clinical trial. JAMA pediatrics American Medical Association; 2019;173(5):446–454.
41. Sayis B, Ramirez R, Pares N. Mixed reality or LEGO game play? Fostering social

interaction in children with Autism. Virtual Reality 2021 Sept 23;26(2):771–787. doi: 10.1007/s10055-021-00580-9

42. Yuan SNV, Ip HHS. Using virtual reality to train emotional and social skills in children with autism spectrum disorder. London Journal of Primary Care Taylor & Francis; 2018 June 7;10(4):110–112. Available from: https://www.tandfonline.com/doi/full/10.1080/17571472.2018.1483000
43. Zhao J, Zhang X, Lu Y, Wu X, Zhou F, Yang S, Wang L, Wu X, Fei F. Virtual reality technology enhances the cognitive and social communication of children with autism spectrum disorder. Front Public Health Frontiers Media SA; 2022 Oct 6;10:1029392. Available from: https://www.frontiersin.org/articles/10.3389/fpubh.2022.1029392/full
44. Jiang M, Wang D, LI E. The effect of VR eye tracking technology in children with autism. JOURNAL OF INTERNATIONAL PSYCHIATRY 2023;50(6):1403–1406.
45. Ip HHS, Wong SWL, Chan DFY, Byrne J, Li C, Yuan VSN, Lau KSY, Wong JYW. Enhance emotional and social adaptation skills for children with autism spectrum disorder: A virtual reality enabled approach. Comput Educ 2018 Feb;117:1–15. doi: 10.1016/j.compedu.2017.09.010
46. Ye J, Song Q, Zhao B. To explore the application of virtual character interaction system in the clinical treatment of children with autism spectrum disorder (ASD). Maternal and Child Health Care of China 2020;35(16):3004–3006.
47. Yue W, Hui JL, Xiao JH. Digital audio visual integrated system combined with virtual reality technology in treatment of childhood autism a case control study. 2016;31(22).
48. Yuen HK, Spencer K, Edwards L, Kirklin K, Jenkins GR. A Magic Trick Training Program to Improve Social Skills and Self-Esteem in Adolescents With Autism Spectrum Disorder. Am J Occup Ther 2023 Jan 1;77(1):7701205120. doi: 10.5014/ajot.2023.049492
49. Bradley R, Newbutt N. Autism and virtual reality head-mounted displays: a state of the art systematic review. Journal of Enabling Technologies Emerald Publishing Limited; 2018 July 13;12(3):101–113. Available from: https://www.emerald.com/insight/content/doi/10.1108/JET-01-2018-0004/full/html
50. Skjoldborg NM, Bender PK, Jensen de López KM. The efficacy of head-mounted-display virtual reality intervention to improve life skills of individuals with autism spectrum disorders: A systematic review. Neuropsychiatr Dis Treat Taylor & Francis; 2022 Oct;Volume 18:2295–2310. Available from: https://www.dovepress.com/the-efficacy-of-head-mounted-display-virtual-reality-intervention-to-i-peer-reviewed-fulltext-article-NDT
51. Newbutt N, Sung C, Kuo HJ, Leahy MJ. The acceptance, challenges, and future applications of wearable technology and virtual reality to support people with autism spectrum disorders. Recent advances in technologies for inclusive well-being: From worn to off-body sensing, virtual worlds, and games for serious applications Springer; 2017;221–241. Available from:

http://link.springer.com/10.1007/978-3-319-49879-9_11
52. Newbutt N, Sung C, Kuo H-J, Leahy MJ, Lin C-C, Tong B. Brief report: A pilot study of the use of a virtual reality headset in autism populations. J Autism Dev Disord Springer; 2016 June 7;46(9):3166–3176. Available from: http://link.springer.com/10.1007/s10803-016-2830-5
53. Strickland D. Virtual reality for the treatment of autism. Virtual reality in neuro-psycho-physiology Ios Press; 1997;81–86. Available from: https://www.medra.org/servlet/aliasResolver?alias=iospressISSNISBN&issn=0926-9630&volume=44&spage=81
54. Zhang K, Chen J, Yang Z. Assessment and intervention with virtual reality technology for children aged 3–12 years with autism spectrum disorders: A scoping review. Education and Information Technologies Springer; 2025 Apr 16;1–38. Available from: https://link.springer.com/10.1007/s10639-025-13561-1
55. Lee I-J. Kinect-for-windows with augmented reality in an interactive roleplay system for children with an autism spectrum disorder. Interact Learn Envir Taylor & Francis; 2020 Jan 7;29(4):688–704. Available from: https://www.tandfonline.com/doi/full/10.1080/10494820.2019.1710851
56. Kandalaft MR, Didehbani N, Krawczyk DC, Allen TT, Chapman SB. Virtual reality social cognition training for young adults with high-functioning autism. J Autism Dev Disord Springer; 2012 May 9;43(1):34–44. Available from: https://link.springer.com/10.1007/s10803-012-1544-6
57. Moore D, Cheng Y, McGrath P, Powell NJ. Collaborative virtual environment technology for people with autism. Focus Autism Dev Dis Sage Publications Sage CA: Los Angeles, CA; 2005;20(4):247–248. Available from: http://ieeexplore.ieee.org/document/1508665/
58. Malihi M, Nguyen J, Cardy RE, Eldon S, Petta C, Kushki A. Evaluating the safety and usability of head-mounted virtual reality compared to monitor-displayed video for children with autism spectrum disorder. Autism SAGE Publications Sage UK: London, England; 2020 July 2;24(7):1924–1929. Available from: https://journals.sagepub.com/doi/10.1177/1362361320934214
59. Boyd BA, Hume K, McBee MT, Alessandri M, Gutierrez A, Johnson L, Sperry L, Odom SL. Comparative efficacy of LEAP, TEACCH and non-model-specific special education programs for preschoolers with autism spectrum disorders. J Autism Dev Disord Springer; 2013 June 28;44(2):366–380. Available from: http://link.springer.com/10.1007/s10803-013-1877-9

Table 1

PICOS criteria for inclusion of studies.

Parameter	Criteria
Population	children and adolescents under 18 years old and were diagnosed with ASD
Intervention	Research involving any type of virtual reality intervention
Comparator	No limitations on the control group except virtual reality interventions, such as no-treatment, waiting-list control, traditional care, or cannot be included in other treatment nodes
Outcomes	Any outcomes regarding social and communication skills that can be measured
Study design	Randomized controlled trials

ASD autism spectrum disorder

Table 2
Characteristics of included studies

Study(year)	Country	Diagnostic criteria	Sample size (E/C)	Sex (E/C)	Age (years,E/C)	Treatment	Protocol Details (E)	Protocol Details (C)	Length	Duration per session	Frequency	Main Outcome index
YangYang Wang,2023	China	DSM-5	30 30	- -	3-5 3-5	Digital platform	**Immersive VR (HLKF-DT-01 platform):** nine modules including (i) attention (piano keys, basketball), (ii) language shadowing (progressive sentence repetition), (iii) spatial orientation (virtual classroom/str	**Conventional rehabilitation—**group OT, ADL training, language therapy via Orff music, family-guided outdoor play and social-story practice.	four weeks	20 mins	Five days/ week	ABC

								eet navigation), (iv) daily-living rehearsal.					

Table 2 Continued

Study(year)	Country	Diagnostic criteria	Sample size (E/C)	Sex (E/C)		Age (years,E/C)		Treatment	Protocol Details (E)	Protocol Details (C)	Length	Duration per session	Frequency	Main Outcome index
JunQiang Zhao,2021	China	DSM-5	57 57	-	-	3-5	3-5	HMD	**Home-based VR (HMD and smartphone app):** identical nine-module curriculum with added (i) affect-expression tasks (avatar facial mimicry), (ii)	**Home rehabilitation care—** daily scenario education, balanced diet/exercise plans, parent-mediated play, token-economy reward system.	six months	20 mins	Two sessions/week	ABC

										fine/gross-motor tracking games (gesture-based).					
Catalin Voss,2019	America	DSM-5	40	31	37M/3F	16M/15F	8.63 ± 2.52	8.74 ± 1.79	Superpower Glass	**Wearable AI system (Superpower Glass):** Google Glass and emotion-recognition	**Home rehabilitation care—** applied behavior analysis (ABA); therapist-delivered ABA	six weeks	20 mins	Four sessions/week	VABS-II

Table 2 Continued

Study(year)	Country	Diagnostic criteria	Sample size (E/C)		Sex (E/C)		Age (years,E/C)		Treatment	Protocol Details (E)	Protocol Details (C)	Length	Duration per session	Frequency	Main Outcome index
										CNN; provides (i) peripheral green-box	at home; discrete trial training, naturalistic				

										for face detection, (ii) emoji and audio cue for 8 emotions.	teaching.				
Batuhan Sayis,2022	Spain	ADOS module 3	36	36	30M/6F	30M/6F	8-12	8-12	MR	**Mixed-reality floor projection (6-m diameter):** cooperative firefly-catching game triggering virtual characters; LED-net tracking and multi-camera motion capture.	**Conventional rehabilitation—**LEGO cooperative play; therapist-guided dyadic construction of pirate ship; hexagonal table setup; verbal prompting for social initiation.	once	15mins	-	ASS

Table 2 Continued

Study(year)	Country	Diagnostic criteria	Sample size (E/C)		Sex (E/C)		Age (years,E/C)		Treatment	Protocol Details (E)	Protocol Details (C)	Length	Duration per session	Frequency	Main Outcome index
Sze Ngar Vanessa Yuan,2018	Hong Kong, China	DSM-5	36	36	31M/5F	33M/3F	8.97±1.10	8.73±1.15	CAVE	**CAVE projection system:** six authentic scenarios—(i) morning routine, (ii) bus ride, (iii) library rules, (iv) tuck-shop conflicts, (v) playground consolidation.	**Wait-list control—**no VR or structured social-skills intervention during study period.	six weeks	60 mins	One session/week	PEP-3
Junqiang Zhao,2022	China	DSM-5	22	22	19M/3F	16M/6F	3-4	3-4	HMD	**Unity3D VR scenes:** six modules—object search, color sorting,	**Conventional rehabilitation—**group oral instruction,	12weeks	15 mins	Three sessions/week	PEP-3

							animal interaction; AI scaffolding: target-highlight	sensory-integration equipment (balance boards, tactile balls),				

Table 2 Continued

Study(year)	Country	Diagnostic criteria	Sample size (E/C)	Sex (E/C)	Age (years,E/C)	Treatment	Protocol Details (E)	Protocol Details (C)	Length	Duration per session	Frequency	Main Outcome index
							for errors; head-turn and click responses.	fine-motor tabletop tasks.				
MiaoMiao Jiang,2023	China	DSM-5	31 31	20M/11F 19M/12F	13.47±1.23 13.87±1.08	HMD	**VR eye-tracking (J2-R2-1020):** gaze-contingent dialogue initiation; saccade-triggered virtual	**Conventional rehabilitation—**oral vitamin D_3, sand-play therapy twice weekly; no digital component.	six months	30 mins	Three sessions/week	ATEC

Table 2 Continued

Study(year)	Country	Diagnostic criteria	Sample size (E/C)		Sex (E/C)		Age (years,E/C)		Treatment	Protocol Details (E)	Protocol Details (C)	Length	Duration per session	Frequency	Main Outcome index
										character interaction (120 Hz sampling, <0.5° calibration).					
Horace H.S.Ip,2017	Hong Kong, China	DSM-5	36	36	31M/5F	33M/3F	8.97±1.11	8.74±1.15	H-CAVE	**4-side CAVE projection:** six social-emotion scenarios with (i) relaxation environment, (ii) school rule practice.	**Wait-list control—** standard school curriculum plus usual outpatient therapy; no VR exposure.	14 weeks	-	Two sessions/week	PEP-3
JianHui Ye,2020	China	DSM-5	32	32	19M/13F	20M/12F	3.51±1.03	3.54±1.05	Computer	**VR-SST platform:** avatar-	**Conventional rehabilitatio**	three months	30mins	Three sessions/week	ABC

										mediated role-play (greeting, sharing); AI immediate feedback.	**n—** traditional SST; therapist-led role-play, feedback, homework; 30-min sessions covering peer interaction, emotion expression.				
YueJuan Wang,2016	China	DSM-4	35	35	30M/5F	29M/6F	4.23±1.63	3.91±1.44	Digital platform	**Dolphin House AV system:** 2–8 kHz bionic dolphin sounds and 3D ocean VR	**Conventional rehabilitation—**table-top social stories, token reinforcement,	six months	45mins	15 day/phase	ABC

Table 2 Continued

Study(year)	Country	Diagnostic criteria	Sample size		Sex (E/C)		Age (years,E/C)		Treatment	Protocol Details (E)	Protocol Details (C)	Length	Duration per session	Frequency	Main Outcome

			(E/C)										n		index
										and rhythmic lighting (0.5–4 Hz); tactile plush dolphin vibration. Acoustic intensity: 60–75 dB; illuminance 200–400 lux.	therapist-guided play; no digital component.				
HonK Yuen,2023	America	DSM-5	9	8	7M/2F	7M/1F	12.3±2.3	10.5±1.2	Computer	**Virtual magic training via Zoom:** OT-student coaches teach 2–3 tricks/session (cards, rubber bands, ropes); Hocus Focus	**Wait-list control**—1-month delay before identical virtual MTTP; no active intervention during control phase.	three weeks	45mins	Three sessions/week	SSIS

	evaluation scale; mailed prop kit.

E Experimental group, ***C*** Control group, ***M*** male, ***F*** female, ***DSM-5*** Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition, ***Digital platform*** Digital evaluation interactive training platform, ***ABC*** Autism Behavior Checklist, ***HMD*** Head-Mounted Display, ***Superpower Glass*** Google Glass works with smartphones, ***ADOS module 3*** Autism Diagnostic Observation Schedule, Module 3, ***VABS-II*** Vineland Adaptive Behavior Scales - Second Edition, ***MR*** Mixed Reality, ***ASS*** Self-made questionnaire: Affective Slider scales, ***CAVE*** Cave Automatic Virtual Environment ***PEP-3*** Psychological Educational Profile - Third Edition, ***ATEC*** Autism Treatment Evaluation Checklist, ***H-CAVE*** Half Cave Automatic Virtual Environment, ***Computer*** Desktop VR common equipment, ***SSIS*** Social Skills Improvement System.

Table 3

Paired comparison league table of the improvement effect of social function by VR intervention measures (Random Effects Model, SMD [95% CI])

Digitalplatform							
-4.92 (-13.58,3.73)	HMD						
-2.89 (-14.27,8.49)	2.03 (-8.77,12.83)	Glass					
3.15 (-8.21,14.51)	8.07 (-2.71, 18.85)	6.04 (-7.03,19.11)	MR				
2.95 (-8.51,14.41)	7.87 (-3.01,18.76)	5.84 (-7.32,19.00)	-0.20 (-13.34,12.94)	CAVE			
1.45 (-10.04,12.94)	6.37 (-4.54,17.29)	4.34 (-8.84,17.52)	-1.70 (-14.87,11.47)	-1.50 (-14.75,11.75)	HCAVE		
-4.40 (-14.05,5.25)	0.53 (-8.44,9.49)	-1.51 (-13.12,10.11)	-7.55 (-19.14,4.05)	-7.35 (-19.04,4.35)	-5.85 (-17.57,5.88)	Computer	
3.25 (-3.37,9.87)	**8.17 (2.60,13.74)**	6.14 (-3.11,15.39)	0.10 (-9.13,9.33)	0.30 (-9.05,9.65)	1.80 (-7.59,11.19)	7.65 (0.63,14.66)	UC

Table 4
SUCRA results

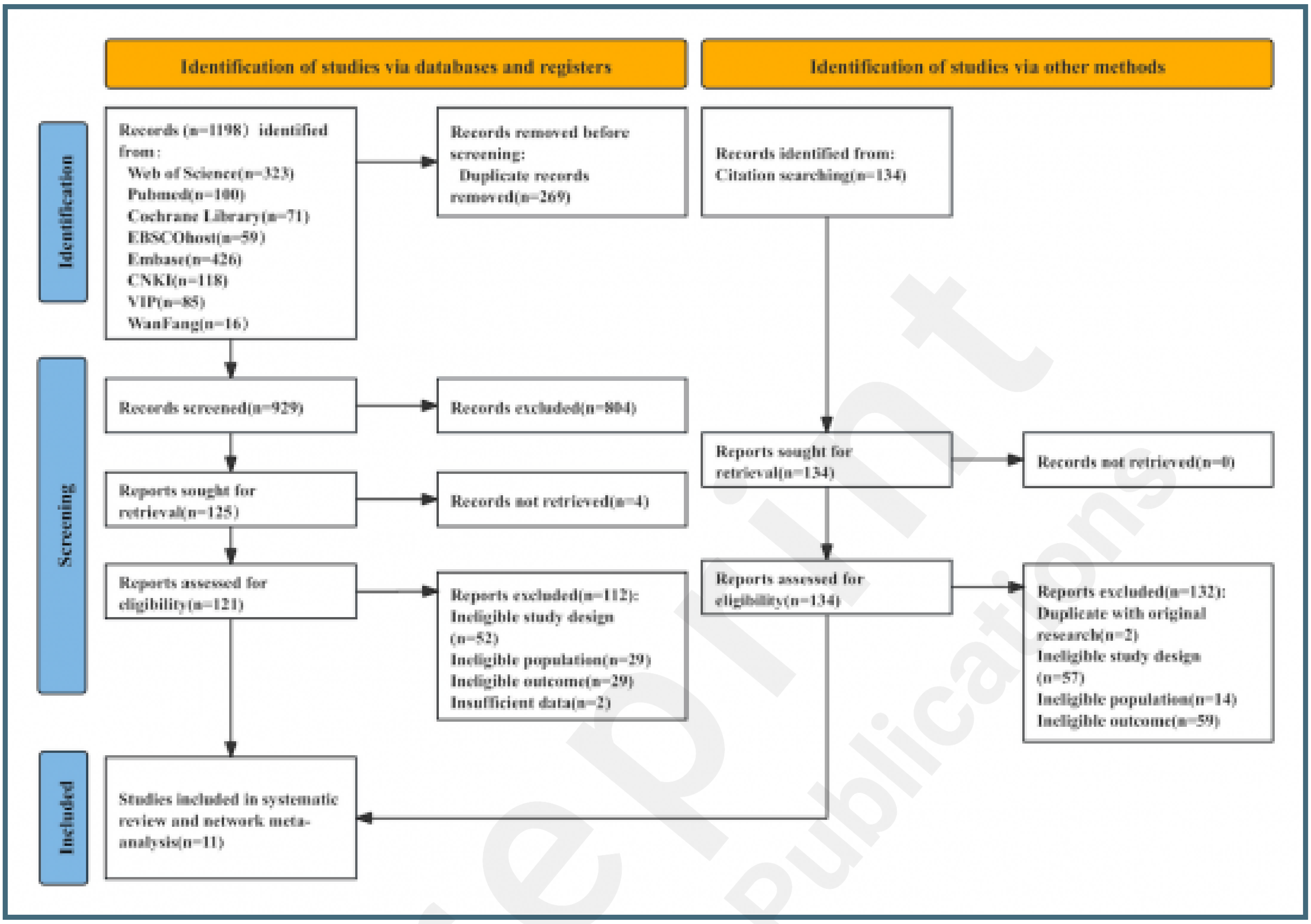
Intervention measure	SUCRA	Rank
HMD	82.6	1
Computer	77.9	2
Glass	67.5	3
Digital platform	49.2	4
HCAVE	40.5	5
CAVE	30.4	6
MR	28.9	7
UC	22.9	8

SUCRA The area under the cumulative ranking probability graph of virtual reality intervention.

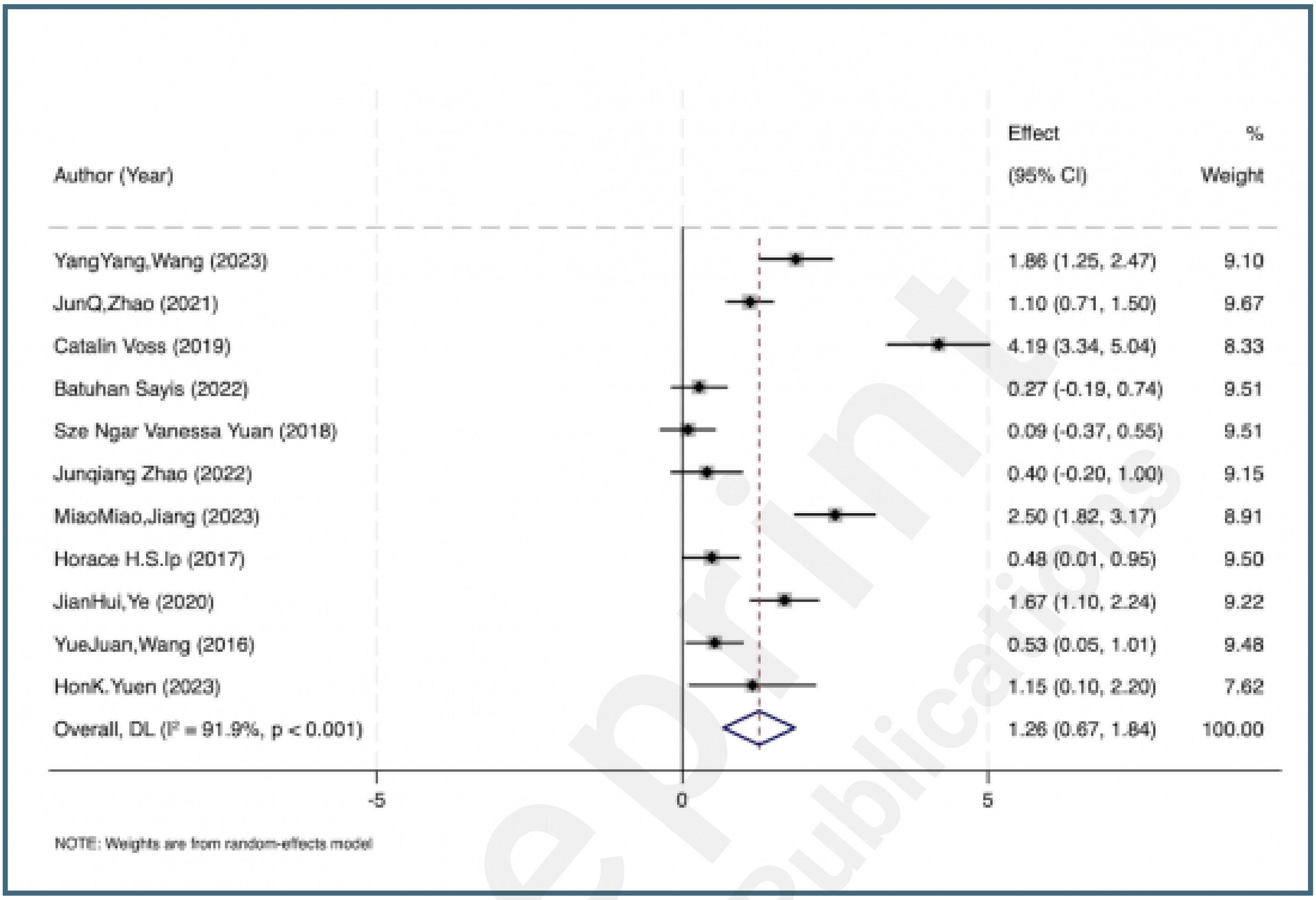
Supplementary Files

Figures

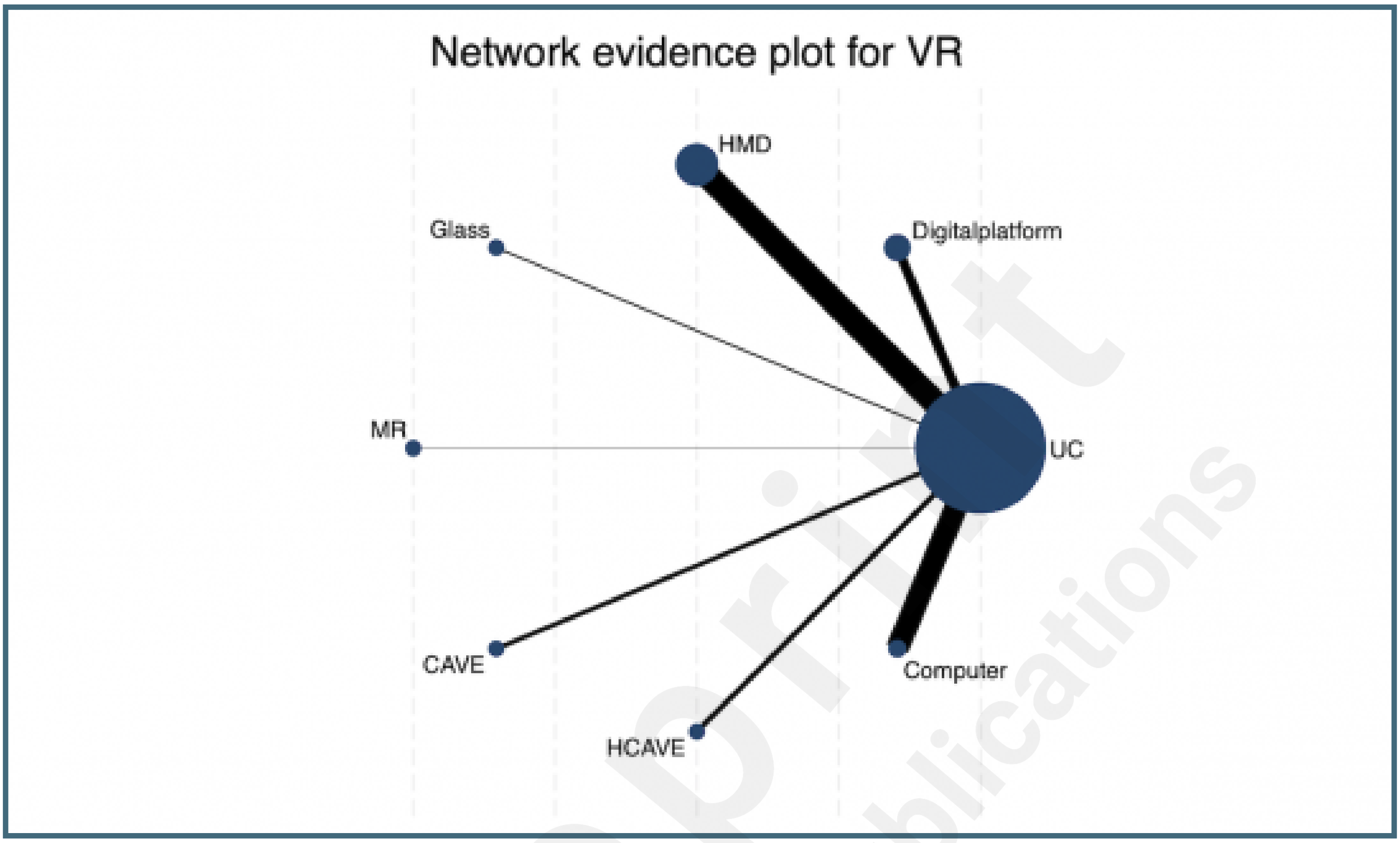
PRISMA study selection and flow chart.



Pairwise comparisons among direct evidence.



Network Relationship Evidence diagram of VR Intervention Measures (Direct Comparative Evidence Based on 11 RCTS).



Multimedia Appendixes

Supplementary materials.
URL: http://asset.jmir.pub/assets/0e95c5ff7b8f820a9084826d542d1972.docx