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Using Virtual and Augmented Reality to Teach Children on the Autism Spectrum with Intellectual Disabilities: A Scoping Review

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Abstract

In recent years, both Virtual Reality (VR) and Augmented Reality (AR) technology have shown great promise for the instruction of individuals with autism spectrum disorder (ASD) by simulating real-world experiences in a safe and controlled environment. However, there are many reports of the failure of such research to include individuals with both ASD and Intellectual Disability (ID). The present scoping review consists of 20 studies which utilized VR/AR to teach various skills to children and youth with comorbid ASD and ID. Findings show that within the small number of eligible studies, a great deal of variation exists in essentially every intervention element (e.g., identification of ID, VR/AR equipment, target skills). Beyond increasing the quantity of VR/AR intervention research conducted on this population, the current review suggests the need for greater uniformity and consistency to improve research, practice, and the lives of those with ASD and ID who may benefit from such interventions.

Keywords: Autism spectrum disorder, intellectual disability, virtual reality, augmented reality, intervention

Summary for Lay Audience

Autism spectrum disorder (ASD) is a neurodevelopmental disorder defined by impairments in social communication and interaction as well as restricted or repetitive behaviours or interests. However, although individuals with ASD may share core traits, there is a great deal of variation that exists within each individual (e.g., severity, communication, intelligence).

Advanced technology, such as Virtual Reality (VR; a three-dimensional virtual environment) and Augmented Reality (AR; a computer-generated image in an individual's view of the real world) have shown great promise for the instruction of individuals with ASD. Such technology allows for repetitive practice of essential skills and the ability to learn from mistakes without the potential negative consequences of real-world decisions. However, the current research examining VR/AR for those with ASD fails to include participants with below average intellectual functioning, also referred to as Intellectual Disability (ID), despite the considerable known overlap between the two conditions.

The present work looked to review the research that used VR/AR technology to teach various skills to children and youth with both ASD and ID. This was done to understand themes and gaps in what has been done so far, as well as make recommendations for future improvement. Despite large advancements in the use of VR/AR to support those with ASD, only 20 studies were found to use the technology to teach those with both ASD and ID. Although the included studies show great promise, the review found a great deal of variation within the small number of available studies (e.g., identification of ID, VR/AR equipment used, target skills, duration), which limits claims that such technology is beneficial for those with ASD and ID at this time. The limited research and understanding of VR/AR interventions can be seen as a

disservice to the field of research, the practice of psychology, and most importantly, the individuals with both ASD and ID who may be denied potentially beneficial services. Future work should look to increase the quality and quantity of research examining VR/AR for this population.

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Introduction

Autism spectrum disorder (ASD) is a pervasive and prevalent neurodevelopmental disorder characterized by core impairments in socio-emotional reciprocity, interpersonal communication, and restricted, repetitive behaviours and interests (American Psychiatric Association, 2013). The autism spectrum comprises various previously used clinical subtypes (e.g., Asperger's Disorder, Pervasive Developmental Disorder) and is used to represent the heterogeneity of individual symptomology and experience.

ASD Terminology

Severity Levels

Within the diagnosis of ASD, the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) specifies three levels of severity based on social communication impairments, and restrictive, repetitive patterns of behaviour: Level 3 - requires very substantial support, Level 2 - requires substantial support, and Level 1 - requires support (American Psychiatric Association, 2013). It should be noted that a criterion for ASD severity in the DSM-5 is that the disturbances are *not* better explained by the presence of Intellectual Disability although the two frequently co-occur. That is, cognitive/intellectual functioning is not one of the diagnostic criteria for ASD.

High and Low-Functioning

Functioning labels (referring to individuals as low- or high-functioning) can be considered an outdated method of identifying individuals on the autism spectrum. As a result, functioning labels have been replaced by the use of severity levels by the DSM-5. However, unlike severity levels, the use of functioning terminology generally corresponds with intellectual ability, with high-functioning referring to those who are of average intelligence and therefore do not have intellectual impairment or disability (Lake et al., 2014). Although functionality labels are used commonly within both lay language and research, such labels can be seen as both misleading and harmful to those in the ASD community as they may fail to accurately describe level of function/ability across multiple domains (e.g., special talents, anxiety, language, sensory challenges) (Burrows et al., 2016). It is critical to understand the distinction between low- and high-functioning levels in the current work as they have previously had important implications with respect to designing interventions tailored to individual learning needs. However, within the current work, the use of high- and low-functioning labels will be used only in reference to past research.

Co-occurrence of Intellectual Disability and ASD

Intellectual Disability (ID) refers to impairment of general mental abilities that impact intellectual and adaptive functioning in the conceptual (e.g., language, reading, writing), social (e.g., empathy, interpersonal communication, social judgement), and practical (e.g., personal care, job responsibilities, recreation) domains of life (American Psychiatric Association, 2013). There are four classifications of ID severity: (1) Mild (approximate IQ range 50-69), (2) Moderate (approximate IQ range 36-49), (3) Severe (approximate IQ range 20-35), and (4) Profound (IQ < 20) (Boat et al., 2015).

ASD is among the most common comorbid disorder of individuals with ID, with an estimated 50-70% of those with ASD also having ID (Goldin et al., 2014; Matson et al., 2009). Along with the co-occurrence, higher rates of stereotypic and challenging behaviour as well as greater deficits in social, adaptive, and communicative functioning have been observed (Matson & Shoemaker., 2009). For example, deficits in social skills are central to both ASD and ID, with additional limitations existing when the two co-occur (de Bildt et al., 2005). Many individuals with ASD and ID typically exhibit fewer positive social skills (both verbal and non-verbal) such as communicating with or smiling at others and tend to exhibit more challenging social behaviours (e.g., self-isolation) (Wilkins & Matson, 2009). Research has found that lower IQ is associated with greater severity of ASD as well as an increase in challenging behaviours (O'Brien & Pearson, 2004). Similarly, a high correlation has also been found between IQ and verbal ability which implies that many non-verbal individuals with ASD also have a learning/intellectual disability (Noens & van Berckelaer-Onnes, 2004). That is, the comorbidity of the two disorders increases the complexity and severity of communication problems (Noens & van Berckelaer-Onnes, 2004). Further, in addition to potentially exacerbating symptomology, the co-occurrence of ASD & ID can also impact long-term outcomes and response to treatment. That is, the absence of ID (the presence of higher IQ) in individuals with ASD has been consistently associated with a greater likelihood of improvement over time (LeCavalier et al., 2011; Fernell et al., 2013; Di Renzo et al., 2021). Along with the absence of ID, the absence of an underlying genetic or metabolic disorder, as well as early diagnosis and timely and appropriate intervention, upper socio-economic strata, and higher levels of parental education have been found as good prognostic factors for individual with ASD (Fernell et al., 2013).

Both ASD and ID are neurodevelopmental disorders that are present in early development. In many cases, ASD can be detected at less than 18 months old, and by two years old many children can receive a diagnosis by an experienced professional (Centers for Disease Control and Prevention, 2022). Given the early onset and lifelong implications of these disorders, specifically in combination, effective early intervention in childhood and youth plays a critical role in ensuring positive long-term outcomes. However, it is speculated that much of the recent advances in research for those with ASD have overlooked individuals with co-occurring ID, regardless of the current understanding of the considerable overlap between the two conditions (Hurley & Levitas, 2007; Matson & Shoemaker, 2009)

Evidence-Based Practices for ASD

Evidence-based practice (EBP) has become standard across many fields including medicine, psychology, education, and allied health to identify the best interventions and treatment programs available (National standards, 2022). With respect to ASD interventions, an EBP refers to an instructional or intervention procedure (or set of procedures) that has been demonstrated by peer-reviewed experimental research to produce positive outcomes for people with ASD (National standards, 2022).

The National Standards Project has identified 14 EBP's for children, youth and adults with ASD which include; behavioural interventions, cognitive behavioural intervention package, comprehensive behavioural treatment for young children, language training (production), modelling, naturalistic teaching strategies, parent training, peer training package, pivotal response treatment, schedules, scripting, self-management, social skills package, and story-based intervention (National standards, 2022). The National Clearinghouse on Autism Evidence and Practice, on the other hand, reviewed the literature published from 1990-2017 and identified 28 EBP's that met criteria including; augmented and alternative communication, antecedent-based intervention, behavioural momentum intervention, cognitive behavioural instructional strategies, differential reinforcement, direct instruction, discrete trial training, exercise and movement, extinction, functional behaviour assessment, functional communication training, modelling, music-mediated intervention, naturalistic interventions, parent-implemented interventions, peer-based instruction and intervention, prompting, reinforcement, response interruption and redirection, self-management, sensory integration, social narratives, social skills training, task analysis, technology-aided intervention and instruction (previously ‘computer aided instruction’), time delay, video modelling, and video supports (Steinbrenner et al., 2020).

Technology-Aided Instruction and Intervention as an Evidence-Based Practice

Specifically relevant to the current work is the EBP of technology-aided instruction and intervention. This EBP refers to when technology (e.g., smart phones, tablets, laptops, desktop computers, speech generating devices, interactive white boards, software for computers, internet) is the central feature supporting the acquisition of a goal for a learner (Steinbrenner et al., 2020;). Studies in the NCAEP report identified technology-aided instruction and intervention as an effective way to address various social, communication, joint attention, behavior, school-readiness, cognitive, motor, adaptive, vocational, and academic outcomes in preschool to high school-aged learners (Steinbrenner et al., 2020). For example, Cihak and colleagues (2010) used handheld computers to facilitate self-monitoring of students with autism in a general education classroom and found that all elementary school students were able to self-monitor and regulate their behaviours in multiple settings as a result of the technology. Similarly, when compared to a control group of typically developing peers, higher functioning preschoolers with autism were found to significantly improve emotion recognition after receiving an emotion comprehension intervention delivered via an animated series (Golan et al., 2010). Technology is found to offer several advantages given that (1) electronic media and devices are often high interest tools for those with ASD, (2) such devices often provide predictable rules and clear instructions, (3) the processes do not involve complex socio-emotional expectations, and (4) they may allow individuals to experiment in virtual/synthetic environments free of the anxieties associated with real world experiences (Serret et al., 2014; Parsons & Mitchell, 2002).

However, regardless of the incorporation of technology, it is important for interventions to incorporate additional EBP's to ensure effectiveness. For example, modelling has been found to have many benefits that are believed to promote acquisition in teaching children with ASD. However, Charlop-Christy et al. (2000) found that in comparison to in-vivo (real-time) modelling of developmental skills, video-modelling led to both quicker acquisition and greater generalization for children with ASD. The use of video modelling may have increased motivation, as well as compensated for social deficits by not adding the pressures of social interaction into the process of skill learning (Charlop-Christy et al., 2000). Such results are consistent with findings that children with ASD are typically visual thinkers, and that using visual cues and digital media may advance the process of learning and increase motivation in children with autism (Kunda and Goel 201; More 2008). In the past, video-modelling was seen as a novelty tool for the instruction of children with ASD, who often were not exposed to such technology, as well as highly reinforcing as it resembled intrinsically motivating activities such as watching T.V. (Charlop-Christy & Daneshvar, 2003). Although the novelty of earlier technology has decreased over the years, it demonstrates the potential for new technology to be equally beneficial, with respect to engagement and motivation, for those with ASD.

The use of more advanced technology has been found to be increasingly popular over recent years, possibly for its ability to seamlessly incorporate various EBP's into a single intervention. For example, Virtual and/or Augmented Reality interventions can simultaneously include visual supports, video modelling, reinforcement, prompting, and discrete trial training, just to name a few. Additionally, unlike other technology interventions that rely on 2-D visuals, Virtual and Augmented Reality technology can produce 3-D environments which can replicate natural environments and experiences relevant to the lives of children and youth with ASD, and such capabilities could have important implications with respect to the generalization of acquired skills to real-life settings (Matsentidou & Poullis, 2014). However, although such advanced technology is becoming increasingly popular for both research and recreational use, the limited evidence base on their efficacy prevents classification as an EBP at this time.

Virtual/Augmented Reality Technology

Virtual Reality (VR) programming refers to the use of computer-based technology to create a three-dimensional virtual environment that can replicate real-life scenarios or create new scenarios (Parsons & Cobb, 2011). VR allows its users to immerse into a scenario such that they are not only able to observe, but also interact with various environments, objects, and avatars (people). There are three primary categories of VR simulations that are used today, based on the degree to which the experience is realistic and immersive for the user, which include (1) non-immersive, such as computers, keyboards, mice, and controllers (2) semi-immersive, such as high-resolution projectors and computers, and (3) fully-immersive, such as VR glasses or head-mounted display (wearable headsets) (Heizenrader, 2022).

Augmented Reality (AR), on the other hand, is defined as a technology that combines the information one perceives from the real world with information generated by a computer in real-time, allowing for a ‘tangible presence/experience’ (Lee, 2012). Compared to VR, AR can be seen as more natural as it allows users to perceive and act in the real world, rather than in a simulated environment (Herrera et al., 2006; Perez-Fuster et al., 2022). For example, the popular phone application/game ‘Pokémon Go’ would be considered an AR application as it allows users to search for animated characters that are layered and displayed in real world locations when looking through a device’s camera (Hayes, 2023).

Virtual/Augmented Reality and ASD

In recent years, the use of both VR and AR programming has been found to be a promising avenue for the instruction of children and youth with ASD as it offers simulations of authentic real-world experiences in a safe and controlled environment (Parsons & Cobb, 2011). That is, VR/AR serves as a beneficial instructional method for children and youth with ASD as it allows for repetitive practice of essential skills and the ability to learn from mistakes without the potential negative consequences of real-world decisions (Parsons & Mitchell, 2002). Additionally, due to deficits in both initiating and maintaining social interactions, individuals with ASD may not be exposed to experiences in which they could practice or increase various skills in the real-world. However, the implementation of VR programming could help overcome a child's lack of social motivation or necessary skills by allowing them to experience and practice in an environment that is not only directly relevant to their everyday lives, but also controlled and comfortable to them (Chevallier et al., 2012).

The acceptability and feasibility of Virtual Reality training programs for children and youth with ASD have been well demonstrated by previous research (Yuan et al., 2018, Ke et al., 2020; Didehbani et al., 2016). Measures of social validity have found that the users of VR/AR programming often report positive experiences such that they find the program to be easy to learn/use, fun and exciting to play, and highly rewarding (Rosenfield et al., 2019). On top of being motivational, rewarding and fun, previous studies have shown that children with ASD can enhance various skills, such as such as perspective-taking, emotion recognition, and social perception, via a naturalistic and meaningful virtual environment (Ke et al., 2020; Mitchell et al. 2007; Kandalaft et al. 2013). For example, Yuan et al. (2018) found positive effects of a VR training program on both emotional and adaptive skills of children with ASD. That is, the 28-

session training improved the emotional expression, emotional regulation, and social interactions of participants substantially. It should be noted, however, that the study only examined the effectiveness of the intervention for children classified as having high-functioning autism (average or above-average intelligence). That is, it did not examine the potential implications for those with ID.

Virtual/Augmented Reality and Intellectual Disability

The use of advanced technology can serve as a necessary alternative opportunity for children with ID to acquire developmental skills as such real-world experiences are often denied to these individuals in comparison to their typically developing peers (Cromby et al., 1996; Standen et al., 2001). VR/AR environments are found to be advantageous as they are free from the social demands that are often challenging and confusing for children with ID's, and such programs can provide immediate, predictable, and repeatable feedback (Ahn, 2021).

However, research with respect to ID has led to mixed findings. For example, a VR training program designed to improve life skills, such as shopping, cooking, and cleaning, in individuals with ID found that although the program significantly improved skills, the VR training was not proven to be better than traditional life-skill training (Cheung et al., 2022). It is important to note, however, that participants of the study reported the VR system was somewhere they felt safe and secure, in comparison to traditional training where they may hesitate or feel embarrassed when repeatedly making mistakes in front of trainers or in the public (Cheung et al., 2022).

Gaps in the Literature

With the increase in popularity of VR/AR technology in recent years, there has not only been an increase in research conducted using the technology for individuals with ASD, but also an increase in reviews on such research. Within recent reviews, there are many reports of the current failure of VR/AR research to support a wide range of individuals on the autism spectrum. Many reviews have reported that VR/AR interventions designed for teaching skills to children and youth with ASD have a lack of participants with below average intellectual functioning (e.g., Deschling et al., 2022). Additionally, even reviews that have specifically examined the use of VR with respect to autism, intellectual and developmental disabilities have noted that participants with comorbid conditions are limited. For example, when examining the use of AR to teach academic skills, Yakubova and colleagues (2021) found that half of the studies in their review targeted specifically ID and the other half specifically targeted ASD, not a combination of the two. A bias for including only 'high functioning' individuals is likely a result of not only the lack of ID, but also the presence of more advanced spoken language that that they typically exhibit (Junaidi et al., 2020). However, similar to past interventions, it is crucial to provide varying levels of instructional/intervention support for children and youth with ASD both with and without ID.

The Present Review

Large advancements in both the creation and usage of Virtual and Augmented Reality programming have been made in recent years, and with such comes an increased need for research on its efficacy. With respect to the instruction of children and youth with ASD, VR/AR has shown many potential benefits such as compensating for social deficits, increasing motivation and attention, as well as allowing for repetitive practice without the associated real-world consequences. However, although past studies have shown that children and youth with ASD can enhance various skills through VR, such research is limited, especially with respect to teaching those with both ASD and ID. Not only is such limited research on the efficacy of

VR/AR interventions a disservice to the field of research, but it can have negative effects of the practice of psychology (e.g., consultation, evaluation, therapy) as a whole, as it limits practioners understanding of potentially beneficial services as well as prevents wide-spread use of such interventions for individuals on the autism spectrum. Most importantly, however, the limitations to both research and practice negatively impact the individuals with both ASD and ID, as they are denied potentially beneficial services.

Thus, the present scoping review was conducted with the intention to increase understanding of the current uses of VR/AR technology for intervention and/or training programs for children and youth diagnosed with both ASD and ID as well as to provide direction for future research in order to fill in current gaps in the literature. The current understanding of the use of VR/AR for individuals with ASD exists primarily within the realm of those previously classified as 'high-functioning' or without ID. Thus, by examining only studies that included participants with comorbid ASD and ID, the present review will allow for conclusions to be made that more accurately reflect the other half of the spectrum. The objectives of the present scoping review are to (a) provide a summary of studies that use VR/AR technology to provide interventions for children and youth with both ASD and ID, (b) identify themes within the literature with respect to target skills, technology use, and methodology, and (c) identify gaps in the literature in order to make recommendations for future research and practice.

Methods

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMAScR) was used as the framework to guide this scoping review (Tricco et al., 2018). Articles identified for review were found in December 2022 across seven relevant databases (PsycINFO, PubMed, ERIC, IEEE Xplore, Web of Science, Science Direct, Education Database). All databases were searched for articles using the following search terms: autism spectrum disorder, OR ASD, OR autis*, AND virtual reality OR augmented reality, AND either child OR youth OR adolescent OR student. No limitations regarding publication year were applied in the search, but the search was limited to peer-reviewed publications.

Inclusion and Exclusion of Studies

The study inclusion criteria when screening was as follows: (1) peer-reviewed journal articles available in English, (2) included participants under the age of 18 who were diagnosed as having ASD, (3) included at least one participant with an ID (4) used Virtual or Augmented Reality/Environments, and (5) used the VR/AR to provide an intervention/teach a skill. The exclusion criteria were (1) non-peer reviewed studies/grey literature (e.g., conference papers, posters, dissertations), (2) studies that used VR/AR as a tool to classify, diagnose, or identify ASD or ID, (3) studies that used VR to examine pre-existing differences between participants with and without ASD, and (4) studies where VR skill improvement was not directly related to people with ASD (e.g., using VR to teach professionals working with people with ASD).

ID was defined as studies reporting that the participant(s) were low-functioning or intellectually/cognitively disabled or impaired and/or when participants had a reported IQ of less than < 70 as measured by standardized instruments, such as the Wechsler Intelligence Scale for Children (WISC-III; Campbell, 1998). Other measures of IQ were accepted, if the study provided the scoring system that classified the participant(s) as having an ID.

Screening and Data Extraction

All studies from this search were exported from the databases into Covidence, an online tool for title/abstract and full-text screening, data abstraction, and quality assessment. After the tool automatically removed duplicate articles, the first round of screening took place. Initial search results were screened for titles and abstracts to determine relevance to ASD, Virtual/Augmented Reality, skill training/teaching, and child/youth participants. Within the second round of screening, the full-text articles were retrieved and examined, with specific attention to indicators of the presence of ID/below average IQ.

From the included studies, the following information was extracted: title, author, publication date, study design, VR/AR equipment used, skills taught/outcomes measured, duration, age range, sample size (total, ASD, ASD+ID), ID identification method/tool, outcome results, follow-up and generalization results, as well as acceptability/social validity data.

Quality Evaluation of Evidence and Determining Evidence-Based Practices in ASD

Evaluation of research report strength as per the Reichow et al. (2011) method involved evaluating each study as a whole for the quality of primary (high, acceptable, and unacceptable) and secondary (evidence and no evidence) quality indicators. Whereas primary indicators are elements of a research design deemed to be critical for demonstrating study validity, secondary indicators are seen as important, but not necessary, in establishing the validity of a study (Reichow et al., 2011). For group research designs, primary quality indicators referred to the (1) participant characteristics, (2) independent variable, (3) comparison condition, (4) dependent variable, (5) link between research question and data analysis, and (6) use of statistical tests. The eight secondary quality indicators for group research included random assignment, interobserver agreement, blind raters, fidelity, attrition, generalization and/or maintenance, effect size, and social validity. For single-subject designs, primary quality indicators referred to the (1) participant characteristics, (2) independent variable, (3) dependent variable, (4) baseline condition, (5) visual analysis, and (6) experimental control. The six secondary quality indicators included interobserver agreement, kappa, fidelity, blind raters, generalization and/or maintenance, and social validity. In order for a research report to be categorized as having a strong level of evidence, it had to receive high quality ratings on all primary quality indicators and demonstrate evidence of three or more secondary quality indicators (single subject design) or receive high quality ratings on all primary quality indicators and demonstrate evidence of four or more secondary quality indicators (group design). To receive an adequate level of evidence rating, a study had to receive high quality ratings on a minimum of four primary quality indicators with no unacceptable ratings as well as a minimum of two secondary quality indicators (single subject and group designs). Finally, a study was categorized as having a weak level of evidence if it had a high-quality rating on fewer than four primary quality indicators or fewer than two secondary quality indicators.

In order to establish a practice as an EBP, ratings of evidence strength/quality needed to meet at least one of eight criteria (although the practice could meet multiple) from the Reichow et al. (2008) method. For example, to be an established EBP the practice could have a) at least 10 single subject studies of at least adequate research report strength meeting the following criteria and/or b) at least two group experimental design studies of strong research report strength conducted in separate laboratories by separate research teams. Similarly, to be classified as a promising EBP, ratings of evidence strength/quality needed to meet at least one of two criteria including a) at least three single subject studies of at least adequate research report strength meeting the following criteria and/or b) at least two group experimental design studies of at least adequate research report strength (can be conducted by the same research team in the same location).

Inter-Rater Agreement

Screening

The author screened all of the publications for inclusion in the present review. A second rater, a trained research assistant, independently coded 100% of the articles during initial screening as well as when the full texts were downloaded for the final level of screening to determine the eligibility for inclusion. The training procedure for the second rater consisted of a meeting in which the author explained the inclusion/exclusion criteria and provided the rater with a data collection checklist (with examples). Both raters conducted the initial and full-text eligibility screening independently. Inter-rater agreement was calculated by dividing the number of agreements by the total number of items available for agreement. Any disagreements were resolved by discussion. Average inter-rater agreement on eligibility for inclusion was 92.5% (89-96%).

Quality Evaluation

The author evaluated the quality of the evidence of all publications with respect to Reichow et al. (2011) evaluation criteria, and a second rater coded 50% of the studies. The training procedure for the second rater consisted of a meeting in which the author explained the evaluation criteria and provided the rater with a data collection checklist which included all primary and secondary indicators as well as a legend for how the indicators should be assessed. Three articles were used as a ‘training set’ in order to ensure both raters had an understanding and agreement of the evaluation criteria prior to continuing to the remaining articles. Both raters conducted the quality assessment independently. Agreement was conducted on an item-by-item basis, with any disagreements resolved through discussion. Average inter-rater agreement on the Reichow et al. (2011) evaluation criteria was 91.5% (89 – 94%).

Results

The initial search identified 2070 articles across all databases. Automatic removal of duplicates by Covidence software resulted in 1591 papers, 114 of which were retrieved for full text review. A further 95 papers were excluded while reviewing full text, resulting in 19 publications with a total of 20 studies (two studies extracted from Sitdhisanguan et al., 2012) meeting the inclusion criteria for inclusion in the present review (see Figure 1 for details). The studies of the current review consisted of experimental studies (n = 14), case reports (n = 2), and clinical demonstrations (n = 4). The results of experimental design studies will be reported separately from non-experimental designs (case reports and clinical demonstrations). The included studies took place between 2006 to 2022 with a majority (12) conducted witin the last five years. The studies are published in various psychology/psychiatry journals (n = 10), hybrid journals of education and technology (n = 4), information technology journals (n = 2), educational journals (n = 1), and the remaining in miscellaneous journals (e.g., children, medicine) (see Deschling et al., 2022 for journal categorization).

Participants

Experimental Studies

The total number of participants with ASD in the included experimental publications was 263 (18.3% female). The age of participants ranged from 2-26 years old. Although the present review looked to examine only participants under 18 years old, two studies that included some adult participants were included in order to examine interventions catered to older adolescents (aged 15-18). Within the 14 studies, nine studies focused specifically on children (participants under the age of 12 years old), three studies focused on children and adolescents (under the age of 17 years old), and two studies included both adolescent and adult participants (see Table 1).

Non-experimental Studies

The total number of participants with ASD in the included non-experimental publications was 35 (11.7% female). The age of participants ranged from 3-16 years old. Within the six studies, three studies focused specifically on children (participants under the age of 12 years old) and two studies focused specifically on adolescents (participants 13-17 years old). One publication (Cakir & Korkmaz, 2019) did not provide the age of participants, and instead only indicated that the study was conducted on children (see Table 1).

Definition and Presence of Intellectual Disability

Experimental Studies

Of the 263 participants with ASD in the included experimental studies, at least 44 participants (16.7%) had comorbid ID. Given the nature of the reporting of ID by some studies, only 44 participants with both ASD and ID can be confirmed within the sample, although it is highly likely that more are present. That is, although 10 studies included specific information regarding the number/presence of participants with ID, four studies did not include a specific number, and instead reported an Intelligence Quotient (IQ) range for the participants as a whole, which would indicate the presence of those with below average cognitive functioning/ID (e.g., an IQ range of 67-110). Participants within the included studies were reported as having ID's ranging from mild (approximate IQ range 50-69) to moderate (approximate IQ range 36-49).

Similarly, the included studies indicated the presence of participants with IDs in various ways. That is, five studies were selected for inclusion based on the terminology the authors used while describing the participants (e.g., moderately mentally retarded, low functioning, presented ID, moderate cognitive impairment, etc.), whereas the remaining nine studies were selected based on the presence of IQ measures/scores (e.g., Weschler Intelligence Scale for Children, Test of Nonverbal Intelligence-Third Edition, The Leiter International Performance Scale, etc.) (see Table 1).

Non-Experimental Studies

Of the 35 participants with ASD in the included non-experimental studies, 29 participants (82.9%) were reported to have comorbid ID. All six studies included specific information regarding the number of participants with ID.

Four studies were selected for inclusion based on the terminology the authors used while describing the participants (e.g., moderately mentally retarded, low functioning, presented ID, moderate cognitive impairment, etc.), whereas the remaining two studies were selected based on the presence of IQ measures/scores (e.g., Raven's Matrices Test, Wechsler Abbreviated Scale of Intelligence). (See Table 2).

Virtual and Augmented Reality Use

Experimental Studies

Of the 14 experimental studies included in the review, 12 studies used VR and the remaining two studies used AR to administer the training/intervention. There was a wide range of equipment used when providing the VR/AR interventions in the selected studies. Such equipment included phone/tablet applications (n = 1), motion sensing 'Kinect' (n = 4), VR glasses (n = 1), head-mounted displays (headsets) and controllers (n = 3), projector/screen set-ups with tangible devices (n = 3), and computers/laptops (n = 2) (see Table 3).

Non-Experimental Studies

Of the six non-experimental studies included in the review, four studies used VR and two studies used AR to administer the training/intervention. VR/AR equipment included phone/tablet applications (n = 1), head-mounted display and controllers (n = 1), projector/screen set-ups with tangible devices (n = 1), computers/laptops (n = 1) and tangible user interface (n = 2) (see Table 4).

Target Skills

Experimental Studies

With respect to the skills targeted using the VR/AR technology, eight studies taught social/emotional skills (e.g., joint attention, empathy, theory of mind, social responding), five studies taught physical skills (e.g., gesture-based communication, coordination, motor skills), two studies taught cognitive/academic skills (e.g., sight words, attention, music), and three studies taught daily work/living skills (e.g., showering, bus travel, interview skills). It should be noted that three studies (Jung et al., 2006a; Jung et al., 2006b; Shahab et al., 2022) taught more than one skill (see Table 3).

Non-Experimental Studies

Two studies were found to teach social/emotional skills, one study taught physical skills, and four studies taught cognitive/academic skills. One study (DeLuca et al., 2021) taught more than one skill (see Table 4).

Procedures and Use of Evidence-Based Practices

The use of EBP's in interventions aimed at supporting individuals with ASD is critical to ensure effectiveness, however, many studies do not explicitly state the inclusion of EBP's within their procedures. Thus, the author of the current work examined the intervention procedures and applied their knowledge of EBP's (see Steinbrenner et al., 2020 to identify EBP's used within each of the studies included in the current review.

Experimental Studies

VR/AR technology was used to deliver each of the interventions in the current review, thus, the EBP of technology-aided instruction and intervention was present in all 14 experimental studies. However, there were also an additional 13 EBP's that were featured within the intervention procedures of the reviewed experimental studies which consisted of reinforcement (n = 8), social skills training (n = 8), modelling (n = 3), prompting (n = 3), augmented and alternative communication (n = 2), sensory integration (n = 2), video modelling (n = 2), visual supports (n = 2), naturalistic intervention (n = 2), parent-implemented intervention (n = 1), behavioural intervention (n = 1), music-mediated intervention (n = 1), time delay (n = 1). Each of the included studies implemented between 1-7 EBP's in their procedures (see Table 3).

Non-Experimental Studies

Similarly, all six of the included non-experimental studies used the EBP of technology-aided instruction and intervention. Eight additional EBP's were also present in the intervention procedures which included reinforcement (n = 3), social skills training (n = 2), modelling (n = 1), exercise and movement (n = 1), cognitive behavioural instructional strategies (n = 1), story-based intervention (1), prompting (n = 1), and visual supports (n =1). Each of the included studies implemented between 1-5 EBP's in their procedures (see Table 4).

Duration/Dosage of Intervention

Experimental Studies

Within experimental studies, duration/dosage of VR/AR interventions ranged from 3-90 sessions, with individual sessions between 10-45 minutes in length. It should be noted that two experimental studies did not report any information regarding duration/dosage of intervention (Cai et al., 2013; De Moraes et al., 2020). Similarly, studies reported the duration of their interventions in various ways which included number of weeks (1), number of weeks and number of sessions (1), number of sessions without length of an individual session (4), number of sessions with length of an individual session (2). Four studies reported all duration/dosage information (number of weeks, number of sessions, and length of an individual session) (see Table 3).

Non-Experimental Studies

Within non-experimental studies, duration/dosage of VR/AR interventions ranged from 1-32 sessions, with individual sessions between 25-40 minutes in length. Two studies reported duration in terms of number of weeks, one reported number of weeks and sessions, one reported number of sessions without length of an individual session, one reported number of sessions with length of an individual session, and one reported all information (see Table 4).

Follow-Up/Maintenance and Generalization

Experimental Studies

With respect to long-term effects, seven experimental studies collected follow-up/maintenance data that ranged from 1-6 months. Six of the articles reported positive follow-up results including the maintenance of skills learned as well as positive long-term outcomes (e.g., vocational success, Smith et al., 2021). One study reported a slight decrease in skills when comparing post-test and follow-up outcomes (Shahab et al., 2022). Additionally, three articles (Perez-Fuster et al., 2022; Saadatzi et al., 2018; Kang & Chang, 2019) reported generalization of skills with each finding that participants were able to apply what they had learned in the VR/AR to real-world scenarios (see Table 2).

Non-Experimental Studies

None of the included non-experimental studies included follow-up/maintenance or generalization data.

Acceptability/Social Validity

Experimental Studies

Acceptability/Social Validity was reported in six of the 14 included experimental studies. Such reports were generally positive in nature. Common themes from participants (n = 3), parents (n = 2), or teachers (n = 2) were that the program/intervention was engaging and enjoyable and useful for teaching the target skill. Additionally, those involved stated that they would be interested in future participation as well as would recommend participation to others. It should be noted that one study collected acceptability ratings from both parents and teachers (Kang and Chang, 2019).

Non-Experimental Studies

Only one non-experimental study, Li et al., 2021 reported acceptability. The study assessed acceptability of the VR headsets used within the study qualitatively and through observation. Findings were generally encouraging, but it was noted that time, practice, and support was needed for participants to adapt to the wearable VR technology and environment.

Quality Evaluation of Evidence

Experimental Studies

Nine studies used a group research design, and five studies used a single-subject research design. With respect to group research design studies, two studies were given a strong level of evidence rating (Kouhbanani et al., 2021; Smith et al., 2021), four were given an adequate level of evidence rating (De Moraes et al., 2020; Herrero et al., 2020; Lorenzo et al., 2017; Simoes et al., 2018), and three were given a weak level of evidence rating (Cai et al., 2013; Jung et al., 2006a; Jung et al., 2006b). Additionally, regarding single-subject design studies, two studies were given a strong level of evidence rating (Perez-Fuster et al., 2022; Saadatzi et al., 2018), two studies were given an adequate level of evidence rating (Cheng & Huang, 2012; Kang & Chang, 2019), and one study was given a weak level of evidence rating (Shahab et al., 2020) (see Table 5).

Non-Experimental Design

The six non-experimental studies included in the review were not evaluated as per the Reichow et al. (2011) evaluation criteria as they did not meet the criteria to be classified as either a group design nor a single-subject design, and thus could not be evaluated in this way (Cakir & Korkmaz, 2018; Li et al., 2021; Sitdhisanguan et al., 2012 - Study 1; Sitdhisanguan et al., 2012 - Study 2; Mitchell et al., 2007; De Luca et al., 2021).

Discussion

The aim of the current scoping review was to (a) provide a summary of studies which use VR/AR technology to provide interventions for children and youth with both ASD and ID, (b) identify themes within the literature with respect to target skills, technology use, and methodology, and (c) identify gaps in the literature in order to make recommendations for future research and practice.

After screening 1591 articles, 20 eligible studies from the literature were examined. Overall, the review revealed that the literature regarding the use of VR/AR technology to teach children and youth with both ASD and ID is in its infancy, and thus research evaluating its effects is limited at this time. Although the included studies show great promise, they highlight the need for more uniformity and/or consistency in this field of research as there currently exists a great deal of variation within the small number of available studies (e.g., identification and/or definitions of ID, VR/AR equipment used, target skills). Additionally, it cannot be concluded that VR/AR interventions are an evidence-based practice for children and youth with both ASD and ID as a result of the limited evidence available at this time. Such findings and more will be discussed in greater detail below.

Participants

The current review looked to examine the use of VR/AR interventions for those under the age of 18 years old but found that the most prominent age demographic for such studies was children under the age of 12 years old, with participants as young as 2-3 years old (Lorenzo et al., 2019; Sitdhisanguan et al., 2012- Study 1; Sitdhisanguan et al., 2012- Study 2).

Early intervention is often a priority in ASD research as it has been found that children who enter such programs at a young age make greater gains than those who enter at a later age (Harris & Handleman, 2000; Corsello, 2005). However, although there are benefits to early intervention, it is important to consider the suitability of such advanced VR/AR technology for use by young children. For example, the MetaQuest/Oculus head-mounted display VR system has been very popular in recent years for both recreational and research use, however, the creators state that their VR systems are designed only for ages 13+, as younger children are at greater risk of injury and adverse effects than older users (Meta quest safety center, n.d.). Potential concerns regarding young children's use of VR headsets include the size/weight of the headsets and the muscular strength required to wear them as well as the possible impact on the developmental process of eyesight (Jones, 2023). Similarly, the creators urge that even teenagers aged 13+ should be monitored when using the VR system to ensure safe use and accordance to guidelines (Meta quest safety center, n.d.).

Within the current review, only two studies that explicitly examined children 12 years of age or younger (ages 8-10 years old, Li et al., 2021; ages 6-8 years old, Shahab et al., 2022) and one study that examined children and adolescents 17 years of age or younger (ages 8-15 years old, Herrero & Lorenzo, 2020) used head-mounted displays/headsets. Although Herrero & Lorenzo (2020) found high acceptance of the headsets in their study, Li and colleagues (2021) noted that the ergonomics of the headsets were not well-suited for use by young children as the straps fit improperly and the headsets became heavy over time (Li et al., 2021).

Many of the included studies, specifically those working with children under the age of 12 years old, opted to deliver VR/AR using a combination of projectors/screens, tangible objects, and motion-sensing technology (Kinect), and did not report any adverse effects or experiences. Thus, it is possible that such methods of delivering VR may be better suited for use by young children in order to eliminate possible negative short- and long-term effects. Alternatively, future work may look to design VR systems specifically for young children. The wide-spread use and popularity of VR is fairly new and as a result there is a lack of long-term data on its potential impacts on developing children. That being said, it is important to be cautious and follow guidelines and regulations set out by those designing the VR systems.

Previous reviews have reported a lack of female participants in VR/AR interventions for children and youth with ASD (e.g., Deschling et al., 2021), and the present review is consistent with such findings. Although ASD is found to be diagnosed more in males than females, the number of female participants within the current review is lower than the reported male-to-female gender ratio of approximately 3:1 (Loomes et al., 2017). Thus, future research examining the effects of VR/AR intervention for those with both ASD and ID should look to include a more proportional number of female participants. Similarly, it has been suggested that the overall discrepancy in ASD prevalence may be due to the ability of females with ASD to ‘camouflage’ their symptoms in comparison to males (Tubío-Fungueiriño et al., 2021). That being said, it is critical for future research to include diagnostic measures that are sensitive to gender differences as well as provide interventions that meet the needs of both male and female participants with both ASD and ID.

Presence of Intellectual Disability

Although there has been a recent increase in the use of VR/AR interventions to support individuals with ASD, such research tends to be more biased towards including individuals classified as 'high functioning', which is consistent with what has been found in most areas of ASD research (Russell et al., 2019). A recent review, conducted by Deschling and colleagues (2022) on the use of VR and AR social skills interventions, found very few studies that included individuals who scored below the threshold for an ID diagnosis. Similarly, even studies that specifically examined VR with respect to both ASD and ID found that interventions targeting the developmental disorders separately were more prominent than those which examined them together (Yakubova et al., 2021). The findings of the current review are consistent with previous suggestions of such bias towards those without ID as only 20 VR/AR intervention studies were found to have at least one participant with comorbid ASD and ID.

Within the limited studies that were included in the current review, roughly a quarter of the ASD participants had co-occurring ID. That is to say, even in studies that included those with ID, most participants were still those classified as 'high functioning' or without ID. Further, it was found that studies not only typically had a low number of participants with ASD and ID, but many specifically excluded the participation of those with ID altogether. During the full-text screening process, 66 articles were excluded because of their eligibility criteria that explicitly denied participation for individuals with ID.

It has been suggested that many studies examining ASD may exclude individuals with comorbid ID in order to allow for the study of "pure autism", not autism that is confounded by the presence of ID (Vivanti et al., 2013). Similarly, individuals with both ASD and ID may exhibit higher rates of stereotypic and challenging behaviour as well as greater deficits in social, adaptive, and communicative functioning, which can make the implementation of interventions more challenging (Matson et al., 2009). However, although Hilton and colleagues (2014) stated that they excluded individuals with lower IQs in order to avoid potential confusion between the effects of impaired intelligence and impaired executive functioning, most studies excluded from the current review did not specify why their intervention would be unsuitable for those with comorbid ID, and instead simply stated an IQ cut-off score.

Due to the failure to provide evidence or reasoning supporting the exclusion of those with ID, it is unclear whether the current VR/AR interventions are unsuitable for those with ID or if this population has been arbitrarily excluded to keep up with the current trends of the literature. A potential consequence may be that future research, understanding, and practice will continue to be built upon the assumption that VR/AR interventions do not apply to and/or are not beneficial for those with ID, even if such views may or may not be founded. Similarly, without knowing the specific components that make VR/AR interventions effective vs ineffective for individuals with ID, it is challenging to design interventions to best support their needs moving forward.

With respect to the present review, one study (Shahab et al., 2020) found that the high-functioning participants demonstrated only minor improvements in cognitive skills during the intervention, likely as a result of ceiling effects. The single participant classified as low-functioning, on the other hand, was found to exhibit the largest improvement (Shahab et al., 2020). Although this study excluded many participants because of their ‘low-functioning’ status, it is possible that such a program may be better suited for individuals with ID. Similarly, it is possible that many studies that have arbitrarily excluded those with ID would be effective (possibly more effective) for those with ID but have not yet been evaluated with respect to that population.

Regardless of the potential reasoning, the current approach to VR/AR intervention research fails to accurately understand the ways in which ASD and ID interact and impact individual experience for many on the autism spectrum. Given that ASD is well known as one of the most common co-occurring disorders of individuals who have ID, examining current interventions more closely as well as designing future interventions capable of supporting a wider range of the autism spectrum should be a high priority moving forward.

Serret and colleagues (2014), for example, believe that although individuals with low- and high-functioning ASD may differ in many ways (such as IQ), they share an interest and preference for rule-based systems. With this idea in mind, the researchers developed an individual, interactive, and multisensory computer game called JeStimMulE which aimed to address gaps in the literature by teaching emotions to adolescents with autism regardless of intellectual, verbal, and academic level (Serret et al., 2014). By creating an 'ASD-friendly environment' that linked emotional and social elements with logical rules, the researchers found significant improvements in most of the tasks involved in the program, despite the heterogeneity of participants. Additionally, JeStiMulE allowed non-verbal as well as non-reader adolescents with ASD to learn and interact in the program by associating emotions with codes (Serret et al., 2014). Such findings have important implications for understanding how interventions and educational programming can be adapted to meet the needs of a wider range of individuals on the autism spectrum.

Definition of Intellectual Disability

The current review also found a lack of uniformity with respect to identifying, measuring, and referring to ID within ASD VR/AR interventions studies. That is, there was great variation regarding how the researchers addressed the inclusion of ID in their studies. For example, nearly half of the included studies did not administer measures of intelligence nor provide participants previous scores on such measures, and instead relied on the use of terminology such as ‘mentally retarded’, ‘low functioning’, and ‘cognitively impaired’ to notify readers of the inclusion of participants with below-average intellectual functioning/ID. Similarly, studies that did administer or provide scoring of psychological measures of intelligence varied greatly. Although various versions of the Wechsler Intelligence Scale for Children (WISC-III; Campbell, 1998) were most used in the included studies, three studies included alternative measures which had their own scoring and classification system. Such variation with respect to ID identification and terminology is a large limitation to the field of research regarding VR/AR use for those with ASD as it limits the ability for researchers, specialists, and the public to be able to easily access information regarding this population.

It has been discussed that the included studies identified ID in various ways, and that many studies which failed the screening process specifically excluded participants with ID. However, there is also a grey area, that is, many studies that were put through the screening process refrained from measuring or mentioning intellectual ability entirely. The exclusion of such information made it impossible to determine if an intervention study involved participants with co-occurring ASD and ID. Although this could allow for the speculation that VR/AR research is being conducted on a wider variety of individuals with ASD than we are presently aware of, it also has the potential to be misleading. The autism spectrum is one of great heterogeneity, and although intelligence may not be the only, nor the most influential differentiating factor between individuals with ASD, it is an essential factor to consider when designing as well as examining the effectiveness of an intervention. Past research has found that the absence of ID as well as the presence of better language skills have been consistently linked with a greater likelihood of improvement over time (LeCavalier et al., 2011). That being said, the co-occurrence of ASD and ID can impact long-term outcomes as well as response to treatment, and thus their presence should be specifically noted in intervention research. By failing to mention the inclusion or exclusion of those with ID, it is possible to mislead researchers, specialists, and the public on the effectiveness of interventions at meeting the needs of the entire spectrum. In order to reduce instances of confusion and misinformation with respect to the impact of co-occurring ID on the potential effectiveness of VR/AR interventions aimed at supporting individuals with ASD, future research should look to include more straightforward and uniform diagnostic information and psychological testing regarding intellectual ability.

Virtual and Augmented Reality Use

Regarding interventions for children and youth with both ASD ID, VR was found to be more prominent within the literature with 75% of the included studies in the current review using VR (vs AR). With respect to VR specifically, a wide range of equipment and level of immersion (the degree to which the experience is realistic and immersive for the user) was found. Four studies used equipment classified as non-immersive (e.g., computer, keyboards, joystick), five studies used equipment classified as semi-immersive (e.g., projectors, screens), and six studies used equipment classified as fully-immersive (e.g., wearable headsets, VR glasses).

A systematic review examining the impact of VR immersion on the assessment and teaching of social skills for individuals with ASD suggests that a high (vs low) level of immersion is more conducive with a successful delivery of intervention (Miller & Bugnariu, 2016). Reasoning for such findings could be linked to the increased ability to interact with the environment as well as the novelty of the technology that makes it both motivating and engaging. However, along with the noted benefits, there are some potential drawbacks of a fully-immersive virtual environment. For example, the experience or technology may be overwhelming, and thus, individuals with ASD may need more time to become comfortable before they can focus on the task at hand (Miller & Bugnariu, 2016). Consistent with these findings, two studies within the current review that used fully-immersive technology (VR Glasses, Cai et al., 2013; Head-mounted display, Li et al., 2021) noted that some participants refused to wear and/or took longer to adjust to the use of the technology. Additionally, as previously mentioned, the ergonomics of head-mounted display technology is not adequately designed for use by some individuals, specifically young children, which causes additional challenges (Li et al., 2021). Given the positive impacts of fully-immersive technology at delivering interventions to young children with ASD, future work should look to design such wearable devices to be more ergonomically suitable for a wider population.

Target Skills

The most prominent category of target skills taught within the included studies was social and emotional skills, followed by physical skills, cognitive/academic skills, and daily work/life skills. Given that children and youth with ASD and ID typically demonstrate deficits in both initiating and maintaining social connections, VR/AR technology has been found to be a useful avenue to practice social/emotional in an environment that is directly relevant to their lives, without the fear, anxiety, and potential consequences of real-life (Parsons & Mitchell, 2002; Chevallier et al., 2012).

In relation to the specific social skills taught, typical targets within the interventions were social understanding, social competence, joint attention, empathy, emotional reciprocity, and social communication. Whereas most of the studies focused on more passive, receptive experiences of learning social skills, two studies (Li et al., 2021; Mitchell et al., 2007) gave participants the opportunity to more actively engage in the experience by allowing them to walk around the environment (e.g., café, school) and approach human-avatars in order to initiate interactions. Overall, the studies of the current review collected quantitative data (with the exception of the case report by Li et al., 2021) and found positive results with respect to teaching social skills as well as the generalization of such taught skills to real-world scenarios (e.g., Perez-Fuster et al., 2021).

Procedures and Use of Evidence-Based Practices

The most prominent EBP within the current review was, of course, technology-aided instruction and intervention which was present in each included study through the use of VR and AR equipment to deliver the interventions. Technology-aided intervention is a commonly used EBP within ASD intervention research as individuals with ASD have been found to show a special interest in as well as adherence to computerized learning programs (Karami et al., 2021). However, although the use of technology is clearly useful, it is not the only necessary element to ensure an effective intervention, that is, it is essential that such technology integrates additional EBP’s to increase its efficacy. That being said, although the novelty and enjoyment of advanced technology plays an important role in ASD instruction and interventions, immediate feedback prompts, and reinforcement, which can be seamlessly incorporated into VR/AR interventions, provide additional benefits for users. For example, within the current review, the virtual job interview experience designed by Smith and colleagues (2021) was able to provide four levels of feedback including 1) real-time feedback during the interview via non-verbal cues, 2) a colour-coded transcript with feedback on why specific responses were unsuccessful and/or how they could be improved, 3) a score out of 100, and 4) a performance assessment via video and text. Such feedback had important implications for users when they applied what they had learned in the VR simulation to real-world job applications and interviews. Additionally, Kang and Chang (2019) provided reinforcement via an animal pop-up in order to give praise when a task was well done. Through their observations of participant use of VR headsets, Li and colleagues noted that providing in-VR facilitation and support through the use of pre-programmed audio and visual instructions as well as feedback was critical to the success of learning. Additionally, such instruction, feedback, prompting, and reinforcement being built into the VR system would decrease the risk of human error, thus increasing procedural fidelity.

However, many of the included studies lacked sufficient detail when describing intervention procedures to be able to identify the incorporation of EBP's. It is possible that more (or less) EBP's are present within the included studies than are currently understood. Given the crucial role EBP's play in the effectiveness of interventions designed to support those with ASD, future work should provide more in-depth procedures in order to inform readers, researchers, and professionals of the EBP's used.

Quality Evaluation of Evidence and Determining Evidence-Based Practices in ASD

When examining independent study findings, VR/AR technology interventions were found to be effective at teaching various skills to children and youth with both ASD and ID. However, the assessment of the 14 eligible experimental design studies as per Reichow et al. (2011) criteria resulted in very few studies that demonstrated strong research quality, with the majority being adequate at best. When taken together, the current review meets the criteria to allow VR/AR interventions to teach children and adolescents with ASD and ID to be considered an evidence-based practice as there was at least four group experimental design studies of at least adequate research report strength conducted in at least two different laboratories by separate research teams (Reichow et al., 2011). However, this claim would be misleading due to the large variation that exists within the included literature. The included studies used a wide variety of VR and AR equipment (e.g., projectors, headsets, computers) as well as taught a wide range of skills (e.g., social emotional, cognitive, motor) which would result in an inaccurate overgeneralization of results. Given the small overall number of studies that examine individuals with both ASD and ID, there is simply not enough evidence to support any one technology, method, or target skill as an EBP at this time. This finding demonstrates the need for an increase in experimental studies with the necessary methodological rigor to provide a strong level of evidence on the effect of such technology on various skills for those with ASD and ID. The limited available studies examining the effects of VR/AR interventions on those with ASD and ID may suggest that the field of VR itself is still in its beginning stages. However, given the ample VR research conducted thus far on participants considered to be 'high-functioning' it is also possible that limited attention has been given to this particular population.

Duration/Dosage of Intervention

Similar to other elements of VR/AR research, great variety exists with respect to the duration/dosage of such interventions. For example, VR/AR intervention programs of the current review ranged from a single session to up to 90 sessions spanning over multiple months. However, such variation with respect to dosage is common in intervention research, as the number of sessions is often dependent on the difficulty of the target skill as well as the speed at which the participants learn the target skill. For length of each individual session, on the other hand, there was a lot less variability, with sessions ranging between 10-45 minutes long. Although it was not explicitly stated by any of the included studies, it is possible that session duration was based on recommendations that suggest 15 minutes of break-time for every 30 minutes of playtime while using VR/AR (specifically VR headsets) in order to reduce instances of eye strain and fatigue (Department of Business, Energy & Industrial Strategy, 2020).

As previously noted, the studies of the present review reported duration/dosage of their VR/AR interventions in various ways including (1) number of weeks, (2) number of sessions, (3) length of individual sessions, or any combination of the three. Future research should look to provide a more uniform and detailed description of VR/AR intervention duration/dosage.

Follow-up/Maintenance and Generalization

Virtual environments are believed to offer realism that make maintenance, as well as generalization of skills learned from treatment to real-world scenarios, easier for those with ASD (Lanyi & Tilinger, 2004; Strickland et al., 2007). However, there is a lack of long-term data on the effect of VR/AR based interventions for children and youth with both ASD and ID as less than half of the included studies conducted follow-up sessions after the intervention was complete. Overall, the majority of the studies that did collect such data found positive results such that the participants maintained the improvement in their skills after the initial intervention. Further, Kouhbanani and colleagues (2021) found that although participants receiving only medication-based treatment (Risperidone) relapsed to their original state after the intervention was complete, those who received both medication and VR did not relapse and instead exhibited a substantial improvement in both behavioural and social problems. From these results, the authors proposed that VR interventions may have a greater impact on social and behavioural problems than medication, especially when used alone (Kouhbanani et al., 2021). Only one study

(Shahab et al., 2020) reported a small, but significant, decrease in follow-up music/melody performance for a single participant with both ASD and ID.

Similarly, there is a lack of generalization data, but initial findings are encouraging. The review found that showering skills in the classroom generalized to real life showering in the participants home (Kang & Chang, 2019), joint attention skills demonstrated towards a 'dummy' generalized to real-world situations (Perez-Fuster et al., 2022), and sight words learned generalized with 100% accuracy to the home environment with parent implementation (Saadatzi et al., 2018). Additionally, although Smith and colleagues (2021) did not report it as generalization data, their VR job application and interview training resulted in a greater number of interviews and competitive employment, thus demonstrating that the interview skills acquired in the VR intervention applied and generalized to the real world.

The long-term course of ASD has been found to be frequently influenced by comorbid ID as well as overall language ability (LeCavalier et al., 2011). That being said, the presence of ID in those with ASD can negatively impact both long-term outcomes and response to treatment, making it critical to understand whether or not VR/AR technology is capable of making lasting changes in the lives of those with ASD and ID. The findings of the current review are a positive start, but more long-term follow-up data is needed moving forward.

Acceptability/Social Validity

Benefits

A majority of the acceptability/social validity data found in the current review was collected through measures/questionnaires with general themes involving the acceptance of headsets, experience satisfaction, and interest in repeating the experience/recommending to others. Overall, participants rated the process as highly acceptable. Through interviews and questionnaires, parents reported strong support for the intervention (would participate in future or recommend to others) as well as stated that the programs were effective, interesting, and enjoyable for their children. Additionally, teachers noted that implementing the VR/AR interventions had a lot of positive contributions to the student's academic achievement such as increased attention, interest, and engagement, as well as mentioned how technology should be included more in education where possible (e.g., Kang & Chang, 2019).

Barriers

As previously mentioned, the present review found that a potential barrier to wearable VR/AR technology, especially for young users, is the fit and feel of the technology. That is, within the included studies, some of the researchers noted that the participants required time to adjust to the use of the VR/AR technology (VR glasses, Cai et al., 2013; VR headsets, Li et al., 2021), and it was recommended that the ergonomics of the technology could be improved. However, it should be noted that no additional short- or long-term adverse effects (e.g., eye strain and fatigue) were reported by participants in the included studies. Another potential barrier mentioned is the need for increased facilitation and support for child and youth users with both ASD and ID when in the VR system. For example, Li and colleagues (2021) noted that the participants would miss or misunderstand instruction or prompts given to them within the VR intervention and would require additional support from the facilitators. Given that the VR headset often confines its user to the virtual scene, it can be both difficult and inconvenient when the facilitator needs to intervene. Thus, it is suggested that additional pre-programmed audio and visual instruction, prompts, and feedback may be necessary to ensure the success of learning.

Overall, the findings with respect to the acceptability/social validity of VR/AR interventions note engagement and motivation as the benefits, and inadequate ergonomics and ease of facilitation when using wearable technology as the potential barriers for children and youth with ASD and ID. Given that less than half of the included studies collected any type of acceptability data, future work should further examine perceptions of VR/AR interventions from consumers in order to increase benefits and address barriers.

Other Noteworthy Findings

With respect to the current work, it is clear that although VR/AR technology can help individuals with ASD experience and explore without the consequences and barriers of the real-world, such technology is not designed for, or at least not frequently examined with respect to, individuals with comorbid ID. That is, the current technology and literature fail to appropriately apply to a wide range of the autism spectrum. However, those with ID are not the only individuals who face barriers when it comes to interacting with VR/AR technology. For example, through structured interviews, Mott and colleagues (2020) identified seven barriers of VR for those with limited mobility which include (1) setting up the VR system, (2) putting on and taking off the VR headset, (2) adjusting and/or using the headset, (3) cord management, (5) manipulating two controllers simultaneously, (6) inaccessible controller buttons, and (7) maintaining the VR system's view of the controllers. It is evident that barriers exist at every stage of use, even as early as setting up and putting on the device, for those with physical disabilities such as wheelchair users or those with upper-body motor impairments.

Aforementioned, age is another barrier to accessing VR/AR technology. That is, wearable VR technology is not adequately designed to support young users at this time with concerns regarding the size, weight, and head straps. Similar concerns also exist for older adults as they may experience limited mobility such as low strength and fatigue. VR/AR use shows great promise for research, therapeutic, and recreational purposes, but future work should look to design such technology with accessibility in mind to ensure that any individual can experience its benefits, regardless of cognitive, language, physical, sensory, or age-related abilities.

Limitations

In addition to the caveats of the literature mentioned above, the main limitations of the current review are the, the exclusion of grey literature, inclusion of only English language articles, the use of child-related search terminology, and the insufficient quality and quantity of information to be able to make claims of effectiveness.

Firstly, in an attempt to increase the quality of the current review, only peer-reviewed journal articles were included. Thus, the decision to exclude grey literature, such as unpublished theses, dissertations, and conference proceedings (even those that are peer-reviewed), was done deliberately. However, it should be noted that grey literature can be a very important and impactful resource, and thus its exclusion is a limitation of the current work. It is possible that there is additional relevant and emerging research, as well as research with null or negative findings, that exists which did not meet criteria for inclusion in the current review. That being said, it could be beneficial for future reviews to include such literature, specifically peer-reviewed conference proceedings, and potentially compare targets, procedures, and findings between grey literature and that which is published. Similarly, the present review was limited to the inclusion of only articles published or available in English. Future research should include articles published in other languages.

Secondly, the use of the search terminology of ‘child’ or ‘youth’ or ‘adolescent’ or ‘student’ may have resulted in the exclusion of papers that included a wide range of ages in their intervention studies (e.g., from 2-72). Two studies in the current review had an upper age range that extended beyond the initial inclusion criteria as a result of having younger participants as well as adults. It is possible that more intervention studies that included such a range were excluded during the screening process due to their lack of child and adolescent-related terminology. Although such age ranges make it more difficult to determine whether effects were observed for children (vs adults), they provide a valuable contribution. It could be beneficial for future reviews examining VR/AR interventions aimed at teaching skills to those with ASD and ID to include participants of any age and allow for comparisons of age within the review itself in order to have a more in-depth understanding of intervention effects across the lifespan.

Finally, the review documented insufficient evidence to be able to claim that VR/AR is an effective intervention for those with ASD who also have ID at this time. The studies included in the current review did not demonstrate strong enough quality of evidence to be deemed an EBP for those with ASD+ ID. Similarly, we did not calculate effect sizes, due to the lack of available data, and thus have limited ability to properly assess the efficacy of such interventions.

Suggestions for Future Research

Based on the findings of the present review, the major suggestions for future research are to (1) increase the uniformity of VR/AR intervention practices and methodology and (2) improve quality with respect to evidence-based practices. Given that the field of research on VR/AR interventions is still in its infancy, especially with respect to those with both ASD and ID, it is likely that these suggestions can be achieved over time as the quantity and quality of such research increases.

Firstly, as mentioned throughout the current work, the research surrounding VR/AR interventions for children and youth with both ASD and ID is one of great variety. Whether it be definitions and terminology of ID or type of technology used, such variation in the field makes it difficult to draw conclusions about the effectiveness of these interventions and highlights the need for greater uniformity in future VR/AR research practices. For example, with respect to definitions and terminology related to ID, it is suggested that researchers follow the DSM-5 (American Psychiatric Association, 2013) definition and criteria moving forward. By doing this, research will become better aligned with current practice which uses the DSM-5 for the determination of diagnosis and allocation of services for those with ID. Not only will this shift be more relevant to current practices, but it will also lead to greater uniformity in research which will ease the ability of researchers and practitioners alike to understand and access the most up-to-date and effective research/interventions for those with ASD and ID.

Similarly, there is a wide definition of what is considered to be VR technology, with such technology ranging from simple computer programs to fully wearable and immersive technology. As previously mentioned, VR technology is often described as having three levels of immersion (1) non-immersive (e.g., projectors, keyboards), (2) semi-immersive (e.g., projectors, screens), and (3) fully immersive (e.g., wearable headsets, VR glasses) (Heizenrader, 2022). That being said, it may be beneficial for researchers to specify the level of immersion of their VR interventions in future work, in order to better categorize and understand the differential effects of various types of VR technology moving forward.

Finally, there is a need to increase the quality of research examining VR/AR interventions for those with ASD and ID. With respect to the Reichow et al. (2011) quality evaluations, there was a lack of strong evidence within the included experimental design studies. Whereas the lower (e.g., ‘adequate’ or ‘weak’) quality ratings that were observed for single-subject design studies were primarily a result of poor performance on the primary indicators of baseline and experimental control, many of the group design studies received an ‘adequate’ instead of ‘strong’ rating as a result of a lack of secondary indicators (e.g., random assignment, IOA, blind raters etc.). Although primary indicators are the only elements of a research design deemed to be 'critical' for demonstrating study validity, secondary indicators play an important role in increasing research strength. That being said, researchers should look to ensure they meet the criteria for all of the necessary primary indicators, as well as incorporate as many secondary indicators as possible in order to strengthen the quality of future research involving VR/AR interventions.

Similarly, not only was there insufficient evidence to classify VR/AR interventions as an evidence-based practice for those with both ASD and ID, but there was also limited and/or unclear inclusion of EBP's in the selected studies. Although the use of technology-aided instruction and intervention is an EBP in itself, such advanced technology is yet to be fully evaluated. Additionally, it is essential for such technology-based interventions to incorporate additional EBP's within their methodology in order to ensure maximum effectiveness for those with ASD. Moving forward, researchers should formally include, as well as acknowledge the inclusion of, EBP's in their VR/AR intervention studies in order to not only improve the effectiveness of their interventions, but to make it clear to both researchers and practitioners why such an intervention was effective.

Implications for Practice

The findings of this scoping review suggest that VR/AR technology may be capable of improving various skills in children and youth with both ASD and ID. Such technology has shown great potential as an instructional/intervention method for children and youth with ASD by allowing for repetitive practice of essential skills and the ability to learn from mistakes without the potential negative consequences of real-world decisions. However, the current scoping review does not have enough evidence to suggest it as an EBP for children and youth with both ASD and ID at this time. Thus, as with any new intervention or technology, particularly those designed to support individuals with ASD and other exceptionalities, it is important for practitioners to proceed with both openness and caution. As such, it is essential for practitioners to consider the suitability of the technology at their own clinical discretion and on the basis of each individual client, as well as follow guidelines and regulations set out by the system designers. For example, whereas the use of fully immersive technology (e.g., headsets) may be appropriate for adults, it may not be suitable for young clients due to improper fit (e.g., Li et al., 2021) and safety guidelines that suggest system use for only ages 13+ (Meta quest safety center, n.d.). That being said, it is possible that less immersive VR/AR technology (e.g., computer, projector) may be better suited for young users as well as those with sensory issues related to wearable technology.

Conclusions

In conclusion, the current literature regarding the use of VR/AR technology is in its infancy with respect to both the quantity and quality of studies, especially when examining participants with both ASD and ID. Further, within the small number of eligible studies, a great deal of variation was found in essentially every intervention element (e.g., duration, type of technology, target skills etc.) which further limits the conclusions that can be made on the efficacy of the technology at this time. The results of this scoping review provide an important contribution by summarizing and highlighting current themes as well as gaps in the literature, such as the lack of uniformity and high-quality experimental methodology. In addition, it reveals various research and practice-based implications and future directions to regarding the efficacy of VR/AR interventions for children and youth with both ASD and ID.

Figure 1

Flow chart of the selection process of included studies

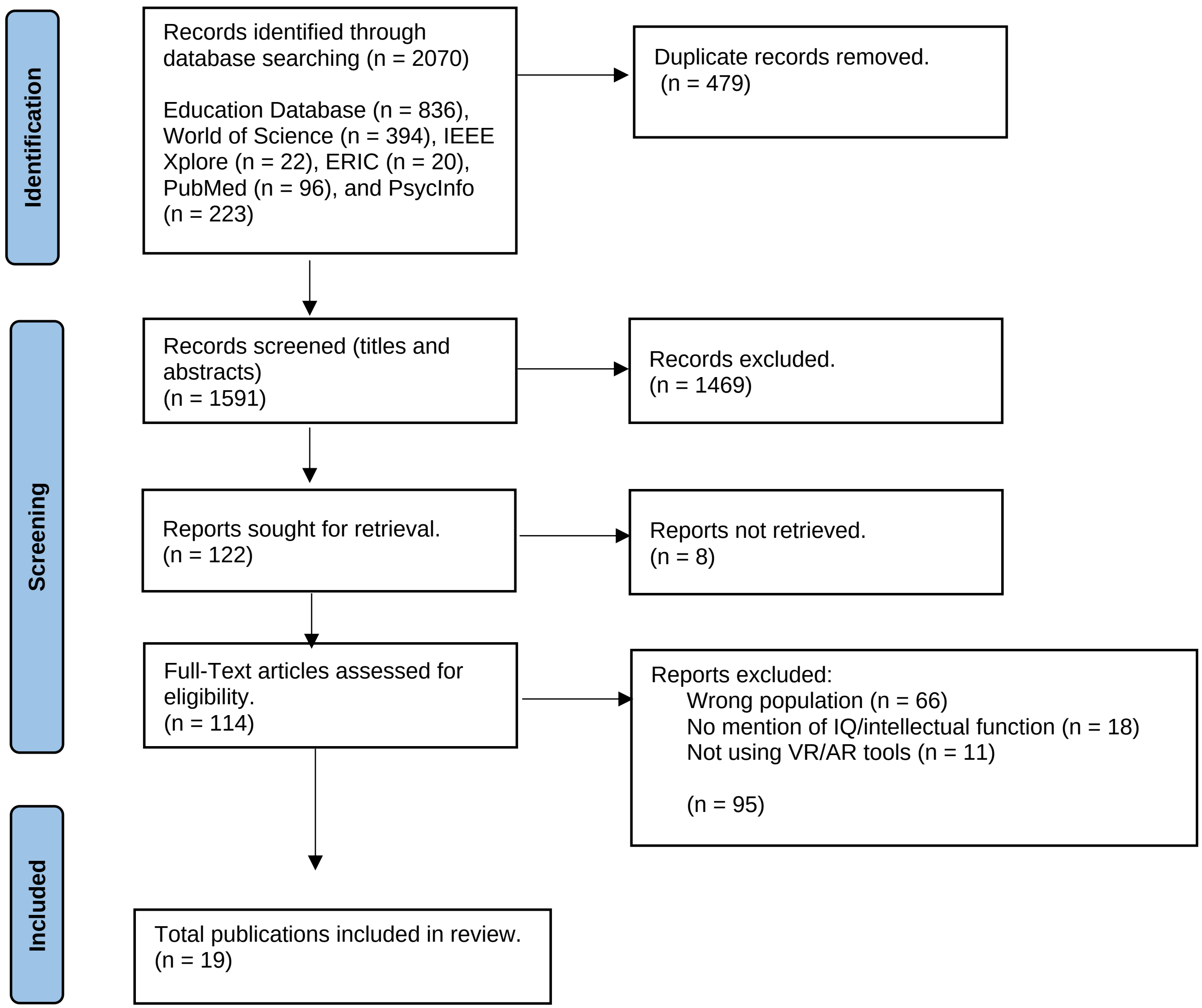

Table 1

Experimental design participant characteristics and diagnostic information

Author (year)	ASD Participants	Age Range	ASD + ID Participants	ID Identification Tool	ID Tool Information/Scoring Provided by Study
Cai et al., 2013	15	6-17	8	Test of Nonverbal Intelligence-Third Edition (TONI-3)	'This norm-referenced non-linguistic problem-solving ability assessment tool is administered to identify if a participant has intellectual impairment or cognitive, language or motor impairments due to neurological conditions. Anyone with an NIQ of below 80 is considered as having intellectual deficiency.'
Cheng & Huang, 2012	3	9-12	3	Wechsler Abbreviated Scale of Intelligence III (WASI; Wechsler, 1999).	Not Reported
De Moraes et al., 2020	50	7-15	Unspecified	Short form of the Wechsler Intelligence Scale for Children (WISC-III; Campbell, 1998)	WISC-III has been shown as a valid measure of general intelligence [Campbell, 1998] and uses the following classification of the intelligence quotient (IQ): mild intellectual disability at 55–70, borderline intelligence at 70–85, normal intelligence at 85 or above, above average intelligence at 115–129, and superior intelligence at 130 or above
Herrero & Lorenzo, 2020	14	8-15	2	Participants classified as having 'low IQ', 1 with 'mild cognitive retard.'	N/A
Jung et al., 2006a	12	5-6	Unspecified	Wechsler Intelligence Scale for Children (WISC-III; Campbell, 1998)	Not Reported
Jung et al., 2006b	12	5-6	Unspecified	Unspecified	N/A

Table 1 *Continued*

Author (year)	ASD Participants	Age Range	ASD + ID Participants	ID Identification Tool	ID Tool Information/Scoring Provided by Study
Kang & Chang, 2019	6	9-11	6	"Cognitive and adaptive functioning fell within the moderate intellectual disability range"	N/A
Kouhbanani et al., 2021	45	6-12	Unspecified	Wechsler Intelligence Scale	Not Reported
Lorenzo et al., 2019	11	2-6	2	"Presented Intellectual Disability"	N/A
Pérez-Fuster et al., 2022	6	3-8	6	Leiter International Performance Scale, Revised	'The brief version of this non-verbal test, which consists of two main broad areas: Visualization and Reasoning. < 85 suggests below average cognitive ability and < 70 is highly suggestive of ID.'
Saadatzi et al., 2018	3	6-8	1	Wechsler Preschool and Primary Scale of Intelligence (WPPSI; Wechsler et al. 2012)	Not Reported
Shahab et al., 2022	5	6-8	1	Referred to participant as 'low functioning'	N/A
Simões et al., 2018	10	M_{age}=18.8	2	IDC-10 Classifications of Mental and Behavioural Disorder. In: Clinical Descriptions and Diagnostic Guidelines	N/A
Smith et al., 2021	71	16-26	11	Reported 18.8% had 'cognitive impairment'	N/A

Table 2

Non-experimental design participant characteristics and diagnostic information

Author (year)	ASD Participants	Age Range	ASD + ID Participants	ID Identification Tool	ID Tool Information/Scoring Provided by Study
Cakir & Korkmaz, 2018	1	N/A	1	Participant defined as 'moderately mentally retarded'	N/A
De Luca et al., 2021	1	16	1	Raven's Matrices Test (RMT; Raven, Raven, & Court, 1998)	'RMT is one of the most commonly used instruments to measure analogical reasoning, capacity for abstraction, and perception the 60 questions allow us to evaluate the "g" factor of intelligence.'
Li et al., 2021	3	8-10	1	Classified as "low functioning"	N/A
Mitchell et al., 2007	6	14-16	2	Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999).	Not Reported
Sitdhisanguan et al., 2012-Study 1	12	3-5	12	'All were diagnosed with LFA according to DSM-IV criteria'	N/A
Sitdhisanguan et al., 2012-Study 1	12	3-5	12	'All were diagnosed with LFA according to DSM-IV criteria'	N/A

Table 3

Experimental design intervention characteristics and outcomes

Author (year)	Study Duration	Target Skills	Equipment Used	VR/AR Procedures & EBP's	Summary Outcome Results	Follow Up/Maintenance
Cai et al., 2013	N/A	Hand gesture-based communication	Immersive Room with Kinect and 3D Glasses (VR)	Technology-Aided, Video Modelling, Reinforcement	Participants varied in their interest in using the program. Many required parent mediation and prompting in order to learn and function.	N/A
Cheng & Huang, 2012	3 months; One 30-40 min session a week	Joint Attention	Desktop workstation computer with projector and data gloves (VR)	Technology-Aided, Social Skills Training, Prompting, Reinforcement	All participants had a significant increase in skills during intervention	Once weekly for 12 days following intervention. All participants maintained skills.
De Moraes et al., 2020	N/A	Motor Skills	Kinect for Windows (VR)	Technology-Aided	Practice of motor and cognitive skills in the virtual task was more difficult (producing more errors) but led to a better performance in the subsequent practice in the real task, with more pronounced improvement in the ASD as compared to the TD group.	N/A
Herrero & Lorenzo, 2020	10 sessions	Emotional and Social Skills	Head Mounted Display – Oculus (VR)	Technology-Aided, Social Skills Training	All participants in the study group improved after the intervention in the majority of areas.	N/A
Jung et al., 2006a	10 sessions	Social Skills & Coordination Ability	Tangible Interaction System; Projector and Tangible Devices (VR)	Technology-Aided, Sensory Integration, Social Skills Training, Reinforcement	All except one of the participants were able to complete the tasks. Social skills training program produced more interaction by conversation with therapist	N/A

Table 3 *Continued*

Author (year)	Study Duration	Target Skills	Equipment Used	VR/AR Procedures & EBP's	Summary Outcome Results	Follow Up/Maintenance
Jung et al., 2006b	10 sessions	Social Skills & Coordination Ability	VR Tangible Interaction System; Projector and Tangible Devices (VR)	Technology-Aided, Sensory Integration, Social Skills Training, Reinforcement	There were no significant results found for the specific skills taught, but the social skills training module elicited various conversations.	N/A
Kang & Chang, 2019	21 sessions across 11 weeks	Shower Training	Kinect Sensor (VR)	Technology-Aided, Naturalistic Setting, Prompting, Visual Supports, Reinforcement, Parent Implemented	The data showed that the percentage of correct task steps significantly increased among all six participants.	Maintenance phase 4 weeks after intervention All participants maintained skills and generalized to real-life showering.
Kouhbanani et al., 2021	3 months; Daily 45 min sessions	Social Skills and Behavioural Symptoms	VR Glasses (VR)	Technology-Aided, Naturalistic Setting, Parent Implemented, Social Skills Training, Behavioural Intervention,	Results of the post-test demonstrated a significant improvement in behavioral problems and social skills of both experimental (Risperidone only & Risperidone + VR) groups.	3 month follow up. Risperidone only relapsed to original state. Risperidone + VR group exhibited sig. improvement in behavioural and social problems.
Lorenzo et al., 2019	20 weeks; Two times a week for 15 min	Social Skills	Android Smartphone Application (Quiver Vision) (AR)	Technology-Aided, Social Skills Training, Reinforcement	No statistically significant differences for the control group or experimental group before and after AR treatment.	N/A

Table 3 *Continued*

Author (year)	Study Duration	Target Skills	Equipment Used	VR/AR Procedures & EBP's	Summary Outcome Results	Follow Up/Maintenance
Pérez-Fuster et al., 2022	8 weeks	Joint Attention	Kinect – Pictogram Room (AR)	Technology-Aided, Augmented & Alternative Comm., Modelling, Reinforcement, Social Skills Training	The intervention was effective for all participants in terms of enhancing their joint attention skills.	4 week follow up. All participants maintained the taught skills. Generalized to real-world situations,
Saadatzi et al., 2018	4 months; Twice a week	Sight Words	Computer Screen with a virtual teacher and a humanoid robot emulating a peer (VR)	Technology-Aided, Naturalistic Setting Augmented & Alternative Comm., Time Delay, Modelling, Prompting, Reinforcement	Participants acquired, 100% of the words explicitly instructed to them, made fewer errors while learning the words common between them and the robot peer, and vicariously learned 94% of the words solely instructed to the robot.	2 month follow up. All participants maintained and generalized the taught skills in a home setting with parent.
Shahab et al., 2022	20 weeks; 8-10 sessions for 10-15 min each week	Music Skills, Fine Imitation, & Social Skills	HTC VIVE Virtual Reality Headset (VR)	Technology-Aided, Music-Mediated, Video Modelling, Social Skills Training	The highest improvement was recorded for the low-functioning child	2-month follow-up. Slight decrease in in comparison with the post-test session.
Simões et al., 2018	3 sessions, 20-40 min each	Bus Travel Training	Head-Mounted Display – Oculus Rift (VR)	Technology-Aided	The intervention was successful in increasing the accuracy of in-game actions as well as sig. increasing knowledge of the process.	N/A
Smith et al., 2021	15 sessions; 45 min each	Interview Training/Skills	Computer Program (VR)	Technology-Aided, Reinforcement	Participants receiving services as usual and Virtual Interview Training (vs as usual only) had better job interview skills and lower job interview anxiety as well as greater access to jobs.	6-month follow-up. More positive vocational outcomes completing VR program (vs training as usual).

Table 4

Non-experimental design intervention characteristics and outcomes

Author (year)	Study Duration	Target Skills	Equipment Used	VR/AR Procedures & EBP's	Summary Outcome Results	Follow Up/Maintenance
Cakir & Korkmaz, 2018	8 weeks; 90 minutes a week	Attention & Academic Development	Tablet Application (AR)	Technology-Aided	The participant's attention was increased, and they were able to perform all tasks independently after the intervention.	N/A
De Luca et al., 2021	48 sessions total (24 with CBT + VR); Three times a week for 40 min	Motor and Cognitive Rehabilitation	BTS-Nirvana (Screen) (VR)	Technology-Aided, Cognitive Behavioural Instructional Strategies, Exercise & Movement	Only the combined CBT+VR approach provided a sig. improvement in cognitive skills and reduction in ideomotor stereotypes	N/A
Li et al., 2021	32 sessions	Social Skills	Head Mounted Display – Oculus Rift (VR)	Technology-Aided, Social Skills Training, Story-based, Prompting, Visual Supports	The participant learned to generalise social norms to new situations without the need for explicit visual hints	N/A
Mitchell et al., 2007	6 weeks	Social Understanding	Laptop with VR software – using a joystick and mouse (VR)	Technology-Aided, Social Skills Training, Reinforcement	Significant gains were more common directly following a session with the Virtual Environment (VE) than during a session that did not directly follow the VE	N/A
Sitdhisanguan et al., 2012 – Study 1	6 sessions; 25 min each	Shape Matching	Tangible User Interface (TUI) System (AR)	Technology-Aided, Modelling	The TUI system provided comparable (apart from exceptional cases) results to the touch-based system which yielded the best results.	N/A

Table 4 *Continued*

Author (year)	Study Duration	Target Skills	Equipment Used	VR/AR Procedures & EBP's	Summary Outcome Results	Follow Up/Maintenance
Sitdhisanguan et al.,2012 - Study 2	4 weeks; 5 sessions a week	Colour Recognition	Tangible User Interface (TUI) System (AR)	Technology-Aided, Reinforcement	Learning efficacy for the participant group using the TUI-based system is significantly higher than those using the touch-based and color-stick method.	N/A

Table 5

Ratings for strength of evidence per Reichow et al. (2011) evaluation criteria

	Primary Quality Indicators						*Secondary Quality Indicators*								*Final*
Group Research	P	IV	CC	DV	DA	ST	RA	IOA	BR	TF	AT	G/M	ES	SV	*Rating*
Cai et al., 2013	H	A	U	H	U	U	E	NE	NE	NE	E	NE	NE	NE	Weak
De Moraes et al., 2020	H	H	H	H	H	H	E	NE	NE	NE	E	NE	NE	E	Adequate
Jung et al., 2006a	A	A	A	H	H	A	NE	NE	NE	NE	E	NE	NE	E	Weak
Jung et al., 2006b	A	A	A	H	H	A	NE	NE	NE	NE	E	NE	NE	E	Weak
Kouhbanani et al., 2021	H	H	H	H	H	H	E	NE	NE	NE	E	E	E	E	Strong
Herrero et al., 2020	H	H	H	H	H	H	E	NE	NE	NE	E	NE	NE	E	Adequate
Lorenzo et al., 2019	H	H	H	H	H	H	NE	E	NE	NE	E	NE	NE	E	Adequate
Simoes et al., 2018	H	H	H	H	H	A	NE	NE	NE	NE	E	NE	NE	E	Adequate
Smith et al., 2021	H	H	H	H	H	H	E	E	NE	NE	E	NE	NE	E	Strong

	Primary Quality Indicators						*Secondary Quality Indicators*						*Final*
Single-Subject Research	P	IV	DV	BL	VA	EC	Kappa	IOA	BR	TF	G/M	SV	*Rating*
Shahab et al., 2020	H	H	H	U	H	U	NE	NE	NE	NE	E	E	Weak
Cheng & Huang, 2012	H	H	A	H	H	A	NE	E	NE	NE	E	E	Adequate
Kang & Chang, 2019	H	H	H	H	H	A	NE	E	NE	E	E	E	Adequate
Perez-Fuster et al., 2022	H	H	H	H	H	H	E	E	NE	E	E	E	Strong
Saadatzi et al., 2018	H	H	H	H	H	H	NE	E	NE	E	E	E	Strong

Note. H High Quality; A Acceptable Quality; U Unacceptable Quality; E Evidence; NE No Evidence P Participant; IV Independent Variable; DV Dependent Variable; CC Comparison Condition; DA Data Analysis; ST Statistical Tests; RA Random Assignment; IOA Inter-Observer Agreement; BR Blind Raters; TF Treatment Fidelity, AT Attrition; G/M Generalization and/or Maintenance; ES Effect Size; SV Social Validity; BL Baseline, VA Visual Analysis; EC Experimental Control.

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