Spherical video-based virtual reality (SVVR) is a type of VR experience that uses 360-degree video footage to create an immersive environment. In recent years, there has been a growing interest in using SVVR technology as an intervention modality for autistic people (Glaser et al., 2022). However, there is a lack of research synthesizing its evidence and guidelines for optimizing its use for autistic users (Glaser & Schmidt, 2022). Accordingly, an evidence-based framework with guidelines and design considerations is essential to help developers and educators to systematically tailor SVVR to autistic learners' various needs. We believe that an analysis of design factors will allow for a systematic adaptation of SVVR to meet autistic learners' diverse needs. Research indicates a significant lack of representation and even disregard for crucial sociocultural and pedagogical elements within system designs (Janke, 2020). To rectify this, we have undertaken a systematic literature review aimed at uncovering sociocultural, technological, and pedagogical factors that currently guide the utilization of SVVR in the field. It is our hope that adopters of this technology will build off of this evidence base and continue to report these critical details. The research questions that informed our systematic literature review are as follows:

(1) What are the sociocultural considerations of SVVR systems for autistic users reported in the literature?,

(2) What are the technological considerations of SVVR systems for autistic users reported in the literature?, and

(3) What are the pedagogical considerations of SVVR systems for autistic users reported in the literature?

Background

Autism is a neurological difference that influences how individuals interact, communicate, and experience the world (Pellicano et al., 2022). Barriers presented by society mean that autistic people may have trouble with socializing and the sensory environment (Robertson, 2010). This can become even more challenging as they grow into adolescence and adulthood, as the social climate becomes more demanding, supports are difficult to access, and employment is low (Levy & Perry, 2011). A variety of technologies exist to provide support for autistic individuals, such as, augmentative and alternative communication (AAC) devices; apps for visual schedules and organization; video modeling; and virtual, augmented, or mixed reality (Bellani et al., 2011; Bellini & Akullian, 2007; Ganz, 2015; Moon et al., 2020). Many of these technologies are seen as being effective, in part because they provide highly controlled visual stimuli, which aligns well with the visual processing strengths that are often associated with some autistic people (Knight et al., 2015). In particular, virtual reality has garnered attention as a technology that can enable users to practice skills in realistic, but controllable environments (Strickland 1997; Parsons, 2016).

Virtual Reality & Autism

Research suggests that VR technology maintains a number of critical affordances and benefits for autistic learners (Parsons, 2016). In particular, the technology may offer various advantages, including predictability, structure, customizable task complexity, control, realism, immersion, automated feedback, assessment, and reinforcement (Bozgeyikli et al., 2018). As a result, the desire to create VR-based interventions for autistic individuals has been increasing steadily for more than two decades (Aresti-Bartolome & Garcia-Zapirain, 2014; Glaser & Schmidt, 2022). This research has been ongoing since preliminary studies focused on assessing the feasibility of using VR equipment and investigating the potential learning benefits for autistic children was conducted (Strickland, 1996, 1997). Since then a range of interventions have been developed utilizing a constellation of VR technologies including desktop-based VR, fully immersive VR, and mobile-based virtual reality (Glaser & Schmidt, 2022). While there is some evidence of effectiveness in these systems, studies that tend to report on the effectiveness of these systems tend to be plagued with a range of methodological flaws (such as using self-report data or reporting highly variable and inconclusive outcomes) (cf., Parsons et al., 2006) and overgeneralizations. In fact, it seems that nearly all research in this area is performed in research institutions (Glaser & Schmidt, 2022); in part because of the innate complexities in designing and deploying VR for autistic users (Schmidt, 2014; Glaser et al., 2022) such as the high cost of development, complex design and development skills requirements, and the lack of portability of traditional VR equipment (Schmidt et al., 2019). Due to the challenges in developing VR systems for this population, researchers have begun to turn their attention to an emerging technology that holds potential for lessening some of the research to practice gaps that exist.

Spherical Video-based Virtual Reality

In a SVVR system, users can view video content that captures the entire field of view, creating a feeling of being physically present in a different location. Users can then view the footage using a VR headset or other device that allows them to move their head and look around within the video environment (Glaser et al., 2022a; Schmidt et al., 2019).

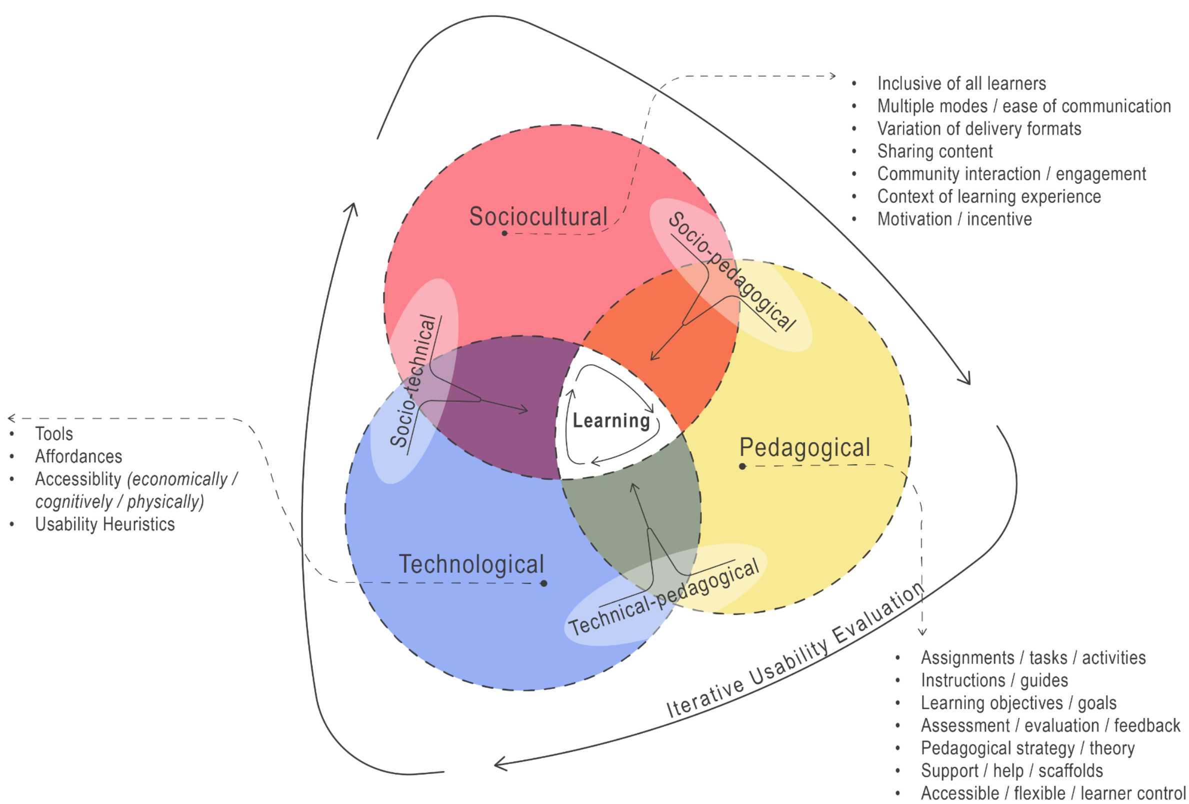
Via simulating real-life scenes and environments, VR helps learners to engage in situated learning experiences. Particularly, in enhancing students' situated learning SVVR has technical advantages over other VR technologies. However, interactivity can be constrained by the pre-recorded video playback, resulting in limited affordances for the users. On the other hand, fully immersive virtual reality (IVR) can enable individuals to have complete body tracking affording high-level interactions in a computer-generated 3D virtual world (Makransky & Petersen, 2021). Despite SVVR's limitations, researchers have used SVVR for autistic individuals due to several benefits (Schmidt et al., 2019). First, SVVR is easier to develop compared to other VR technologies (Chien & Hwang, 2022), and requires less specialized devices and software (Glaser et al., 2022). Second, the benefits of SVVR allows designers to easily deploy the content compared to other VR settings (Ye et al., 2021; Wu et al, 2021). Lastly, its high compatibility with various devices enhances its affordability.

Sociotechnical-Pedagogical (STP) Framework

A method of 'optimizing both the technological and the social dimensions of the learner experience' (Janke et al., 2020, p.130), the STP framework, used as a heuristic tool, guides us to evaluate the sociocultural (Schmidt et al, 2022), technological, and pedagogical dimensions of a technology-based tool or system designed to support learning (see Figure 1). Developed to address a gap identified by Janke et al. (2020) where multiple published heuristics, commonly applied to the design and development of technologies, missed important sociocultural factors that are essential aspects of learning design, while only a few explored pedagogical aspects. This multidimensional conception of usability works to mitigate 'barriers to learner inquiry and navigation within the learner environment' (Janke et al., 2020, p.130) as well as the negative impact that barriers can have on the formation of knowledge. The STP framework views technology as a tool that can be used to support and enhance teaching and learning, and it emphasizes the importance of designing learning activities and environments that are socially and culturally relevant (Lu & Schmidt, 2022). In the context of developing technologies to support autistic users, the STP framework can be particularly relevant. By considering the unique sociocultural factors that impact the experiences of autistic users, as well as the technical and pedagogical aspects of the technology being designed, developers can create technologies that are more effective and meaningful for this population. This can include incorporating user-centered design principles, considering the diversity of the autistic community, and integrating best practices in teaching and learning for autistic users.

Figure 1

Adapted from, Multi-Dimensional Usability Framework in the Context of Learner Experience (Jahnke et al., 2020)



Methods

A systematic review was undertaken to address the overarching aims (Davis et al., 2014) with the goal of providing reliable conclusions to better inform the field regarding identified issues (Page et al., 2020). The Preferred Reporting Items for Systematic reviews and

Meta-Analysis (PRISMA) procedures were adhered to in order to ensure the highest quality of methodology and reporting (Page et al., 2020). The Problem, Interest, COntext approach (PICo) was implemented to shape the focus of the systematic review (Stern et al., 2014), which is a qualitative reworking of the established PICO framework for meta-analyses (Stern et al., 2014; Butler et al., 2016). Keyword and controlled vocabulary search strategies and search filters were established using the PICo framework for Qualitative Studies (Butler et al., 2016)

(1) **Population (P):** Researchers of SVVR interventions for autistic users.

(2) **Interest (I):** Sociocultural, technological and pedagogical designs and considerations of SVVR training applications and interventions for autistic users.

(3) **Context (Co):** Research projects that use SVVR as a tool to deliver training or educational opportunities for autistic users.

To identify articles to be included for this review, six electronic databases were searched (see Information Sources).

Eligibility Criteria

Eligible manuscripts for inclusion were peer-reviewed articles in English, published in academic journals after 2014, describing a SVVR system specifically designed for autistic users, used to deliver training, intervention, or an educational lesson, with evaluation or research data presented and involving autistic users. The year 2014 was chosen as the cutoff for this review because SVVR technologies are still relatively new and there's a dearth of literature in this area prior to the advent of commercially available head-mounted displays (Bradley et al., 2018); Conference proceedings were also considered for this literature review as design considerations of VR-based technologies are often included in IEEE conference proceedings. Literature reviews, conceptual pieces, patents, and citations were excluded. Papers that reported SVVR systems not specifically designed for autistic users were excluded as well as, systems used for diagnosis or entertainment, and studies without an educational component or with only expert/parent perceptions.

Information Sources

Searches for this systematic review of the literature were conducted in February 2022. Six electronic databases were searched: ERIC, IEEE Xplore, PsychInfo, Scopus, & Web of Science, Google Scholar was also searched as a secondary tool to seek additional literature found in ancestral searches. While Google Scholar's immense dataset serves as a multidisciplinary collection of knowledge, it lacks many of the features required for conducting a systematic search (Gusenbauer & Haddaway, 2020; Haddaway et al., 2015). Therefore, this search engine was only used as a secondary tool to seek literature that may have been missed in the full systematic review of the electronic databases

Search Strategy

An iterative process was employed to create the search strategy. Initial searches were conducted and the literature found was examined to understand the nature of the returned results. This strategy was improved over multiple cycles. The overarching search terms employed in this systematic review were "autism" and "spherical video-based virtual reality," as well as various permutations of those terms. An example of our unstructured query is provided in Appendix A. We also applied filters and limits to the search based on the capability of the index and the nature of the search. These filters included (1) being published between 2014-2022, (2) being a peer reviewed journal or proceeding article, (3) being published in English, and (4) excluding materials such as patents or citations.

Search Results Reliability

To assess the reliability of the search results a second member of the research team conducted database searches a week after the initial search was conducted. These searches were conducted using the same search strategy (queries, keywords, filters, etc.) to validate the number of returned results. No differences were found in the number of returned results.

Selection Process

Records from each database search were exported as a Research Information Systems (RIS) file type. These files were then imported into RefWorks (http://refworks.proquest.com/) as it has a robust set of automated tools to seek out duplicate entries. A combination of searches (Exact Match, Close Match, and Legacy Close Match) as well as a manual review were conducted and duplicate entries were removed. Second, we reviewed the titles and abstracts of the remaining documents based on our inclusion and exclusion criteria. Third, we examined the full text of the remaining articles and again applied our inclusion and exclusion criteria. Fourth, and last, we conducted an ancestral search based on additional manuscripts found in the references of our included corpus. At the end of this process we had a total of 16 articles included in our full review representing 8 projects. The study selection process is illustrated in Figure 2.

Study selection inter-rater reliability

The second author performed the initial screening of articles, with the first author screening a subset to establish inter-rater reliability. The first author applied inclusion and exclusion criteria to approximately 75% of the remaining articles (n = 993; see Figure 2), and reliability was calculated by comparing results and calculating the percentage of agreement. The two researchers met to resolve any discrepancies. Agreement estimate was 92%, indicating high agreement.

Data Collection Process

We conducted a thorough review of all relevant publications related to a given SVVR project in order to gather information on sociocultural, technological, and pedagogical considerations. Since our research questions were focused on design factors rather than empirical findings, it was necessary to group articles that reported on the same project, as not all design details may have been reported in a single article and had to be gathered from multiple sources. To organize the articles, we assigned each project a unique identifier. These identifiers were created by combining the project name, if provided, and the principal investigator's last name. For projects without a stated name, we created a descriptive title (e.g. "Miller et al., Blood Draw Phobia VRET"). We used a customized Google Form to extract and organize information on the sociocultural, technological, and pedagogical considerations of the SVVR systems described in the articles. A total of 8 projects were identified from the included manuscripts.

Data Items

To address our research questions we extracted a range of variables and design considerations and used the STP framework as a basis for our efforts. These data items include (1) sociocultural factors such as attitudes, age, gender, education, income, and disability, (2) technological factors such as system hardware, software, compatibility with different platforms and devices, interface design, functionality, performance, security and privacy, etc., and (3) pedagogical factors in the relationship between technology and its users including learning objectives, instructional design, supports and scaffolds, learning theories, and assessment and evaluation. While these data items were organized into three RQs, the STP framework recognizes that the relationship between technology and its users is complex and dynamic, and that the various technological, pedagogical, and sociocultural considerations are all reflexive and interplay with one another (Janke, 2020). This means that the impact of one consideration can influence the impact of another, and that the relationship between technology and its users is constantly evolving and changing. Data were extracted iteratively with the goal of synthesizing any reported considerations across the dimensions of the STP framework.

Risk of Bias

This review, while aligned with PRISMA guidelines for reporting systematic reviews (Page et al., 2020), is inherently a qualitative review and thus necessitates a distinctive approach to the evaluation of risk of bias. In contrast to quantitative research, where bias signifies systematic error, the interpretative nature of qualitative research involves inherent subjectivity (Finlay, 2002). Instead of traditional bias assessments, we addressed issues of transparency, rigor, and reflexivity - both within the primary studies and our review process (Morse et al., 2002). Further, instead of collating and synthesizing results across multiple studies, our aim is to report design principles across a variety of SVVR systems designed for autistic users across different settings, sociocultural dimensions, pedagogical practices, and technological systems. Given this scope, we deemed certain methodologies, such as the enhancing transparency in reporting the synthesis of qualitative research (ENTREQ) framework, not entirely appropriate (Tong et al., 2012). Despite this, we took steps to ensure methodological rigor and transparency, conducting our review (Morse et al., 2002) according to adapted PRISMA guidelines (Page et al., 2020). Specifically, we present our search result reliability and study selection inter-rater reliability details make the work more transparent and rigorous. Through our approach, we have been able to systematically review the literature to present a robust articulation of design principles in SVVR systems for autistic users, making a significant contribution to the field.

Results

The following section summarizes the results of this literature review. First we present the results of our systematic selection process. These results are followed by a detailed overview of sociocultural, technological, and pedagogical considerations of SVVR systems for autistic users that are reported in the literature.

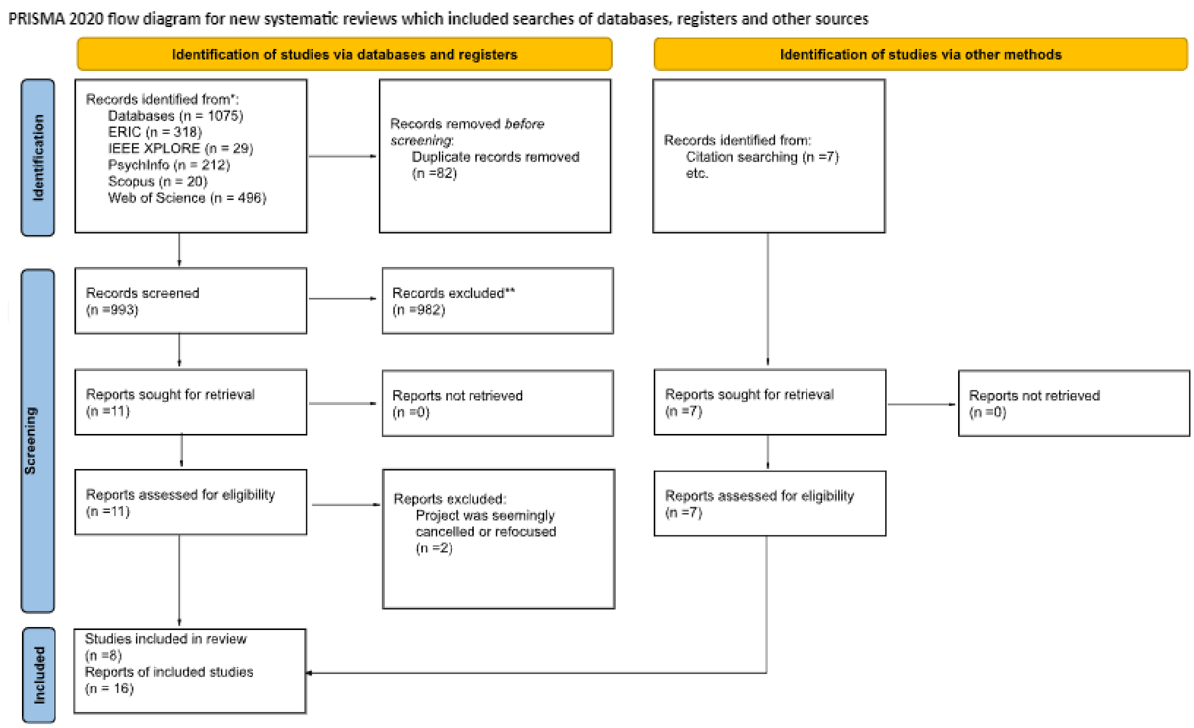
Study Selection

An initial search across five databases resulted in a total of 1,075 results. This pool of resources was culled to 993 articles after duplicates were removed. A total of 18 articles remained after a review of titles and abstracts was conducted for relevance. A full-text review was performed on these 18 articles by the first author and inclusion and exclusion criteria were applied. A secondary analysis was performed by the second author on these 18 articles. The outcome of this process was a final corpus of 16 articles that met the inclusion criteria. A diagram illustrating the search and selection process is provided in Figure 2.

According to PRISMA (Page et al., 2020), the initial screening and selection process involves identifying and screening individual publications, whereas results should be reported based on the number of unique studies. Therefore, we categorized the 16 identified publications by study, with the final outcome representing 8 unique studies.

Figure 2

Flow diagram illustrating search and selection process



RQ1: What are the sociocultural considerations of SVVR systems for autistic users reported in the literature?

[INSERT TABLE 1]

Participant Demographics

SVVR systems have been designed and deployed for autistic users from a wide range of age, demographics, and diagnoses. The age ranges of participants provided in the included studies varied from 0-9 years for children (36.4%), 10-19 years for adolescents (27.3%), and 20+ years for adults (36.4%), with one study not specifying age ranges.

The results show that, among the study participants discussed in this paper, receiving a medical diagnosis from a licensed professional is the most common method for diagnosing autism. It should be noted that only a few studies included participants who self-diagnosed or received a diagnosis through a school therapist or practitioner (see Table 1).

Where is this Research Taking Place?

Findings indicate that the majority of studies utilizing SVVR technologies are taking place within community settings (i.e. home of the participant) that are contextual to the needs of the participants and the learning outcomes. There are also a few projects that are being conducted within medical contexts such as a doctor's office and within university research labs.

What is the Virtual Context?

The virtual environments and contexts of identified SVVR systems vary depending on the study, including 360-degree videos of real streets, college campuses, a dog park, inside a bus, and more. In fact, most of the SVVR systems seem to provide 360-footage of scenarios that are relevant, individualized, and based on a real-life setting unique and important to the participant. These systems provide virtual scenarios including verbal exchanges and noises occurring in different environments, such as a doctor's office, school bus, and an airport in San Diego. While in the minority, some designers opted for fantasy environments that were more abstract in nature and presented like a cartoon (e.g., XOOM).

Inclusion of Autistic Participants in the Design Process

In the majority of projects, autistic end-users were not brought into the design and development process until it was time to evaluate the SVVR system. None of the papers reported how the research team solicited the voice, experiences, perspectives, or needs of the autistic users during the front-end analysis or design process. In the Virtuoso-SVVR project, researchers reported that they guided their conceptualization and design based on feedback from an autism day program director. The XOOM project is unique where instead of providing a singular SVVR experience, it instead provides an interface for researchers, practitioners, care providers, and autistic people to develop their own SVVR scenarios or to edit pre-existing scenarios.

RQ2: What are the technological considerations of SVVR systems for autistic users reported in the literature?

[INSERT TABLE 2]

Headset Hardware used in SVVR Systems and Cost

Findings show that the majority of SVVR systems being designed for autistic users are being primarily deployed within some kind of lightweight headset that is designed for use with mobile devices. Examples include the Blood Draw Phobia VRET and the Virtuoso-SVVR application. In the Blood Draw Phobia VRET system, videos were played on an iPhone 6 through the Tzumi Dream Vision headset. The Virtuoso-SVVR project was designed to support a broad range of headsets including the Google Daydream (now off the market) and the Google Cardboard. The Virtuoso-SVVR application was deployed on a Motorola zForce smartphone, but it was developed to work on any Android device and could also be loaded on fully immersive headsets such as the Oculus Rift. Only two of the identified projects were designed and deployed solely for fully immersive headsets. These were the Safety Training and Pedestrian Skills VR system and the Bus Scenario VR.

Further, Table 2 lists the estimated costs of equipment and supplies needed for developing and deploying the listed SVVR projects. The costs are broken down by each stage (Develop and Deploy) and specific components needed for each stage are provided. The costs for each component and stage vary, with some being more expensive than others. For example, the Oculus Rift headset costs $450, while the Google Cardboard costs only $15. While there are some shared costs by many of these projects, it seems that developing and deploying SVVR systems can vary depending on the specific needs and goals of the project.

Spherical Video Design Details

Results of this review found that all SVVR videos are being presented in a first person perspective in some form or another. In a first-person video perspective, the camera is positioned as if the viewer is the one recording the video, and they see the events as if they are experiencing them directly. In the XOOM experience, users are free to use any perspective they like and to edit existing 360-degree content. In the Turning Heads project, the developers experimented with a true first-person perspective and with another where the camera was positioned next-to-first-person.

Results from this review also found that narration details were largely absent with little information provided into the pacing, tone, delivery, or other design considerations. Of the projects, only two provided insight into how narration was provided. The first is Wildcard where the narration was adaptive based on the gaze of users. However, no other details regarding the narration messaging design was provided. The second was the Virtuoso-SVVR project. In this project the researchers designed the narration to be delivered from the perspective of the user with statements to mirror their inner monologue (e.g., "Today I need to catch a shuttle to get to work"). Instructions in the video were provided by a recording from a support staff in conversational tone with built-in prompting.

RQ3: What are the pedagogical considerations of SVVR systems for autistic users reported in the literature?

[INSERT TABLE 3]

Which Skills are Targeted by SVVR Systems for Autistic Users?

All of the identified articles reported on developed SVVR systems that targeted skills for daily living. This includes preparing participants to navigate an airport (see Virtual Reality Air Travel Training), identify when it's safe to cross various streets at different times of the day (see Safety Training and Pedestrian Skills VR), navigate and access public transportation on a college campus (see Virtuoso-SVVR), ride a school bus (see Bus Scenario VR), visit a school, store, and museum (see Wildcard), and receive medical care at a doctor's office (see Blood Draw Phobia VRET). Moreover, one project targeted multiple daily living skills (i.e. washing, drying, and folding laundry; visiting a cafe, ordering and paying for a drink, and sitting with friends; street crossing and navigating a campus and building; walking, street crossing, and visiting a dog park in the community) with goals to identify user preferences and design considerations (see Turning Heads). The Turning Heads project integrated a target for communication and social skills, including ordering a drink and interacting with friends in a cafe. Two projects focused on health-related concerns of anxiety, including a participant's phobia or fear of having blood drawn at doctors office (Blood Draw Phobia VRET), and evaluating anxiety and cybersickness experienced by autistic users while using a SVVR system that presented a school bus riding scenario (Bus Scenario VR). Finally, one project, Wildcard, described how a SVVR system could be created to present social stories for autistic users to support school and community location access, but did not describe specific skills targeted for instruction.

Instructional Design Strategies and Theories

The majority of manuscripts did not specifically state any instructional design or theoretical underpinnings. However, strategies and theories were sometimes briefly alluded to. When they are provided, the instructional design strategies seem to be highly contextualized to the needs of the target users. Example supports include (1) using procedural task analysis to inform the design of the task, (2) creating short videos, and (3) fading of supports. Theoretical underpinnings were largely absent. Only the Virtuoso-SVVR project specifically described instructional theory.

To What Extent Did Authors Report Learning Outcomes and Generalization?

Half of the SVVR systems examined reported research outcomes. The Safety Training and Pedestrian Skills VR was developed to teach street crossing skills and observed improvement in participants' responses during SVVR intervention and natural environment data probes. Bus Scenario VR was designed as a school bus riding scenario for autistic users, with SVVR intervention demonstrating no significant difference in anxiety and ease of use compared to monitor-displayed video. However, users experienced an increased sense of spatial presence and naturalness, and preferred the SVVR intervention. The Blood Draw Phobia VRET was developed as an SVVR intervention for autistic users' phobia of blood draws, observing improvement in user's completion of blood draw procedures. Lastly, the Virtual Reality Air Travel Training was developed to provide air travel training for autistic users, observing increased attentiveness, comprehension, and language function in participants. Other SVVR projects reviewed did not report outcomes.

Where were the Targeted Skills Assessed for Generalization?

Four projects on SVVR systems for autistic users reported generalization contexts, including proximal and distal generalization. Dixon et al. (2020) evaluated the distal generalization of their SVVR system for teaching street crossing skills in natural settings, which revealed that participants displayed mastery criteria with street crossing outside the research context. The Safety Training and Pedestrian Skills VR research team assessed proximal generalization of their SVVR system for school bus riding skills by obtaining feedback from parents a month after the intervention, indicating a positive change in participants' attitudes towards riding the school bus. In regards to the Blood Draw Phobia VRET, proximal generalization was assessed for blood draw phobia in the user's actual doctor's office, showing that the user fully completed the 10-step blood draw procedure with two different nurses after the intervention. Due to research constraints, the Virtual Reality Air Travel Training project only evaluated proximal generalization of their SVVR system for air travel training by collecting post-test data for user comprehension and real-world rehearsal of navigating through an airport. The other four SVVR projects reviewed did not report any assessment of skills generalization.

Discussion

In this section, we sequentially unpack our results as they pertain to each research question. We begin with a review of findings related to sociocultural considerations of SVVR systems for autistic users reported in the literature (RQ1). Next, we dive into technological considerations of SVVR systems for autistic users reported in the literature(RQ2). We then turn our attention to pedagogical considerations of SVVR systems for autistic users reported in the literature (RQ3) The section concludes with a discussion on the limitations of the systematic review.

Discussion of RQ1: What are the sociocultural considerations of SVVR systems for autistic users reported in the literature?

Participant Demographics

Recent years have witnessed diversified uses of VR systems for autistic individuals. While most studies focused on children and adolescents (Mesa-Gresa et al. 2018; Glaser & Schmidt, 2021), there's increasing recognition of the need for adult interventions (Gerhardt & Lanier, 2011). Age data from studies show a balanced distribution: 36.4% children, 27.3% adolescents, and 36.4% adults. Yet, diagnosis methods in these studies predominantly rely on medical professionals, overlooking those diagnosed by school therapists (Sarret, 2016). This oversight may bias results and affect the generalizability of findings using SVVR systems.

The inclusion of adults in SVVR autism research is significant but requires careful interpretation due to differing needs from younger age groups (Hume et al., 2021). Design and intervention strategies effective for children may not suit adults. While early intervention is vital (Mesa-Gresa et al., 2018), using SVVR for 'lifelong intervention' could benefit adults who missed early opportunities or face new challenges with age.

Where is this Research Taking Place?

The settings in which SVVR research is conducted, especially for autism interventions, are crucial for applicability. While traditionally confined to academic settings (Glaser & Schmidt, 2021), there appears to be a shift towards community-based locations, including participants' homes and medical offices. The affordability and portability of SVVR technology facilitates its use in real-world settings, addressing accessibility and transportation issues faced by the autistic community (Shea et al., 2021; Carmien et al., 2005). Shifting from academic labs to community settings not only makes interventions more accessible but also captures a broader range of experiences, addressing the risk of missing critical perspectives (Palmen et al., 2004). This move also enhances research validity. With SVVR systems being easier to develop than immersive VR, we can anticipate more research in this domain (Glaser et al., 2022). However, immersive VR research might remain relegated to more controlled environments until the technology is easier for a broader population to use and becomes a common commodity..

What is the Virtual Context?

Given the fact that SVVR systems utilize video recordings, it is not entirely surprising to find that developers are creating scenarios that are based on the naturalistic settings of autistic participants. This contrasts with most VR research where fantastical settings offer only abstract real-world representations (Glaser & Schmidt, 2022). Given autistic individuals' propensity towards literal and concrete thinking (Hobson, 2012), many see this abstraction as a limitation, advocating for VR systems that mirror real-world contexts for skill practice (Schmidt & Glaser, 2021). The ease of development of SVVR content provides a promising opportunity to address these concerns (Glaser et al., 2022a; Glaser et al., 2022b; Schmidt et al., 2019).

Inclusion of Autistic Participants in the Design Process

Based on the projects examined, autistic end-users have largely been omitted from SVVR design, typically only being included in product evaluations (Newbutt et al., 2023). Excluding autistic users from the design process could lead to systems that do not address their unique needs. Despite the obvious importance of involving autistic perspectives in VR development, this is disturbingly rare (Monahan et al., 2023), which raises serious ethical concerns about representation. This is especially relevant, given that SVVR is seen as an assistive technology to enhance quality-of-life (Parsons et al., 2020). SVVR systems designed without autistic input might miss key features or have non-intuitive interfaces, potentially reducing engagement and effectiveness (Newbutt et al., 2023). Beyond ethics, involving autistic voices is practical, ensuring systems are accessible and relevant, which decreases the likelihood that they will be abandoned. For instance, the XOOM project, with its customizable interface, exemplifies this user-centric approach, suggesting a model for future SVVR endeavors (Gelsomini et al., 2017; Garzotto et al., 2017).

Discussion of RQ2: What are the technological considerations of SVVR systems for autistic users reported in the literature?, and

Headset Hardware used in SVVR Systems and Cost

Using mobile-compatible headsets for SVVR systems like the Blood Draw Phobia VRET and Virtuoso-SVVR enhances accessibility (Meindl et al., 2019; Glaser et al., 2022a; Schmidt et al., 2021). This contrasts with pricier, immersive VR headsets which are less common (Glaser & Schmidt, 2021). The affordability of solutions like Google Cardboard, priced around $15 versus the $450 Meta Quest, makes SVVR interventions more accessible, especially considering the financial challenges of autism therapies (Horlin et al, 2014). Further, deploying SVVR on common devices like smartphones boosts social validity, making SVVR a practical daily tool for autistic individuals, in line with the trend of home-based healthcare (Neuer, 2020). However, as noted previously, challenges remain in involving autistic perspectives in system design (Newbutt et al., 2023). To unlock SVVR's full potential, inclusion of autistic end-users is imperative in actively shaping the design of these interventions.

Spherical Video Design Details

The review highlights two main SVVR features: the prevalent use of first-person perspectives and the underexplored area of narration design. Systems like XOOM and Turning Heads primarily use a first-person view, which is believed to enhance immersion (Gelsomini et al., 2017; Garzotto et al., 2017; Sitbon et al., 2019; Zervogianni et al., 2020). While potentially effective, the consistent use of first-person perspective may miss opportunities for alternative viewpoints better suited for specific contexts (Violante et al., 2019). For example, using a third-person perspective could be useful as a counterpoint to a first-person perspective for illustrating social cues. Further, narration, crucial in instructional videos (Mayer, 2017; Bennet et al., 2017), lacks detailed exploration in the literature. Of the included studies, only Wildcard and Virtuoso-SVVR offered insights into their narrative approach (Gelsomini et al., 2016; Glaser et al., 2022a; Schmidt et al., 2021). The lack of focus on narration design, vital for reinforcing content and aiding comprehension, is concerning and remains an area for future research.

Discussion of RQ3: What are the pedagogical considerations of SVVR systems for autistic users reported in the literature?

Which Skills are Targeted by SVVR Systems for Autistic Users?

SVVR systems for autistic users mainly target daily living skills, such as navigating public areas and safe street crossing (Miller et al., 2020; Dixon et al., 2020; Glaser et al., 2022; Malihi et al., 2020b; Gelsomini et al., 2017; Meindl et al., 2019). These systems address practical, real-world challenges commonly faced by autistic individuals. Beyond daily living skills, some SVVR projects explore multiple skills to discern user preferences (Sitbon et al., 2019). Some focus on communication, like cafe interactions, while others address health concerns like anxiety in medical contexts (Meindl et al., 2019; Malihi et al., 2020b). The varied focus of SVVR systems, while promising, prompts queries about their breadth and precision. Including social and communication skills could highlight the diverse needs of autistic individuals beyond just functional behaviors. Addressing concerns like anxiety could underscore emotional and psychological factors associated with autism, and, given the success that interventions like exposure therapy have had with VR (Meindl et al, 2019), represent a potentially clinically relevant and socially valid area for future research.

Instructional Design Strategies and Theories

The current review unveils a notable lack of clear instructional design strategies in most SVVR studies for autistic users. Though some projects hint at strategies tailored to users, like task analysis and fading supports, there remains a significant void in defined instructional frameworks or theories in the literature.

The lack of instructional design in SVVR studies poses concerns about their generalizability and replicability. Adapting or expanding these systems becomes difficult without understanding their foundational strategies or theories. This omission also restricts our depth of understanding regarding SVVR effectiveness. Theoretical frameworks help interpret results and discern success drivers. Most studies offer context-less observations, with only one project detailing an instructional theory (Glaser et al., 2022a; 2022b; 2022c; Schmidt et al., 2021; Schmidt & Glaser, 2021a, 2021b). While this is progress, more research should include clear strategies and theories to ensure rigor and pave the way for future work.

To What Extent Did Authors Report Learning Outcomes and Generalization?

VR systems for autistic users target various skills, but the transition of these skills from digital to real-world settings is underexplored (Schmidt et al., 2023). While VR's potential for skill generalization is often cited, evidence remains sparse (Glaser & Schmidt, 2021; Mesa-Gresa et al., 2018). Moreover, guidance on designing VR for generalization is disturbingly limited (Schmidt & Glaser, 2021). While SVVR projects like those by Dixon et al. (2020) and Meindl et al. (2019) report on in-setting effectiveness, they do not address generalization to real-world naturalistic contexts. Studies exploring generalization often have methodological issues, such as relying on subjective self-reports (Parsons et al., 2006) or showing inconsistent results. Despite the potential of SVVR for promoting generalization, there is a need for more rigorous research on generalization (Schmidt et al., 2023). The disparity between SVVR's promise and the limited evidence on real-world generalization highlights the need for better research designs, ensuring meaningful improvements for autistic individuals.

Limitations

The systematic review has several limitations that should be considered when interpreting the findings and implications of the study. One of the limitations is that the procedures used in this manuscript deviate somewhat from suggested guidelines for reporting systematic literature reviews (Davis et al., 2014; Page et al., 2020). Specifically, there were three main issues: (1) the complexity of extracting qualitative data for a systematic literature review, (2) extracting these data across multiple publications from the same dataset or research projects, and (3) difficulties in determining if a SVVR platform was unique due to some projects not naming their interventions. The second guideline, originally put forth by Kitchenham (2004), emphasizes the need to omit multiple publications that draw from the same dataset, as this could skew the results. However, in our case, we deviated from this recommendation due to the specific focus of our research questions. We were less concerned with reporting study outcomes and more interested in examining the qualitative aspects of VR systems and designs. For this reason, it was crucial for us to include all papers that used the same dataset. Often, individual reports did not provide the complete data relevant to our inquiry, or the information was unclear and needed to be cross-verified through multiple papers to establish its accuracy. These limitations are in line with other research that suggests the challenges of conducting qualitative reviews of the literature (Belur et al., 2018; Kitchenham et al., 2009).

Conclusion

SVVR technology has the potential to offer various benefits to autistic individuals, however, several challenges need to be addressed. First, While SVVR requires fewer inputs than VR and is, hence, more accessible for autistic individuals with co-occurring conditions (e.g., learning difficulties), limited evidence-based research exists on its learning affordance and ethical considerations. Second, as autism exists on a spectrum, it presents a challenge for integrating SVVR technology as symptoms and needs can vary significantly. Inclusive and participatory design and development of SVVR-based interventions are essential to build more accessible and relevant solutions tailored to each individuals' needs. Third, educators and designers lack practical guidelines for integrating SVVR into educational or therapeutic interventions, particularly for pre-training in SVVR. Given that VR-based learning requires more time to become familiar with computer-based interactions, providing teaching and learning resources that address the design and execution of pre-training for SVVR can ensure its successful implementation. Last, there are challenges in using video modeling techniques to support the implementation of SVVR technologies. It is essential to conduct inclusive and participatory future research to determine the flexibility of video in supporting the generalization of complex skills that are important to the autistic population. There is promise in creating flexible, branching scenarios that can be individualized to the unique needs of each user through no-cost SVVR development platforms. However, issues related to generalization and evidence-based design related to SVVR remain areas for future research.

References

Aresti-Bartolome, N., & Garcia-Zapirain, B. (2014). Technologies as support tools for persons with autistic spectrum disorder: A systematic review. *Int. J. Environ. Res. Public Health, 11*(8), 7767–7802. https://doi.org/10/f6fzs2

Bellani, M., Fornasari, L., Chittaro, L., & Brambilla, P. (2011). Virtual reality in autism: State of the art. *Epidemiology and Psychiatric Sciences, 20*(3), 235-238. https://doi.org/10.1017/S2045796011000448

Bellini, S., & Akullian, J. (2007). A meta-analysis of video modeling and video self-modeling interventions for children with autism spectrum disorders. *Exceptional Children, 73*(3), 264-287. https://doi.org/10.1177/001440290707300301

Belur, J., Tompson, L., Thornton, A., & Simon, M. (2018). Interrater reliability in systematic review methodology: Exploring variation in coder decision-making. *Sociological Methods & Research, 50*(2), 0049124118799372. https://doi.org/10.1177/0049124118799372

Bennett, K. D., Crocco, C., Loughrey, T. O., & McDowell, L. S. (2017). Effects of video prompting without voice-over narration among students with autism spectrum disorder. *Behavioral Development Bulletin, 22*(1), 147.

Bishop-Fitzpatrick, L., Minshew, N. J., & Eack, S. M. (2013). A systematic review of psychosocial interventions for adults with autism spectrum disorders. *Journal of Autism and Developmental Disorders, 43*(3), 687-694. https://doi.org/10.1007/S10803-012-1615-8

Bozgeyikli, L., Raij, A., Katkoori, S., & Alqasemi, R. (2018). A Survey on Virtual Reality for Individuals with Autism Spectrum Disorder: Design Considerations. *IEEE Transactions on Learning Technologies, 11*(2), 133–151.

Bradley, R., & Newbutt, N. (2018). Autism and virtual reality head-mounted displays: a state of the art systematic review. *Journal of Enabling Technologies, 12*(3), 101-113.

Butler, A., Hall, H., & Copnell, B. (2016). A guide to writing a qualitative systematic review protocol to enhance evidence-based practice in nursing and health care. *Worldviews on Evidence-Based Nursing, 13* (3), 241–249. https://doi.org/10.1111/wvn.12134

Carmien, S., Dawe, M., Fischer, G., Gorman, A., Kintsch, A., & Sullivan, J. F., JR. (2005). Socio-technical Environments Supporting People with Cognitive Disabilities Using Public Transportation. *ACM Trans. Comput. -Hum. Interact., 12*(2), 233–262. https://doi.org/10/dcqdg6

Chang, C. Y., Sung, H. Y., Guo, J. L., Chang, B. Y., & Kuo, F. R. (2022). Effects of spherical video-based virtual reality on nursing students' learning performance in childbirth education training. *Interactive Learning Environments*, *30*(3), 400-416. https://doi.org/10.1080/10494820.2019.1661854

Chien, S. Y., & Hwang, G. J. (2022). A question, observation, and organisation‐based SVVR approach to enhancing students' presentation performance, classroom engagement, and technology acceptance in a cultural course. *British Journal of Educational Technology*, *53*(2), 229-247. https://doi.org/10.1111/bjet.13159

Davis, J., Mengersen, K., Bennett, S., & Mazerolle, L. (2014). Viewing systematic reviews and meta-analysis in social research through different lenses. *SpringerPlus, 3*(1), 511. https://doi.org/10.1186/21931801-3-511

Dixon, D. R., Miyake, C. J., Nohelty, K., Novack, M. N., & Granpeesheh, D. (2020). Evaluation of an immersive virtual reality safety training used to teach pedestrian skills to children with autism spectrum disorder. *Behavior Analysis in Practice*, *13*(3), 631–640.

Finlay, L. (2002). "Outing" the researcher: The provenance, process, and practice of reflexivity. *Qualitative health research, 12*(4), 531-545.

Garzotto, F., Gelsomini, M., Matarazzo, V., Messina, N., & Occhiuto, D. (2017). XOOM: An End-User Development Tool for Web-Based Wearable Immersive Virtual Tours. In J. Cabot, R. De Virgilio, & R. Torlone (Eds.), *Web Engineering* (pp. 507–519). Springer International Publishing. https://doi.org/10.1007/978-3-319-60131-1_36

Ganz, J. B. (2015) AAC interventions for individuals with autism spectrum disorders: State of the science and future research directions. *Augmentative and Alternative Communication, 31*(3), 2013-214. https://dx.doi.org/10.3109/07434618.2015.1047532

Gelsomini, M., Garzotto, F., Matarazzo, V., Messina, N., & Occhiuto, D. (2017). Creating Social Stories as Wearable Hyper-Immersive Virtual Reality Experiences for Children with Neurodevelopmental Disorders. *Proceedings of the 2017 Conference on Interaction Design and Children*, 431–437. https://doi.org/10.1145/3078072.3084305

Gelsomini, M., Garzotto, F., Montesano, D., & Occhiuto, D. (2016). Wildcard: A wearable virtual reality storytelling tool for children with intellectual developmental disability. *2016 38th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, 5188–5191. https://doi.org/10.1109/EMBC.2016.7591896

Gerhardt, P. F., & Lainer, I. (2011). Addressing the needs of adolescents and adults with autism: A crisis on the horizon. Journal of Contemporary Psychotherapy, 41, 37-45. https://doi.org/10.1007/s10879-010-9160-2

Glaser, N., & Schmidt, M. (2022). Systematic Literature Review of Virtual Reality Intervention Design Patterns for Individuals with Autism Spectrum Disorders. *International Journal of*

Human–Computer Interaction, 38(8), 753–788. https://doi.org/10.1080/10447318.2021.1970433

Glaser, N., Newbutt, N., Palmer, H., & Schmidt, M. (2022). Video-Based Virtual Reality Technology for Autistic Users: An Emerging Technology Report. *Technology, Knowledge and Learning*. https://doi.org/10.1007/s10758-022-09594-x

Glaser, N., Newbutt, N., & Palmer, H. (2022). Not perfect but good enough: A primer for creating spherical video-based virtual reality for autistic users. *Journal of Enabling Technologies*, https://doi.org/10.1108/JET-01-2022-0008

Glaser, N., Schmidt, M., & Schmidt, C. (2022). Learner experience and evidence of cybersickness: Design tensions in a virtual reality public transportation intervention for autistic adults. *Virtual Reality*, 20.

Glaser, N., Schmidt, M., Schmidt, C., Palmer, H., & Beck, D. (2021). T*he Centrality of Interdisciplinarity for Overcoming Design and Development Constraints of a Multi-user Virtual Reality Intervention for Adults with Autism: A Design Case*. In B. Hokanson, M. Exter, A. Grincewicz, M. Schmidt, & A. A. Tawfik (Eds.), Intersections Across Disciplines: Interdisciplinarity and learning (pp. 157–171). Springer International Publishing. https://doi.org/10.1007/978-3-030-53875-0_13

Gusenbauer, M., & Haddaway, N. R. (2020). Which academic search systems are suitable for systematic reviews or meta-analyses? Evaluating retrieval qualities of Google Scholar, PubMed, and 26 other resources. *Research Synthesis Methods, 11*(2), 181–217. https://doi.org/10.1002/jrsm.1378

Hobson, R. P. (2012). Autism, literal language and concrete thinking: Some developmental considerations. *Metaphor and Symbol, 27*(1), 4-21.

Horlin, C., Falkmer, M., Parsons, R., Albrecht, M. A., & Falkmer, T. (2014). The cost of autism spectrum disorders. *PloS one, 9*(9), e106552. https://doi.org/10.1371/journal.pone.0106552

Huang, H., Hwang, G. J., & Chang, S. C. (2021). Facilitating decision making in authentic contexts: An SVVR-based experiential flipped learning approach for professional training. *Interactive Learning Environments*, 1-17. https://doi.org/10.1080/10494820.2021.2000435

Hume, K., Steinbrenner, J.R., Odom, S.L. et al. Evidence-Based Practices for Children, Youth, and Young Adults with Autism: Third Generation Review. *J Autism Dev Disord 51*, 4013–4032 (2021). https://doi.org/10.1007/s10803-020-04844-2

Jahnke, I., Schmidt, M., Pham, M., & Singh, K. (2020). *Sociotechnical-pedagogical usability for designing and evaluating learner experience in technology-enhanced environments*. Learner and user experience research.

Kitchenham, B., Pearl Brereton, O., Budgen, D., Turner, M., Bailey, J., & Linkman, S. (2009). Systematic literature reviews in software engineering – A systematic literature review. *Information and Software Technology, 51*(1), 7–15. https://doi.org/10.1016/j.infsof.2008.09.009

Knight, V., Sartini, E., & Spriggs, A. D. (2015). Evaluating visual activity schedules as evidence-based practice for individuals with autism spectrum disorders. *Journal of Autism and Developmental Disorders, 45*, 157-178.

Landa, R. J. (2018). Efficacy of early interventions for infants and young children with, and at risk for, autism spectrum disorders. *International Review of Psychiatry, 30*(1), 25-39. https://doi.org/10.1080/09540261.2018.1432574

Levy, A., & Perry, A. (2011). Outcomes in adolescents and adults with autism: A review of the literature. *Research in Autism Spectrum Disorders, 5*(4), 1271-1282. https://doi.org/10.1016/j.rasd.2011.01.023

Makransky, G., & Petersen, G. B. (2021). The cognitive affective model of immersive learning (CAMIL): A theoretical research-based model of learning in immersive virtual reality. *Educational Psychology Review*. *33*(3), 937–958. https://doi.org/10.1007/s10648-020-09586-2

Malihi, M., Nguyen, J., Cardy, R. E., Eldon, S., Petta, C., & Kushki, A. (2020a). Short report: Evaluating the safety and usability of head-mounted virtual reality compared to monitor-displayed video for children with autism spectrum disorder. *Autism*, *24*(7), 1924–1929. APA PsycInfo. https://doi.org/10.1177/1362361320934214

Malihi, M., Nguyen, J., Cardy, R., Eldon, S., Petta, C., & Kushki, A. (2020b). Data-Driven Discovery of Predictors of Virtual Reality Safety and Sense of Presence for Children With Autism Spectrum Disorder: A Pilot Study. *FRONTIERS IN PSYCHIATRY*, *11*. https://doi.org/10.3389/fpsyt.2020.00669

Mayer, R. E. (2014). Multimedia instruction. In the *Handbook of Research on Educational Communications and Technology* (pp. 385-399). New York, NY: Springer.

Mayer, R. E. (2017). Using multimedia for e‐learning. *Journal of computer assisted learning, 33*(5), 403-423.

Meindl, J. N., Saba, S., Gray, M., Stuebing, L., & Jarvis, A. (2019). Reducing blood draw phobia in an adult with autism spectrum disorder using low‐cost virtual reality exposure therapy. *Journal of Applied Research in Intellectual Disabilities*, *32*(6), 1446–1452.

Mesa-Gresa, P., Gil-Gómez, H., Lozano-Quilis, J.-A., & Gil-Gómez, J.-A. (2018). Effectiveness of Virtual Reality for Children and Adolescents with Autism Spectrum Disorder: An Evidence-Based Systematic Review. *Sensors, 18*(8), 2486. https://doi.org/10.3390/s18082486

Miller, I., Miller, C., Wiederhold, M., & Wiederhold, B. (2020a). Virtual Reality Air Travel Training Using Apple iPhone X and Google Cardboard: A Feasibility Report with Autistic Adolescents and Adults. *AUTISM IN ADULTHOOD*, *2*(4), 325–333. https://doi.org/10.1089/aut.2019.0076

Miller, I. T., Miller, C. S., Wiederhold, B. K., & Wiederhold, M. D. (2019). Virtual reality air travel training with autistic individuals—Design considerations and future directions. *Annual Review of CyberTherapy and Telemedicine*, *17*, 129–135. APA PsycInfo.

Miller, I. T., Wiederhold, B. K., Miller, C. S., & Wiederhold, M. D. (2020b). Virtual Reality Air Travel Training with Children on the Autism Spectrum: A Preliminary Report. *Cyberpsychology, Behavior, and Social Networking*, *23*(1), 10–15. https://doi.org/10.1089/cyber.2019.0093

Moon, S. J., Hwang, J., Hill, H. S., Kervin, R., Birtwell, K. B., Torus, J., McDougle, C. J., & Kim, J. W. (2020). Mobile device applications and treatment of autism spectrum disorder: A systematic review and meta-analysis of effectiveness. *Archives of Disease in Childhood, 105*(5), 458-462. https://doi.org/10.1136/archdischild-2019-318258

Moore, J. L., Dickson-Deane, C., & Liu, M. Z. (2014). *Designing CMS courses from a pedagogical usability perspective. Perspectives in Instructional Technology and Distance Education: Research on course management systems in higher education*, 143-169.

Morse, J. M., Barrett, M., Mayan, M., Olson, K., & Spiers, J. (2002). Verification strategies for establishing reliability and validity in qualitative research. *International journal of qualitative methods, 1*(2), 13-22.

Newbutt, N., Glaser, N., Francois, M.S. et al. How are Autistic People Involved in the Design of Extended Reality Technologies? A Systematic Literature Review. *J Autism Dev Disord* (2023). https://doi.org/10.1007/s10803-023-06130-3

Newbutt, N., Glaser, N., & Palmer, H. (2022). Not perfect but good enough: a primer for creating spherical video-based virtual reality for autistic users. *Journal of Enabling Technologies*, *16*(2), 115-123. https://doi.org/10.1108/JET-01-2022-0008

Nielsen, J. (2020). Nielsen Norman Group: *10 Usability Heuristics for User Interface Design.* Nielsen Norman Group: Fremont, CA, USA.

Neuer, A. (2020). COVID-Sparked Practices Driving New Patient-Centric Behaviors. Applied *Clinical Trials, 29*(6), 14-18.

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., ... & Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *International journal of surgery, 88*, 105906.

Palmen, S. J., van Engeland, H., Hof, P. R., & Schmitz, C. (2004). Neuropathological findings in autism. *Brain, 127*(12), 2572-2583.

Parsons, S. (2016). Authenticity in Virtual Reality for assessment and intervention in autism: A conceptual review. *Educational Research Review, 19*, 138–157.

Sarrett, J. C. (2016). Biocertification and neurodiversity: The role and implications of self-diagnosis in autistic communities. *Neuroethics, 9*, 23-36. https://doi.org/10.1007/s12152-016-9247-x

Schmidt, M., Galyen, K., Laffey, J., Babiuch, R., & Schmidt, C. (2014). Open source software and design-based research symbiosis in developing 3D virtual learning environments: Examples from the iSocial project. *Journal of Interactive Learning Research, 25*(1), 65–99.

Parsons, S., Yuill, N., Good, J., & Brosnan, M. (2020). "Whose agenda? Who knows best? Whose voice?" Co-creating a technology research roadmap with autism stakeholders. *Disability & Society, 35*(2), 201–234.

Robertson, S. M. (2010). Neurodiversity, quality of life, and autistic adults: Shifting research and professional focuses onto real-life challenges. *Disability Studies Quarterly, 30*(1).

Schmidt, M., Schmidt, C., Glaser, N., Beck, D., Lim, M., & Palmer, H. (2021). Evaluation of a spherical video-based virtual reality intervention designed to teach adaptive skills for adults with autism: A preliminary report. *Interactive Learning Environments*, *29*(3), 345-364. https://doi.org/10.1080/10494820.2019.1579236

Schmidt, M., & Glaser, N. (2021a). Investigating the Usability and Learner Experience of a Virtual Reality Adaptive Skills Intervention for Adults with Autism Spectrum Disorder. *Educational Technology Research and Development*, *69*(3), 1665–1699. ERIC.

Schmidt, M., & Glaser, N. (2021b). Piloting an adaptive skills virtual reality intervention for adults with autism: findings from user-centered formative design and evaluation. *Journal of Enabling Technologies*, *15*(3), 137-158. https://doi.org/10.1108/JET-09-2020-0037

Schmidt, M., Glaser, N., Schmidt, C., Kaplan, R., Palmer, H., & Cobb, S. (2023). Programming for generalization: Confronting known challenges in the design of virtual reality interventions for autistic users. *Computers & Education: X Reality*, *2*. https://doi.org/10.1016/j.cexr.2023.100013

Shea, L. L., Verstreate, K., Nonnemacher, S., Song, W., & Salzer, M. S. (2021). Self-reported community participation experiences and preferences of autistic adults. *Autism, 25*(5), 1295-1306.

Sitbon, L., Brown, R., & Fell, L. (2019). Turning Heads: Designing Engaging Immersive Video Experiences to Support People with Intellectual Disability when Learning Everyday Living Skills. *The 21st International ACM SIGACCESS Conference on Computers and Accessibility*, 171–182. https://doi.org/10.1145/3308561.3353787

Stern, C., Jordan, Z., & McArthur, A. (2014). Developing the review question and inclusion criteria. *AJN The American Journal of Nursing, 114*(4), 53–56.

Strickland, D. (1996). A virtual reality application with autistic children. *Presence: Teleoperators and Virtual Environments, 5*(3), 319–329. https://doi.org/10.1162/pres.1996.5.3.319

Strickland, D. (1997). Virtual reality for the treatment of autism. *Studies in Health Technology and Informatics,* 81–86.

Violante, M. G., Vezzetti, E., & Piazzolla, P. (2019). Interactive virtual technologies in engineering education: Why not 360° videos?. *International Journal on Interactive Design and Manufacturing (IJIDeM), 13*(2), 729-742.

Wu, W. L., Hsu, Y., Yang, Q. F., Chen, J. J., & Jong, M. S. Y. (2021). Effects of the self-regulated strategy within the context of spherical video-based virtual reality on students' learning performances in an art history class. *Interactive Learning Environments*, 1-24. https://doi.org/10.1080/10494820.2021.1878231

Zervogianni, V., Fletcher-Watson, S., Herrera, G., Goodwin, M., Pérez-Fuster, P., Brosnan, M., & Grynszpan, O. (2020). A framework of evidence-based practice for digital support, co-developed with and for the autism community. *Autism, 24*(6), 1411-1422.

Table 1

RQ1 Results: Social Considerations of SVVR Systems Design and Evaluation

Study Name and Citations	**Participant Info**	**Diagnosis Type**	**Diagnosis Details**	**Context of Research:**	**Autistic Inclusion?**
Safety Training and Pedestrian Skills VR (Dixon et al. 2020)	0-9 (children), 10-19 (adolescent) All male	Medical Diagnosis	Diagnosed by a licensed professional Participant characteristics were described by the Pervasive Developmental Disorder Behavior Inventory	**Physical:** Doctor or medical setting, Other community setting **Virtual:** 360 degree videos of real streets from the participants' community	Evaluation
XOOM experiences (Gelsomini et al., 2017; Garzotto et al., 2017)	0-9 (children) No gender details reported	Self Diagnosed, Medical Diagnosis, School Diagnosis	Not described due to nature of the SVVR system	**Physical:** Other community setting **Virtual:** Contextual. Can use existing scenes and make your own	Neurodiverse Users and programs have been involved throughout
Wildcard (Gelsomini et al., 2016)	0-9 (children) No gender details reported	Medical Diagnosis	No details provided. Only stated that the work takes place at a medical facility Participants described as having 'minor' and 'medium' developmental disabilities.	**Physical:** Doctor or medical setting **Virtual:** Fantasy worlds based on stories and characters from the lives of participants	Evaluation
Virtuoso-SVVR/Virtuoso-VBVR (Glaser et al., 2022a; 2022b; 2022c; Schmidt et al., 2021; Schmidt & Glaser, 2021a, 2021b;)	20+ (adult) All male	Medical Diagnosis	Participants required greater support needs Participant characteristics were described by the PPVT, SRS, BRIEF	**Physical:** University Lab or setting **Virtual:** College of education and surrounding campus of day program that participants were enrolled in	Evaluation

Turning Heads (Sitbon et al., 2019)	20+ (adult) No gender details reported	Medical Diagnosis	Moderate to severe disability reported	**Physical:** University Lab, Other community setting **Virtual:** The videos were of various spaces such as a house, the University campus, a dog park and a café	Evaluation
Bus Scenario VR (Malihi et al., 2020b, 2020a)	10-19 (adolescent) 15 male, 10 female	Medical Diagnosis	Diagnosis reported by Autism Diagnostic Observation Schedule Participant characteristics were described by the Wechsler Abbreviated Scale of Intelligence, Social Communication Questionnaire, and a screen for Child Anxiety Related Emotional Disorders. Full-scale and verbal IQ > 70	**Physical:** University Lab or setting **Virtual:** School bus environment, stationary bus with bus driver and other students. Verbal exchanges occurred on the bus, students entered the bus, and noises occurred (i.e. sirens; construction equipment).	Evaluation
Blood Draw Phobia VRET (Meindl et al., 2019)	20+ (adult) Male	Medical Diagnosis	The participant required more substantial support needs including in-home therapy Described as having a moderate intellectual disability	**Physical:** Other community setting **Virtual:** participant's doctor's office	Evaluation
Virtual Reality Air Travel Training (Miller et al., 2020; Miller et al., 2019, 2020)	All Age Ranges 6 male, 1 female	Medical Diagnosis	Diagnosis confirmed by clinical records	**Physical:** Doctor or medical setting, Other community setting **Virtual:** San Diego Airport	Evaluation

Table 2

RQ2 Results: Technological Considerations of SVVR Systems Design and Evaluation

Project Name and Citations	SVVR System Description	VR Hardware and Software	Hardware and Software used to create system	Estimated Cost of Equipment and Supplies	Video Perspective	Narration Design
Safety Training and Pedestrian Skills VR (Dixon et al. 2020)	A 360-degree video system was developed to showcase real-life street scenes familiar to the participants. The participants viewed the videos using an Oculus Rift headset while seated at a table in the clinic. The researchers monitored the participant's responses and instructional processes by observing the Oculus device through laptops.	**Hardware:** Oculus Rift **Software**: Not stated	**Hardware:** Samsung Gear 360 camera **Software**: Steam Client Software	**Develop:** Samsung Gear 360 camera: $270 **Deploy:** Oculus Rift: $450 VR-ready device ($1500)	First Person	Not stated
XOOM experiences (Gelsomini et al., 2017; Garzotto et al., 2017)	A social story program was designed using an immersive head-mounted display (Cardboard). The program includes a tool that enables users to create and customize their own social stories or modify existing ones. Additionally, parents can record 360-degree videos to provide a contextual experience in familiar environments.	**Hardware:** Smartphone within a Google Cardboard **Software**: Bespoke software XOOM	**Hardware:** Desktop PC, and any 360 degree camera **Software**: Custom software developed using html, javascript, php, and public libraries including A-Frame, heatmap.js, Firebase	**Develop:** Desktop PC: $1000 360-camera: $400 **Deploy:** Smartphone: $400 Google Cardboard: $15	Contextual	Contextual

Wildcard (Gelsomini et al., 2016)	A system has been designed to manage the creation and customization of interactive multimedia stories for individuals with developmental disabilities. The stories are presented using Google Cardboard and are based on characters and themes relevant to the children using the system. Therapists have the ability to oversee the activities within the system and personalize it to meet the specific needs of each child. Two modes of interaction are offered: "Story360" where users navigate an avatar through an environment using eye gaze (by keeping their focus on the avatar), and "Exploration" which is more flexible and allows for exploration by fixating on various checkpoints.	**Hardware:** Smartphone within a Google Cardboard **Software**: Unity package deployed on a smartphone	**Hardware:** Desktop PC **Software**: Unity	**Develop:** Desktop PC: $1000 Unity: $0 **Deploy:** Smartphone: $400 Google Cardboard: $15	First Person	Narration designed where the user's actions and gaze impacts the story being told.
Virtuoso-SVVR/ Virtuoso-VBVR (Glaser et al., 2022a; 2022b; 2022c; Schmidt et al., 2021; Schmidt & Glaser, 2021a, 2021b;)	Virtuoso-SVVR was part 2 of a 4 stage task analysis of a larger Virtuoso shuttle training intervention. The stage-wise approach consists of: (1) skill introduction, (2) 360-degree video modeling of the skill, (3) VR rehearsal of the skill, and (4) real-world practice of the skill. 4 short 360-degree videos were presented to users in the form of a video lobby (check schedule, walk to bus, check app, get on shuttle).	**Hardware:** VR headsets supported includes: Google Daydream & Google Cardboard deployed in a smartphone (Motorola zForce) though it supports any compatible smartphone and fully immersive HMD,	**Hardware:** Samsung Gear 360 Camera, Desktop PC **Software**: Unity	**Develop:** Samsung Gear 360 camera: $270 Desktop PC: $1000 **Deploy:** Smartphone: $400 Google Cardboard: $15	First Person	Gender-neutral robotic voice, inner monologue perspective, instructions provided by support staff in conversational tone with prompting

		Software: Google VR SDK for Unity with Android. And a custom Unity package for Oculus Rift		Oculus Rift: $450		
Turning Heads (Sitbon et al., 2019)	A collection of 360-degree content was developed to focus on various skills, and user feedback was integrated into the design.	**Hardware:** Samsung Gear VR with a Samsung S6 phone mounted inside (supports other mobile devices) **Software**: None	**Hardware:** 360-degree camera, Desktop PC **Software**: Unity	**Develop:** 360-camera: $400 Desktop PC: $1000 Unity: $0 **Deploy:** Samsung Gear VR: Discontinued Smartphone: $400	First-person, Next-to-first person, Stationary view	Not stated
Bus Scenario VR (Malihi et al., 2020b, 2020a)	A virtual school bus experience where the user is seated among a driver and other children, who engage in verbal interactions with each other. The scenario includes sensory and social triggers, such as street noises and children's voices.	**Hardware:** Oculus Rift (could turn with their head or a computer mouse) and a monitor-displayed 360° video control condition **Software**: Not stated	**Hardware:** Not stated **Software**: Not stated	**Develop:** N/A **Deploy:** Oculus Rift: $450 VR-ready device ($1500)	First-person	Not stated

Blood Draw Phobia VRET (Meindl et al., 2019)	A 360 degree VR system that simulates the experience of having blood drawn	**Hardware:** Tzumi Dream Vision VR Headset an iPhone 6s (supports other phone devices) and an Apple Pencil stylus used to simulate the needle insertion **Software**: Not stated	**Hardware:** Insta360 One VR camera **Software**: Not stated	**Develop:** Insta360 One VR camera: $330 **Deploy:** Tzumi Dream Vision VR Headset: $10 Smartphone: $400 Phone Stylus: $30	First Person	Not stated
Virtual Reality Air Travel Training (VR-ATT) (Miller et al., 2020; Miller et al., 2019, 2020)	This system presents a virtual simulation of the steps required to go through an airport including entering, checking in, getting through security, waiting at the gate, and boarding.	**Hardware:** iPhone and Google Cardboard VR (supports other mobile) **Software**: Not stated	**Hardware:** Not stated **Software**: Built upon existing virtual airport simulation	**Develop:** N/A **Deploy:** Smartphone: $400 Google Cardboard: $15	First Person	Narrative script based on social stories

Table 3

RQ3 Results: Pedagogical Considerations of SVVR Systems Design and Evaluation

Project Name and Citations	Brief Description of the Objective	Clinical Target of skills	Instructional Design Strategies & Supports	Learning & Other Theories Considered	Learning Outcomes & Generalization Details
Safety Training and Pedestrian Skills VR (Dixon et al. 2020)	Teach children with ASD to identify when it's safe to cross the street	Daily living	● Low profile monopod was used to reduce distractions ● Short videos (5- 10 mins) ● Distractions gradually introduced to simulate real street crossing situations.	None stated	**Reported:** Yes **Type:** Distal (removed from research context) **Evaluation Method:** A nonconcurrent multiple-baseline design for each participant across baseline, natural environment probes, VR probes, and training conditions
XOOM experiences (Gelsomini et al., 2017; Garzotto et al., 2017)	XOOM presents a range of social stories based on everyday situations. Users can watch and edit existing social stories or create their own.	Social, Daily living, Allows for custom	● External play control of social story to cue user attention ● Gaze focus controlled by head rotation ● Interact with active object with sustained gaze ● Users may create new or modify social stories ● Customize SVVR with image cues ● User interaction data is gathered	None stated	**Reported:** No **Transfer Type:** N/A **Evaluation Method:** N/A

Wildcard (Gelsomini et al., 2016)	Delivering stories and learning activities within immersive VR technology to interact with users. Targets 'common behavioral skills useful in every day's life'	Daily living	● User or VR guided modes, eye gaze control ● Choices for themes, story, and interaction modes ● Personalized avatars and images ● Adjustable avatar speed	None stated	**Reported:** No **Transfer Type:** N/A **Evaluation Method:** N/A
Virtuoso-SVVR/Virtuoso-VBVR (Glaser et al., 2022a; 2022b; 2022c; Schmidt et al., 2021; Schmidt & Glaser, 2021a, 2021b)	Teach autistic adults how to catch public transportation on a university setting	Daily living	● Four-tired scaffolding approach that moves from an introduction to the skill, modeling of the skill (SVVR), rehearsal of skill, and demonstration of skill ● Procedural task analysis ● Picture Exchange Communication System icons used throughout	● Bandura's Social Learning Theory ● Reduced Generalization Theory ● Complexity Theory	**Reported:** No **Transfer Type:** N/A **Evaluation Method:** N/A
Turning Heads (Sitbon et al., 2019)	Presented a SVVR system with life-skills training for people with intellectual disability (e.g. laundry, ordering a drink at a cafe and sitting with friends, interacting at a dog park) to identify user preferences and design considerations	Social, Daily living, Communication	● Avoided abstract symbols, ● Small digestible pieces of information	● Social practice theory	**Reported:** No **Transfer Type:** N/A **Evaluation Method:** N/A
Bus Scenario VR (Malihi et al., 2020b, 2020a)	Determine the safety and usability of VR head mounted display	Daily living, Phobia or fear	● Co-design of school bus scenario with feedback from families and clinicians ● Authentic setting audio	● Telepresence theories ● Generalization theories	**Reported:** Yes **Type:** Proximal (highly contextualized) **Evaluation Method:** Follow-up phone call with parents 1 month

					after to identify how participants felt about riding a school bus.
Blood Draw Phobia VRET (Meindl et al., 2019)	Reduce phobia of having blood drawn at a doctors office	Daily Living, Phobia or fear	● Procedural task analysis ● Fading of supports	● Generalization theories ● Behaviorism	**Reported:** Yes **Type:** Proximal (highly contextualized) **Evaluation Method:** Baseline data was collected. Generalization probes scheduled approximately one week apart. Maintenance was assessed with a follow-up probe conducted one month after the fourth generalization probe.
Virtual Reality Air Travel Training (Miller et al., 2020a; Miller et al., 2019, 2020b)	Teaches autistic adults and children how to get through an airport	Daily living	● Use of social stories ● Narrated script to provide training context ● Task analysis	None stated	**Reported:** Yes **Type:** Proximal (highly contextualized) **Evaluation Method:** Participants received VR-ATT training sessions at a local San Diego therapy clinic once per week for 3 weeks. A final fourth session was a real-world practice.