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Multimodal Technologies in Autism Spectrum Disorder Interventions: A Systematic Review

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ABSTRACT

The rising prevalence of autism spectrum disorder (ASD) has prompted a continual search for innovative interventions to enhance the lives of individuals across the spectrum. In this systematic literature review, we embark on a comprehensive exploration of multimodal technologies in ASD Interventions. ASD, characterized by challenges in social communication, repetitive behaviours, and sensory sensitivities, necessitates versatile therapeutic strategies. Recent advances in technology have ushered in a new era of possibilities in the realm of ASD interventions. Multimodal technologies, which encompass a wide spectrum of digital platforms, software applications, wearable devices, and virtual reality, offer unprecedented opportunities to engage, educate, and empower individuals with ASD. This systematic review critically evaluates the multifaceted landscape of technological interventions within the context of ASD. Subsections dedicated to screening and diagnosis, communication, social skills, emotional regulation, and sensory integration provide a comprehensive overview of the diverse applications of multimodal technologies. The review synthesizes findings from a range of studies, including randomized controlled trials, quasi-experimental designs, and case studies, to elucidate the effectiveness, limitations, and prospects of these interventions. Furthermore, this review highlights the ethical considerations, accessibility challenges, and the need for continued research and standardization in the field. By examining the evolving role of technology in enhancing the lives of individuals with ASD, this systematic review offers valuable insights for researchers, clinicians, educators, and policymakers. It underscores the potential of multimodal technologies to revolutionize ASD interventions, making them more personalized, engaging, and effective, ultimately fostering improved outcomes and quality of life for individuals on the autism

Keywords:

Autism Spectrum Disorders; Information communication technology; Multimodal; Human computer interaction; User eXperience (UX)

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spectrum.

1. Introduction

Autism Spectrum Disorder (ASD) is a complex neurodevelopmental condition characterized by persistent challenges in social communication and interaction, as well as restricted and repetitive patterns of behavior. Individuals with ASD often face significant difficulties in various areas of daily functioning, including language development, social skills acquisition, and emotional regulation [1]. As the prevalence of ASD continues to rise globally, there is a growing need for effective interventions that can support individuals with ASD in reaching their full potential and improving their overall quality of life.

Traditionally, interventions for ASD have primarily focused on addressing specific deficits or symptoms through individual therapy sessions or group-based interventions. However, recent advancements in technology have opened new possibilities for enhancing intervention approaches by incorporating multimodal technologies. These technologies leverage the strengths of various sensory modalities, such as visual, auditory, and haptic, to deliver interventions that are more engaging, individualized, and ecologically valid.

The purpose of this systematic review is to comprehensively explore and evaluate the existing literature on the use of multimodal technologies in ASD interventions. By conducting a rigorous synthesis of the available evidence, this review aims to provide insights into the potential benefits of integrating multimodal technologies into interventions for individuals with ASD. By critically analyzing and synthesizing the findings from a wide range of studies this systematic review aims to provide evidence-based recommendations and insights for researchers, practitioners, and policymakers interested in utilizing multimodal technologies to enhance interventions for individuals with ASD.

Overall, this systematic review seeks to contribute to the growing body of knowledge surrounding the application of multimodal technologies in ASD interventions. By understanding the current state of the field and identifying areas that require further investigation, we can pave the way for the development of innovative and effective interventions that can maximize the potential for individuals with ASD to thrive and succeed in various aspects of their lives.

2. Methodology

One of the most significant discussions currently taking place about systematic evaluations is taking place globally. Unfortunately, only a small number of research under Malaysia's Multimodal Technologies in Autism Spectrum Disorder Interventions [1-3] were conducted. The method used to answer the research questions raised by the previous research, on the other hand, is discussed in the next section. The two ways of classification and detection used in this paper's investigation and detailed exploration of Multimodal Technologies in Autism Spectrum Disorder Interventions. Investigating the incidence rate in-depth and how it is managed is another sub-objective. The scientific literature is then reviewed and summarized in this section to highlight, choose, and evaluate key Multimodal Technologies in research on Autism Spectrum Disorder Interventions. Finally, to address the issues raised in this article's problems, we tried to offer some directions for future research. In this study, the pre-recording systematic reviews and meta-analysis (PRISMA) method—a widely used method for conducting a systematic literature review—was employed. In essence, the purpose of publication rules is to aid authors in assessing the accuracy of a review by supplying pertinent and necessary information. PRISMA [4] also emphasizes the randomized investigations assessments survey, which may be a key factor in systematic analysis reports for

different sorts of study. Due to their reliability, Scopus, PubMed, and ScienceDirect databases were used to analyze the research's methodology. However, none of the databases, including Scopus, ScienceDirect, and PubMed, are exhaustive and complete. This part also covers the four main sub-sections of identification, screening, eligibility, and data abstraction.

2.1 Identification

The selection of several pertinent papers for this study was done using the systematic review technique, which comprises three main parts. Using thesaurus, dictionaries, encyclopedias, and previous research, the initial phase comprises the identification of keywords and the search for associated, related terms. Search words have been created for Scopus, PubMed, and ScienceDirect databases once all relevant terms have been chosen (see Table 1). During the initial phase of the systematic review procedure, the current study project was successful in obtaining 180 papers from three databases.

Table 1
The search string

Scopus	TITLE-ABS-KEY (multimodal OR multi-modal AND technolog* AND autism) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (LANGUAGE , "English"))
PubMed	(Multimodal OR multi-modal) AND technolog* AND autism
ScienceDirect	(Multimodal OR multi-modal) AND technolog AND autism

2.2 Screening

Duplicate papers were removed from consideration during the initial screening. 140 papers were rejected in the first stage of the study, and 40 publications were assessed in the second stage using different exclusion and inclusion criteria from the experts. It was the first criterion applied because literature (research articles) is the primary source of useful guidance. The review was also restricted to works published in English. The strategy was created with the past two years (2012-2022) in mind, therefore it's crucial to keep that in mind. On the basis of certain criteria, 140 publications were ultimately disqualified.

2.3 Eligibility

The third level, known as eligibility, contains a total of 40 items. At this point, all article titles and important text were closely examined to ensure that they met the inclusion criteria and the goals of the current study. As a result, 15 publications were eliminated since, according to empirical data, their title and abstract did not significantly relate to the goal of the study. Lastly, 25 articles have been made available for review (see Table 2).

Table 2
The selection criterion is searching

Criterion	Inclusion	Exclusion
Language	English	Non-English
Timeline	2012-2022	< 2012
Literature type	Journal (articles)	Conference, Book, Review
Publication Stage	Final	In Press

2.4 Data Abstraction and Analysis

To investigate and synthesize a variety of research designs (quantitative, qualitative, and mixed methodologies) in this study, an integrative was used as one of the assessment strategies. The objective of the expert study was to pinpoint pertinent subjects and subtopics. The theme's conception started with the data gathering phase. The authors painstakingly examined a collection of 25 articles, as shown in Figure 1, looking for claims or content pertinent to the subjects of the present study. The influence of multimodal technology on children with ASD is then evaluated by the authors as they find and create noteworthy groupings in the second step. The method's two main outcomes are the impact on diagnosis and intervention. The author was cooperative depending on the evidence in the context of this research, develop topics with other co-authors. A log was always kept during the data analysis process to record any analyses, opinions, puzzles, or other ideas that were relevant to the data interpretation. Finally, the writers compared the findings to look for any discrepancies in the theme design procedure. Discrepancies between the concepts are discussed among the authors if there are any, it is important to note. The final themes were adjusted to guarantee consistency. To determine the authenticity of the issues, two experts—one with expertise in information technology and the other in children with ASD—performed the analysis. The expert review process contributes to ensuring the clarity, significance, and applicability of each sub-theme by proving domain validity. The author modifies his or her assessment considering suggestions and expert opinions.

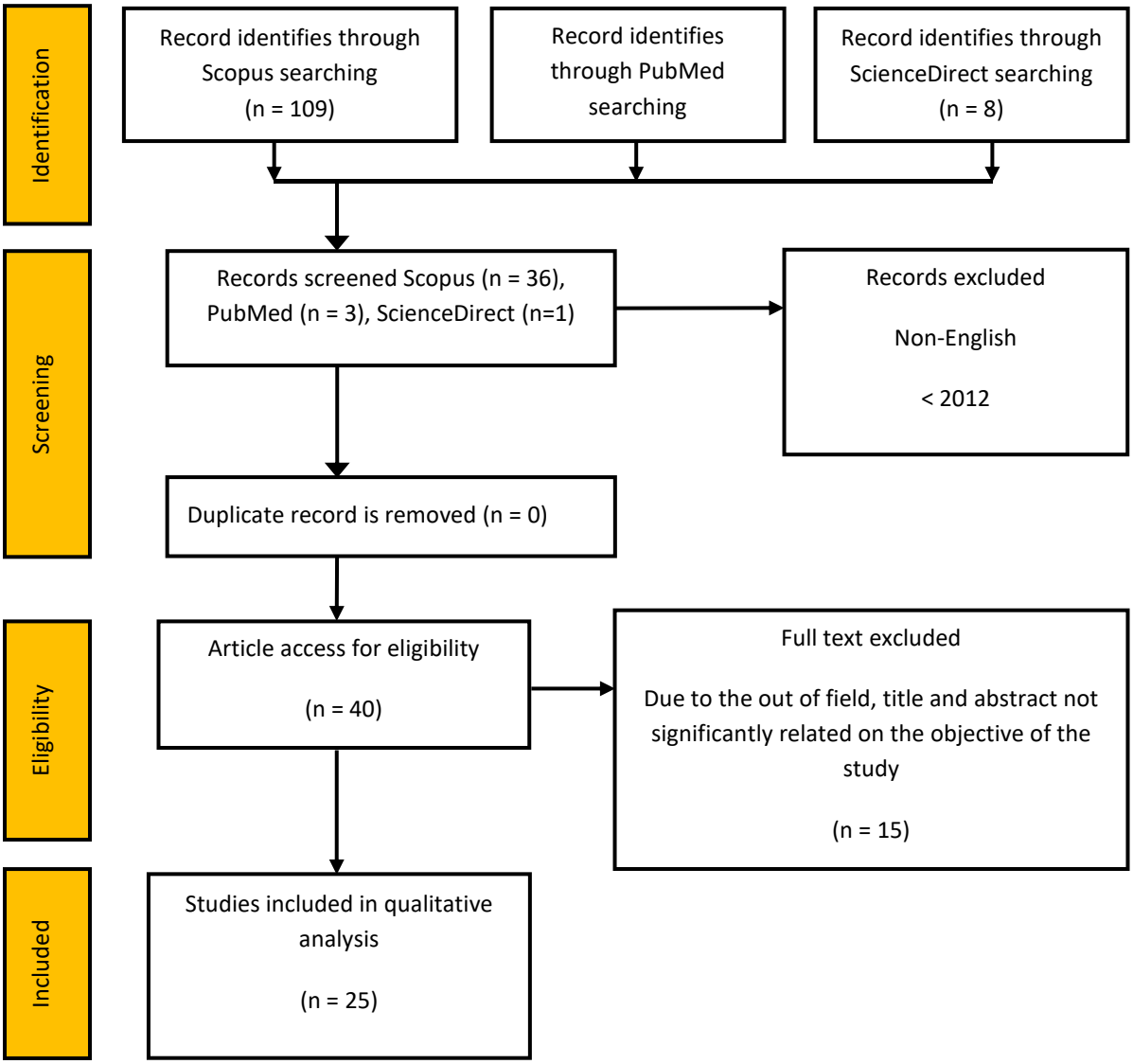

Fig. 1. Flow diagram of the proposed searching study [6]

3. Results

Twenty-five (25) articles were extracted and analyzed using the search technique. All papers were classified into two categories: diagnosis and intervention.

3.1 Diagnosis

Advancements in technology have paved the way for transformative approaches to diagnosing and interventions of ASD children. Traditionally, diagnosis relied heavily on clinical assessments, behavioural observations, and caregiver reports. However, the subjectivity and potential for human error in these methods prompted the exploration of more objective and quantifiable approaches, facilitated by various technological modalities. Screening tools and diagnostic aids harnessing technology have become instrumental in expediting the identification of ASD, particularly in early childhood [4]. These tools encompass a diverse array of modalities, including eye-tracking systems, electroencephalography (EEG), machine learning algorithms [5], and mobile applications. Eye-tracking systems, for instance, have enabled the precise measurement of gaze patterns and attentional shifts in response to social stimuli, providing valuable insights into early signs of social

communication deficits characteristic of ASD. EEG-based assessments offer a window into the neural correlates of ASD, offering potential biomarkers for early detection. Furthermore, mobile applications have gained prominence as accessible and cost-effective tools for caregivers and clinicians. These applications often incorporate interactive games and exercises designed to assess key ASD-related behaviours and provide structured data for analysis. The use of machine learning algorithms to analyse data from these technologies has shown promise in enhancing the accuracy and efficiency of ASD screening and diagnosis. While these technological interventions hold great promise, their integration into clinical practice is not without challenges. Ethical considerations, standardization of protocols, and ensuring equitable access to these tools are critical areas of concern. Moreover, continued research is essential to validate the reliability and validity of these approaches across diverse populations and age groups. In this subsection, we will delve into the current landscape of technological interventions in ASD screening and diagnosis, critically examining their strengths and limitations, and offering insights into the evolving role of technology in improving the early identification of ASD. Table 3 show a summary about classification of diagnosis.

Table 3
Summary of diagnosis of classification

Authors	Year	Source title	Problem	Methodology	Results and advantages	Project
[7]	2023	Sustainability (Switzerland)	Lack of experts make the technology-based ASD screening methods more demanding.	Case study.	• Using the two modalities to detect different ASD symptoms improved our screening accuracy by more than 10%. • Can be used at homes or clinics for screening ASD without high expertise, can improve the life of children with ASD and their families.	Sensorized toy car functionalities by adding shaft encoders to detect attention to details and interest in rotating objects in children with ASD.
[8]	2023	British Journal of Special Education	• Little research has focused on the implementation of iPad practices in real contexts and the identification of relevant challenges and enablers. • Issues are highlighted around pedagogy and teaching methods.	Qualitative by interviewing.	The findings were evaluated using Abbott's concept of e-inclusion (2007), considering the impact of the relationship between technology, individuals and context on iPad use in situ.	iPads for autistic pupils' social communication (SC) and emotional regulation (ER)
[9]	2021	Current Directions in Biomedical Engineering	To engage in socio-emotional interactions, children with autism spectrum conditions (ASC) that need support to understand and convey emotions.	Qualitative by observation.	The captured emotions of all subjects were annotated to identify low and high arousal parts and positive and negative emotions. Extracted HR from rPPG-data indicated a correlation with the annotated emotions.	A humanoid robot (Pepper, Softbanks Robotics) acts as a tutor for the child within autism care.
[10]	2021	Sensors (Switzerland)	• Two-thirds of children with ASD display problem behaviour. • human prediction of problem behaviour is possible without the assistance of technology.	A feasibility study.	Results indicate that the M2P3 platform was well tolerated by the children and PreMAC could predict precursors of problem behaviours with high prediction accuracies.	Predictive multimodal framework (PreMAC).
[11]	2021	International	The purpose of this study was to	Thematic analysis.	Only 32% of the 381 educators and	None.

		Journal of Speech-Language Pathology	examine educators' and specialists' provision of communication adjustments for students on the autism spectrum in mainstream and supported education settings.		specialists reported using adjustments. Significant associations were apparent between groups and the use of specific adjustments including naturalistic communication strategies. Significant differences were evident in the proportion of specific adjustments used by participants in supported as opposed to mainstream settings.	
[3]	2020	Journal of Imaging	Current state-of-the-art approaches do not take advantage of all the information offered by fMRI scans.	Deep learning methods.	Our multimodal training strategy achieves a classification accuracy of 74% and a recall of 95%, as well as an F1 score of 0.805, and its overall performance is superior to using only one type of functional data.	A deep multimodal model that learns a joint representation from two types of connectomic data offered by fMRI scans.
[12]	2020	Journal of Clinical Medicine	Autism spectrum disorder (ASD) is mostly diagnosed according to behavioural symptoms in sensory, social, and motor domains.	Experimental.	The findings showed the feasibility of applying machine learning and virtual reality to identify body movements' biomarkers that could contribute to improving ASD diagnosis.	Multimodal virtual reality experience
[12]	2020	IEEE Transactions on Biomedical Engineering	A critical limitation of the existing anxiety detection systems is that physiological arousal is not specific to anxiety and can occur with other user states such as physical activity	A novel multiple model Kalman.	Evaluation of the algorithm using data from a sample of children with ASD shows a significant reduction in false positives compared to the state-of-the-art, and an overall arousal detection accuracy of 93%.	Wearable technologies.
[13]	2020	Neuropsychology	The etiology of paediatric brain tumour survivor (PBTSs) social difficulties is not well understood.	Comparison experimental.	Groups significantly differed in gaze preference across conditions, with PBTSs looking less at social areas of interest than TD youth and in a manner comparable to youth with ASD. Among PBTSs, multimodal tumour-directed therapy was	Eye Tracking Technology During Naturalistic Social Perception

					associated with reduced gaze preference for faces.	
[14]	2016	International Journal of Language and Communicatio n Disorders	Yet little is known about the interactional aspects of such dyadic assessment situations that might contribute to the ways in which children respond to the test questions.	A case study: The Sally–Anne evaluation.	Both children modified or changed their previous responses. Through monitoring each other, the tester and the child produced actions highly responsive to the features of each other's conduct, which underpinned the conduct of the test itself.	None.
[15]	2013	IEEE Transactions on Visualization and Computer Graphics	with many ASD having tremendous difficulty accessing such care due to lack of available trained therapists as well as intervention costs.	A usability studies.	These results will be used in the future for an online adaptive VR-based multimodal social interaction system to improve emotion recognition abilities of individuals with ASD.	An innovative VR-based facial emotional expression
[16]	2012	Personal and Ubiquitous Computing	We present an interdisciplinary methodology for designing interactive multi-modal technology for young children with autism spectrum disorders (ASDs).	ECHOES' methodology.	We reflect on the methods needed to develop a TEL environment for young users with ASDs by identifying key features, benefits, and challenges of this approach.	The ECHOES project
[17]	2011	International Journal of Social Robotics	The development of sensorimotor coordination in infancy is fundamental for regulating interactional dynamics with peers and adults.	Preliminary tests.	Considerations on the future development of the device underscore the meaningful contribution that such platform can offer to child-robot interaction research.	Child-robot interaction
[18]	2008	Advanced Robotics	Although force platforms have extensively been used for large-size animals, only a few attempts have been made to measure GRFs at a single paw for animals as small as mice or rats.	Preliminary tests.	Preliminary testing was performed with both Reeler and wild-type mice. Fourier analysis validated the hypothesis of a direct connection between tremor and in-plane GRFs.	A sensorized environment for behavioural phenotyping of animal models
[19]	2000	American Journal of	The nature of the underlying brain dysfunction of childhood	Comparison experimental.	The first autistic group had a highly significant hypoperfusion in both	None.

	Psychiatry	autism, a life-long severe developmental disorder, is not well understood.	temporal lobes centred in associative auditory and adjacent multimodal cortex, which was detected in 76% of autistic children. PET and voxel-based image analysis revealed a localized dysfunction of the temporal lobes in school-aged children with idiopathic autism.

3.2 Interventions

In the realm of ASD interventions, technological innovations have opened new vistas of possibilities [20]. These interventions, appropriately termed "Technological Interventions," encompass a wide array of strategies that employ digital platforms, software applications, wearable devices, and virtual reality [21] to engage, educate, and empower individuals with ASD. One of the noteworthy aspects of technological interventions is their capacity to cater to the diverse and evolving needs of individuals on the autism spectrum. These interventions span various domains, including but not limited to communication, social skills, emotional regulation, and sensory integration. Augmentative and Alternative Communication (AAC) applications, for instance, empower non-verbal or minimally verbal individuals with ASD to express themselves effectively. These applications utilize symbols, pictures, or text-to-speech technology to facilitate communication, bridging the gap between intent and expression. Technological interventions are also instrumental in cultivating social competence. Virtual reality-based social skill training programs immerse individuals with ASD in controlled, realistic social scenarios, providing a safe space for practicing social interactions. These programs often incorporate artificial intelligence to offer real-time feedback and guidance, enhancing social learning. Sensory integration challenges, prevalent among many individuals with ASD, are also addressed through technological interventions. Wearable devices equipped with biosensors can monitor physiological responses to sensory stimuli, aiding therapists, and caregivers in tailoring interventions to an individual's sensory profile.

Despite the undeniable potential, it is crucial to critically evaluate the effectiveness, accessibility, and ethical considerations associated with technological interventions. Their integration into clinical practice necessitates a nuanced understanding of individual differences in technology adoption and response. Moreover, questions of privacy, data security, and equitable access must be addressed. In this sub-section, we embark on a comprehensive journey through the realm of technological interventions in ASD treatment. We will explore their applications, their documented outcomes, and the challenges that lie ahead, offering a holistic perspective on the role of technology in enhancing the lives of individuals with ASD. Table 4 show a summary about classification of interventions.

Table 4
Summary of interventions of classification

Authors	Year	Source title	Problem	Methodology	Results and advantages	Project
[22]	2022	Frontiers in Education	Autistic children are often marginalised and excluded from design processes.	Participatory method and analysis.	The findings highlight the valuable opportunities that participatory design processes can provide for students as both learners and as expert knowers.	Computer game
[23]	2021	JMIR Formative Research	Individuals with autism spectrum disorder (ASD) often exhibit difficulties in social and communication skills.	Semi structured interviews and questionnaire.	The SELSA-S questionnaire results showed no change in the family subscale; however, the social loneliness subscale showed a difference between prestudy and poststudy.	Multimodal Messaging App (MAAN)
[24]	2021	Scientific Reports	However, little is known about how children with ASD coordinate their visual attention and manual actions during toy play.	Exploratory method.	We found no differences in how 24- to 48-mo children with and without ASD distribute their visual attention, generate manual action, or coordinate their visual and manual behaviours during toy play with a parent.	Head-mounted eye tracking
[2]	2021	ACM Transactions on Internet Technology	However, the contradiction between the terminal interaction capability and availability cannot meet the needs for real application scenarios. At the same time, the lack of diverse data cannot provide individualized care for autistic children.	Experimental cases.	An interactive testbed for children with ASD treatments is demonstrated and experimental cases for test subjects are presented.	Wearable Robotics: a novel AI-based first view-robot architecture
[25]	2020	Multimodal Technologies and Interaction	Critical skills of acquire and appropriately use social skills can be difficult to teach	Experimental.	Current experimental applications exploring their use via the iAnimate Live project.	iAnimate Live
[26]	2020	Future Generation Computer Systems	The existing autism-treatment systems intended for children pay	A multimodal data fusion	A demo platform is built to verify the feasibility of the	Wearable robot-assisted emotion

			little attention to the emotion cognition disorder.	method.	proposed system.	communication
[27]	2019	Applied Sciences (Switzerland)	However, reported auditory processing impairments associated with autism may affect how an individual interacts with their virtual therapy application.	Comparison experimental.	Despite associated sensory processing difficulties, those with ASD can correctly decode the auditory cues simulated in current spatial audio rendering techniques.	a multi-modal virtual reality environment.
[28]	2013	Australian Journal of Early Childhood	-	Case study.	This article illustrates the successful drawing together of pre-service teachers' technological, pedagogical, and content knowledge (TPACK), as well as their knowledge of the children concerned.	None.
[29]	2009	Annual Review of CyberTherapy and Telemedicine	the use of traditional play therapy with adolescents, who may feel uncomfortable engaging in traditional play with toys they may be too old for.	Case study.	researching the effect of social game design mechanisms on social-emotional development, particularly for those who experience difficulty with social interaction.	video games
[30]	2005	IEEE Transactions on Visualization and Computer Graphics	This paper presents an adaptive physical environment that allows children with severe autism to successfully interact with multimodal stimuli, giving them a sense of control of the interaction and, hence, providing them with a sense of agency.	Qualitative study.	Qualitative evaluation by psychologists shows very good results and sketches an encouraging future for research on these environments.	The MEDIATE project.

4. Discussions and Recommendations

The application of multimodal technologies in ASD interventions faces inherent limitations and challenges. These include the diverse and heterogeneous nature of ASD, requiring highly customizable interventions that can be tailored to individual needs, thus demanding extensive technological development. Additionally, issues of accessibility and equity arise due to varying access to technology among individuals with ASD, highlighting a digital divide that warrants attention from policymakers and educators. Ethical considerations, such as data privacy and the potential for technology to supplant human interaction, underscore the need for clear ethical guidelines to govern the responsible use of multimodal technologies in ASD interventions, ensuring both the efficacy and ethical integrity of these approaches.

The future of multimodal technologies in ASD interventions should prioritize addressing several research gaps. Long-term efficacy studies are imperative to determine the enduring impact of these interventions on individuals with ASD, guiding decision-making regarding their integration into care plans. Emphasis should be placed on personalization and adaptability, exploring the development of AI-driven systems that dynamically tailor interventions to the evolving needs of individuals. Additionally, understanding the influence of cultural factors on the design and effectiveness of these technologies is crucial, necessitating research that adapts and tailors' interventions to diverse populations.

Practitioners and educators seeking to integrate multimodal technologies into ASD interventions should begin with comprehensive, individualized assessments to determine each learner's unique needs and preferences. Collaborating closely with technology experts ensures the selection and implementation of the most suitable tools and strategies, aligning technology with therapeutic goals and pedagogical principles. Continuous training and professional development are essential to stay abreast of the latest technological advancements in the field. Involving families in technology-based interventions empowers caregivers to support their children's learning, extending the benefits beyond formal therapy. Robust data collection and assessment mechanisms should be implemented to monitor progress and adapt interventions as required, ensuring they remain effective and responsive to the changing needs of individuals with ASD.

5. Conclusions

In conclusion, this systematic review underscores the remarkable potential of multimodal technologies in shaping the future of interventions for individuals with ASD. Through an extensive analysis of the existing literature, it is evident that these technologies have the capacity to enhance the effectiveness, engagement, and personalization of interventions across a wide spectrum of domains, from communication and social skills to sensory integration and emotional regulation. However, while the promise of multimodal technologies is evident, it is equally clear that the field is still in its infancy, with many questions and challenges yet to be addressed.

As we move forward, it is imperative that researchers and practitioners in the field of ASD interventions continue to collaborate, innovate, and rigorously evaluate the use of multimodal technologies. This review highlights the need for further high-quality research, including randomized controlled trials and long-term outcome studies, to provide a deeper understanding of the optimal ways to harness the potential of these technologies. Additionally, issues related to accessibility, ethics, and individual differences in responding to multimodal interventions require careful consideration [10,17,22,28]. By addressing these challenges and building upon the insights gained from this systematic review, we can aspire to create a future where individuals with ASD are

empowered by cutting-edge, evidence-based interventions that cater to their unique needs and foster their fullest development and participation in society.

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