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Integrating Artificial Intelligence-based programs into Autism Therapy: Innovations for Personalized Rehabilitation

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***Abstract*—Autism Spectrum Disorder (ASD) is a challenging clinical condition that requires tailored therapies to boost cognitive and social skills in those affected. Lately, artificial intelligence (AI) has shown great potential in the field of autism assessment and rehabilitation. This article explores how AI plays a crucial role in improving autism clinical conditions. Thus, smart systems for early diagnosis, personalized treatment, and continuous progress tracking were adopted. The paper looks at the difficulties and possibilities of using AI in individuals with ASD. This included concerns like safeguarding data privacy, accurately understanding behavioral cues, and developing interactive, welcoming therapy settings. More specifically, the article explored how techniques from machine learning and artificial intelligence could be woven into rehabilitation methods to enhance learning and promote independence and social inclusion for individuals with autism. This examination provided a fresh and enlightening view on how clinical approaches are evolving, showing how AI could greatly improve the lives of individuals with autism. Implications for research and clinical practice were critically discussed.**

Keywords:
Autism Spectrum Disorders, Artificial Intelligence, Rehabilitation, Machine Learning

I. Introduction

ASD IS a neurodevelopmental condition that affects communication and social interaction, often involving repetitive behaviors and reduced interests [13]. Over the years, the number of people diagnosed with ASD has risen significantly. In 2000, the prevalence was 1 in 150 children, which increased to 1 in 36 by 2017. This rise has made ASD a leading cause of disability in children, posing significant management challenges and financial burdens. In the U.S., lifetime support for an individual with intellectual disabilities can cost around 2.4 million, and about 2.2 million in the U.K., heavily impacting families and society [2]. Persons with autism spectrum disorders (ASD) may have notable difficulties, requiring tailored therapies that can improve cognitive, emotional, and social skills. Over the past few years, there has been an increasing interest in using AI to enhance autism rehabilitation. This overview investigates how AI holds potential in improving therapy results for children diagnosed with ASD [31]. The literature review emphasizes how AI technologies play a role in improving outcomes through early diagnosis, personalized treatment strategies, and ongoing progress monitoring. Important features to be considered include but are not limited to safeguarding data privacy, accurately interpreting behavioral cues, and developing interactive and inclusive therapy environments. Addressing these challenges is essential to optimize the effectiveness and ethical implementation of AI in supporting individuals with autism [10]. The article further explores how machine learning and AI methods can be incorporated into rehabilitation plans to improve learning results and encourage independence and social inclusion for individuals with ASD [1]. Integrating AI can be considered promising in improving therapeutic methods and fostering increased independence and inclusion for individuals with ASD [7]. This analysis provides insights concerning how clinical practices are evolving in autism rehabilitation, showcasing how AI has the potential to greatly enhance the lives of individuals with ASD. Integrating AI can be considered promising in improving therapeutic methods and fostering increased independence and inclusion for individuals with ASD [20]. Recently, AI has made significant strides in helping treat ASD. For example, the humanoid robot Kaspar has improved daily living skills in children with ASD by mimicking human behavior [30]. Research showed that children who participated in robot-assisted learning programs were more engaged and learned better, suggesting that AI robots could be highly beneficial in classrooms. Additionally, augmented reality smart glasses have been effective in reducing irritability, lethargy, rigid behaviors, and speech difficulties in children with autism. Studies indicate that AI technology enhances cognitive and social skills and holds great potential for rehabilitating chil-

dren and adolescents with severe intellectual disabilities [4]. The aim of this paper was to summarize and compare the current literature pertaining to rehabilitation in children and adolescents diagnosed with ASD through AI to provide an overview of effective strategies and successful improvements in both clinical practice and research. The novelty features may include the newest empirical studies on this specific topic and targeting comprehensive rehabilitative strategies. This review addressed the existing gap in the literature regarding comprehensive and contemporary analyses of AI applications in ASD rehabilitation. It summarized recent empirical studies, offering novel insights into the efficacy of AI-based interventions. By critically evaluating diverse AI technologies and discussing ethical considerations, this review provided new knowledge on practical implementation strategies. The review intended to analyze the current rehabilitation tools that exploit AI and the related therapeutic methods, in order to highlight the best strategies to promote autonomy and social inclusion for people with ASD, and lightened the burden of operators and caregivers. Furthermore, this overview, by analyzing the results of empirical studies conducted on the topic, addressed perspectives for future research, especially regarding the possibility of combining the use of AI-based programs with other methodologies and rehabilitation strategies used to promote social skills in people with ASD.

II. Understanding Autism Spectrum Disorder: Causes, Prevalence, and Diagnostic Challenges

While the exact cause of ASD is currently unknown, research suggests it can be linked to genetics, brain structure differences, and environmental factors [6]. Diagnosing ASD can be challenging because there are no standard medical tests, like blood tests, for it. The process usually begins with general practitioners (GPs) screening for possible autistic-like traits. If there are symptoms of ASD, the GP will refer the child to specialized psychologists or psychiatrists for a more thorough behavioral and cognitive assessment. Although the diagnostic process can start with toddlers as young as 18 months, a final diagnosis might not be made until late [3]. The diagnosis involves clinical experts evaluating the child's developmental age across various categories, such as behavior, communication, self-care, and social skills. This approach, known as clinical judgment, is widely accepted. Common diagnostic tools include the Autism Diagnostic Observation Schedule (ADOS) and the Autism Diagnostic Interview-Revised (ADI-R), where professionals assess the child through a series of questions and activities. Early diagnosis is crucial because it takes advantage of neuroplasticity, which is greater when children are younger[8]. Recent studies suggest that AI technology not only boosts the cognitive and social skills of children with ASD but also has great potential for rehabilitating children and adolescents with severe intellectual disabilities [17]. Additionally, it's important to highlight the often-neglected negative impact on the quality of life for those with ASD and their families. ASD can significantly increase the burden on caregivers and families, underscoring the need for effective AI-driven interventions to alleviate these challenges. The impact of ASDs on quality of life and families is profound and multifaceted, as highlighted by the study on health-related quality of life (HRQoL) of parents with children diagnosed with ASDs [11]. The research, utilizing both quantitative and qualitative methods, underscores several critical areas of concern. Quantitatively, parents of children with ASDs reported HRQoL scores that were notably lower than those of the general population, particularly in areas related to stress and mental health. The average HRQoL score from SF-6D was 0.74, a clinically significant deviation from the normative U.S. population, indicating substantial stress and mental health challenges. Furthermore, 40% of parents reported experiencing clinical depression symptoms, with unmarried parents showing higher depression levels than their married counterparts. This statistic alone is alarming, highlighting the severe emotional toll on parents. Additionally, families with three or more CSHCN experienced even lower HRQoL and higher caregiving burdens. This finding emphasizes how the cumulative demands of caring for multiple children with special needs can exacerbate stress and reduce overall family well-being. The qualitative data collected through focus groups further corroborates these findings, revealing the deep-seated challenges parents face in managing their children's conditions. This evidence clearly shows that ASDs significantly strain families, affecting both the mental health and overall quality of life of parents. Such impacts are often neglected in broader discussions about autism, which tend to focus primarily on the affected children. However, the well-being of caregivers is crucial; their mental health and quality of life directly influence their ability to provide effective care and support for their children[12]. Therefore, it is imperative that interventions for children with ASDs also include components aimed at supporting parents and reducing their caregiving burden. A recent study [17] suggests that AI technology not only boosts the cognitive and social skills of children with ASD but also has great potential for rehabilitating children and adolescents with severe intellectual disabilities. In light of the above, a selective overview of the newest empirical studies on the use of AI-based programs for recovery ASD individuals was the main objective of this paper. Strengths and weaknesses of the reviewed studies were emphasized, and the implications of the findings were critically discussed.

III. Method

To analyze the fundamental characteristics of AI-based programs for the promotion of social skills in children and young adolescents with ASD, a search for empirical studies on the topic was conducted on Scopus. The standard guidelines adopted in this review were in line with PRISMA statement [19] as also demonstrated in Figure 1. The inclusion criteria were:

Keywords: "autism spectrum disorders", artificial intelligence" and "rehabilitation";

Studies published from 2013 to 2024;

Empirical studies;

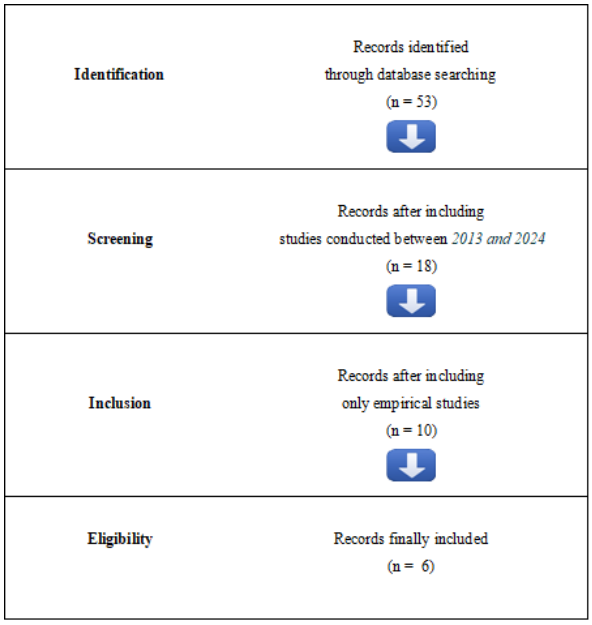

Fig. 1. Flowchart of the studies selection process

Language: English;
Setting: school;
Pertinence to the research question (AI-based programs for promoting social skills in young adolescents with ASD);
Participants: young adolescents (aged between 5 and 11 years).
The exclusion criteria were:
assessment, home or medical center setting;
reviews and conference papers;
age of participants: over 11 years.
An initial search was conducted on Scopus, entering the search keywords "artificial intelligence", "autism" and "rehabilitation"; the search produced fifty-three results. Including all studies conducted between 2013 and 2024, 18 documents were identified. The search led to eighteen documents. Of these studies, reviews were excluded, and only empirical studies were considered, for a total of ten studies. The eligibility criterion adopted is relevance to the topic of the use of AI-based programs for the promotion of social skills in children and young adolescents with ASD. The research therefore led to six results.

IV. Literature Overview

An overview was conducted to identify existing research on ASD, AI applications in healthcare, and rehabilitation strategies as also shown in Table I. Documents published between 2013 and 2024 were considered to ensure the inclusion of the most recent and relevant studies. Li et al.[16] showed the idea for the Modular Learning Augmentative and Alternative Communication (MLAAC) system was born from observing a participant with ASD struggling to communicate using existing tools like Picture Exchange Communication System (PECS). Despite these challenges, the participant was able to use an iPad to watch videos and play games. A virtual interface has been developed based on the principle of augmentative and alternative communication (AAC), compatible with devices such as the iPhone. This initial project evolved into MLAAC, a sophisticated communication tool that used modular network technology and required minimal synchronization. Unlike traditional vector graphics, MLAAC leverages advanced web programming languages to offer customizable features such as adjustable sizes, group settings, high-contrast modes, and responsive feedback. These features could be tailored by the user or caregiver, ensuring the tool met individual needs. Overall, MLAAC was aimed to address the diverse communication needs of AAC users through its adaptable, user-friendly design, providing a practical and accessible solution for individuals with communication challenges. Marrauwi et al.[18] showed that using the Internet of Things (IoT) and AI technologies to analyze behavior was rapidly becoming an integral part of their daily lives. As ASD became more prevalent, there was an increasing need to leverage IoT to train and rehabilitate individuals with autism according to their unique abilities and needs. One critical skill for people with autism was transitioning from one place or activity to another. However, specialists often struggled to track progress and determine the effectiveness of different aids and responses to these aids. This challenge was compounded by external factors in school, social, or health settings. Their study focused on developing a sensor-based software tool to analyze the behavior of individuals with autism as they learned to transition from their classroom to the specialist's room for treatment or rehabilitation. The tool provided indicators of progress and the effectiveness of personalized training programs. By using spatial sensors with Ultra-Wide Band technology, they could accurately track the subject's movements, dispersion, and the time it takes to transition, while accounting for external influences. The tool successfully processed data from both the entered variables and the sensors, offering trainers and supervisors daily and continuous feedback on the training process. This feedback allowed for quick adjustments to the training plan, thereby reducing the time required to master this transition skill. The result was an efficient and effective training process tailored to the needs of individuals with autism. Safi et al. [23] showed that young adolescents with ASD often struggled with communication and social interaction, primarily due to difficulties in language acquisition. While AI has shown promise in aiding young adolescents with ASD, the effectiveness of Virtual Voice Assistants (VVAs) in this context has not been thoroughly explored. This study was aimed to evaluate the impact of VVAs on enhancing speech and social interaction skills in young adolescents with ASD. The findings revealed notable improvements in the participants' expressive verbal vocabulary, ability to produce short phrases, and social interactions during the intervention phases compared to traditional methods. Young adolescents interacted effectively with the VVA platform, showing progress in expressive verbal output and social engagement. They pronounced more words correctly with fewer attempts and increased interactions

TABLE I
SYNOPTIC TABLE OF THE REVIEWED STUDIES

Ref	Objectives	Participants	Results
[16]	To evaluate machine learning augmentative and alternative communication (MLAAC) to enhance communicative abilities	Three persons with ASD who showed impaired verbal contact (age not specified)	MLAAC improved communicative abilities of participants
[18]	To evaluate a sensor-based software tool to analyze a person's behavior with ASD	Seven children with ASD (age not specified)	The tool successfully processed the data and provided the trainer and supervisor with daily and ongoing feedback on the training. This resulted in an automatic and rapid examination of the outputs of the individual training plan to make any necessary adjustments, resulting in a reduction in the time spent training this skill.
[23]	To evaluate Virtual Voice Assistant (VVAs) to improve speech skills and social interaction skills	Three young adolescents with ASD (4–11 years old)	Participants showed increases in social interactions. VVAs had positive effects on the speech and social interaction skills of young adolescents with ASD
[29]	To evaluate efficacy of an automated imitation assessment system	Twenty children with ASD (mean age: 4.95 years), and twenty typically developing children s (mean age: 5.30 years)L	The proposed system is able to continuously assess the quality of actions
[32]	To improve the reliability of data acquisition and maximize the potential of data using a multimodal data-driven rehabilitation strategy auxiliary feedback	Twenty children with ASD aged three to seven participated in the study	Multimodal data-driven rehabilitation strategy auxiliary feedback method can provide effective feedback for individuals or groups
[33]	To evaluate a smart rehabilitation product service system based on virtual scenarios for upgrading the rehabilitation service system	Twelve children with ASD (age not specified)	The service system based on the proposed methods can construct an optimal virtual driving system and a rehabilitation program based on the evaluation of patients

with their siblings. Mothers reported satisfaction with the program, indicating that VVAs could be a valuable home-based intervention for young adolescents with speech and social difficulties. Similar findings were reported by Sahin et al. [24], who used digital augmented reality in interventions for social communication, motivation, and cognition in individuals with ASD in a school setting. This study evidenced a technology readily available at home, reinforcing the idea that VVAs' "humanlike" conversational skills could support speech and social development at home. Studies by Parsons et al. [22] also showed improvements in social interactions using avatars and virtual reality applications in simulated environments. This study aligned with those findings, demonstrating the effectiveness of VVAs in enhancing speech and social skills. Mothers noted multiple benefits, including increased sibling interaction and young adolescents' heightened interest in activities involving Siri. Some young adolescents began imitating new words they heard from Siri, which indicated that VVAs could indirectly benefit from expressive language and social interaction. While the study showed positive effects, it remained unclear if these improvements were solely due to the VVAs or also influenced by the mothers' adherence to the intervention. Nonetheless, the children's interest in VVAs over traditional methods suggested that VVAs played a significant role. A single-subject design, used in this study, allowed for rich, in-depth data collection and individual progress tracking, making it advantageous for ASD interventions. Given the heterogeneity of ASD, customized experimental interventions tailored to each participant's needs and goals were beneficial, as each child's pre-study performance served as their baseline. The work of [29] showed that one of the main symptoms of ASD in children was difficulty with imitation skills. In their study, they examined the body gesture imitation performance of 20 children with autism (ASD group) and compared it to 20 typically developing children (TD group) through a series of imitation tasks involving both robots and humans. Manual scoring by two specialists revealed that the TD group significantly outperformed the ASD group in these tasks. Both groups performed better in human-child interactions compared to robot-child interactions within their experimental setup. To advance an automated system for assessing imitation skills, they tested various mathematical models using State-Image based algorithms such as Acceptable Bound, Mahalanobis Distance, and Signals' Cross-Correlations, along with Hidden

Markov Models based on time-dependent kinematic data of participants' joints. Among these models, the "State-Image Acceptable Bound method with position, velocity, and acceleration features" emerged as the most effective, showing a mean Pearson correlation of around 45 per cent, which was comparable to related studies outside the autism field in assessing dynamic action quality. For therapeutic purposes, they proposed using AI algorithms for an automated and unbiased evaluation of children's behaviors. Their suggested approach involved a reciprocal gross imitation human-robot interaction platform, which holded potential for aiding the cognitive rehabilitation of children with autism. Zhao et al. [32] was inspired by observing children with ASD struggling to communicate, researchers developed a multimodal data-driven rehabilitation strategy called MLAAC. This approach combined various technologies to provide effective auxiliary feedback for rehabilitation. The rapid development of Industry 4.0 technologies, such as sensors and deep learning, has revolutionized the medical industry. However, relying on a single technology to meet data requirements is often insufficient. To address this issue, researchers proposed a multidimensional analysis approach that matched technology to the specific needs of doctors and patients. By integrating various data collection methods, a reliable tool could better support the patient's rehabilitation process. Using devices like Microsoft Kinect for ethology (movement tracking) and fNIRS for brain function, researchers collected stable, high-quality data. These tools helped track patients' movements and monitor brain activity, providing comprehensive insights into their condition. Data analysis involved motor representation and statistical methods to correlate movement and brain function changes, creating a robust foundation for auxiliary diagnosis. This layer focused on providing feedback through both quantitative and qualitative analyses. The system collected multidimensional patient data and used correlation and difference analysis to establish relationships between ethology and brain function. These results supported intervention treatment plans, making the rehabilitation process more targeted and effective. The study examined the use of this approach in rhythm rehabilitation training for children with ASD. By observing ethological differences and brain function activation in children with ASD, researchers found that these factors might be age-related. This insight could guide the age-specific design of interventional therapies. In [33] authors showed that the SRP (Smart Rehabilitation Platform) service system leverages virtual scenarios to prioritize user needs by collecting data on user interactions, physiological responses, and behaviors. This comprehensive data collection helped establish reliable evaluation standards for innovative rehabilitation services. The system fostered collaboration between physicians and manufacturers throughout the rehabilitation process, enhancing service quality and promoting user rehabilitation. A case study on a virtual driving system demonstrated the system's effectiveness in creating tailored rehabilitation programs and guiding subsequent rehabilitation stages. Compared to traditional methods, the SRP system allowed for the creation of knowledge graph-based rehabilitation plans, optimizing virtual scenario-based product designs based on patient rehabilitation evaluations. This approach encouraged cooperation between medical institutions and manufacturers, optimizing medical services and products, and improving rehabilitation outcomes. Industry 4.0 has enabled the use of intelligent terminals and sensors to collect extensive data, making smart rehabilitation services more objective, quantitative, and efficient than traditional methods. This study included a design method for the SRP service system, focusing on virtual scenarios, particularly virtual driving for young adolescents with ASD. The system's main contributions included: 1. Overall Design Architecture: Integrating scene building, data collection, data analysis, and innovative services to enhance SRP service modes and promote intelligent development. 2. Quantitative Evaluation Method: Improving the accuracy of rehabilitation efficacy evaluation through comprehensive multimodal data analysis. 3. Collaborative Rehabilitation Services: Helping physicians and manufacturers create knowledge graph-based rehabilitation plans and optimization schemes, guiding subsequent rehabilitation stages. 4. Case Study on Virtual Driving for Young Adolescents with ASD: Analyzing interaction, physiological, and behavioral data to evaluate rehabilitation effects and verify the proposed service system framework. By focusing on these areas, the SRP service system aimed to provide more effective and personalized rehabilitation services, leveraging the latest technological advancements to meet diverse health needs.

V. Discussion

The reviewed studies demonstrated how AI-based programs significantly enhance the assessment and rehabilitation of individuals with ASD. By leveraging advanced technologies, these programs provided tailored and precise interventions that addressed the unique needs of each individual. For instance, Li et al. [16] developed the MLAAC system, which utilizes a customizable virtual interface to support communication, demonstrating that AI could create adaptable tools that cater to specific user requirements. This flexibility ensured that individuals with ASD receive the most appropriate and effective support. AI-based programs have also been instrumental in fostering inclusion in daily settings. Marrauwi et al. [18] highlighted how IoT and AI technologies could track and analyze behavior, particularly in transitions between activities, a common challenge for individuals with ASD. Their sensor-based software tool provided continuous feedback, allowing for real-time adjustments to training programs. This approach not only enhanced the individual's ability to navigate daily environments but also promoted greater independence. The use of safe AI to support independence and quality of life emerged in several studies [5]. Safi et al. [23] showed that Virtual Voice Assistants (VVAs) improved speech and social interaction skills, making home-based interventions more effective. The ability of young adolescents to interact with VVAs and show progress in verbal and social skills highlighted the potential for AI to create supportive and engaging environments that promoted independence and self-determination [23]. Construc-

tive engagement through AI-based interventions was another significant benefit. Taheri et al. [29] demonstrated how a human-robot interaction platform could aid cognitive rehabilitation by assessing imitation skills. The use of AI algorithms for automated evaluations ensured objective and unbiased assessments, facilitating personalized and effective therapy. The burden on caregivers and families is also alleviated through AI interventions. Safi et al. [23] reported that mothers of young adolescents using VVAs noted improvements in their young adolescents' interactions and expressed satisfaction with the program. This suggested that AI tools could provide meaningful support to families, reducing the stress and effort involved in managing ASD-related challenges. However, there were notable weaknesses in the reviewed studies. Many of them relied on small sample sizes, which limited the generalizability of the findings. For example, Taheri et al. [29] included only 20 children in each group, making it difficult to draw broad conclusions. Additionally, there was often a lack of long-term follow-up, which was crucial to understanding the sustained impact of AI-based interventions. The studies also varied in their methodologies and outcome measures, making direct comparisons challenging. In conclusion, AI-based programs hold significant promise for enhancing the assessment, rehabilitation, and quality of life for individuals with ASD. These technologies offered personalized, adaptable, and engaging interventions that could support independence and reduce caregiver burden. However, future research should address the limitations of current studies by including larger sample sizes, ensuring long-term follow-up, and standardizing methodologies to validate and expand upon these initial findings.

VI. Conclusion

This overview addressed a critical gap in the literature by providing a comprehensive and up-to-date analysis of AI-based programs for enhancing social skills in young adolescents with ASD. It synthesized recent empirical studies, offering novel insights into the efficacy of various AI-driven interventions. By evaluating the effectiveness of these technologies, discussing ethical considerations, and providing practical implementation strategies, this review significantly advanced our understanding of AI's role in ASD rehabilitation. The findings underscored the potential of AI to create personalized, adaptable, and engaging therapeutic environments that foster independence and improve quality of life for individuals with ASD. AI tools such as the MLAAC system, sensor-based behavior analysis software, Virtual Voice Assistants, and human-robot interaction platforms demonstrated considerable promise in addressing communication challenges, promoting social inclusion, and reducing the burden on caregivers. The reviewed studies collectively highlighted the transformative potential of AI-driven tools in addressing core challenges faced by individuals with ASD. Specifically:

Enhanced Communication: Tools like the Modular Learning Augmentative and Alternative Communication (MLAAC) system provided customizable and user-friendly solutions that cater to individual communication needs. These advancements suggested a move towards more adaptable and accessible communication aids that could be tailored by caregivers and users alike.

Behavioral Monitoring and Training: The use of IoT and AI technologies for real-time behavioral tracking, as demonstrated by Marrauwi et al., enabled precise and continuous feedback. This facilitated more effective and personalized training programs, allowing for quicker adjustments and improvements in skill acquisition.

Virtual Voice Assistants (VVAs): Safi et al.'s [23] findings on VVAs underscored their potential as home-based interventions that could significantly enhance verbal expression and social interactions. The accessibility and convenience of VVAs made them a practical addition to traditional therapeutic approaches, offering supplementary support that could be seamlessly integrated into daily routines.

Imitation and Interaction: The exploration of human-robot interactions by Taheri et al. [29] pointed to the potential of AI in assessing and improving imitation skills. This approach could lead to more objective and automated evaluation methods, reducing the reliance on manual scoring and potentially increasing the accuracy and efficiency of assessments.

Multimodal Rehabilitation Strategies: The studies by Zhao et al. [32] illustrated the benefits of integrating multiple technologies to provide comprehensive rehabilitation support. The Smart Rehabilitation Platform (SRP) and similar multimodal approaches offered a holistic view of the patient's progress, enhancing the personalization and effectiveness of intervention plans.

VII. Limitations and Future Research Perspectives

Despite the potential practical applications of using AI for the development of rehabilitation strategies aimed at young adolescents with ASD, some limitations emerged from the reviewed studies, which need to be addressed in future research on the topic.

Li W. et al [16] showed that the core functionality of MLAAC is nearly complete, but there are still a few details that need refinement. One key area needing further assessment is the deep learning capability. It's crucial to tailor intelligent suggestions to be genuinely useful rather than irritating or misleading. Researchers have enabled the option to turn these advanced features on or off based on user needs, aiming to understand better how people interact with and utilize these suggestions to perfect them. Beyond this detailed assessment, deep learning techniques could be further developed to offer more precise recommendations. For instance, the device could suggest additional cards based on the user's current location. Additionally, expanding audio processing to include different voice and speech options, as well as refining audio clips, would enhance the device's functionality. Adding compre-

hensive photo identification and saving features would also be beneficial. Ultimately, the identity design process could incorporate more user data to offer customizable platform configurations, improving the overall user experience.

The study of [23] had several limitations. First, the single-subject design and low number of participants limit the generalizability of the findings. Second, the use of the A-B-A design due to time constraints could be improved with an A-B-A-B design, which would offer a second evaluation phase to better assess the intervention's impact on target skills or behaviors. Third, the limited number of sessions per phase may have restricted the accuracy in determining the intervention's effectiveness. Increasing the number of sessions could provide a clearer picture of the VVA intervention's impact. To build on these findings, future research should address these limitations. Expanding the target population to include not only young adolescents with ASD but also those with other speech and social difficulties would be beneficial. Additionally, comparing the impact of mothers' interventions with regular therapy sessions conducted by therapists or special education teachers using validated assessment tools would provide valuable insights. Despite its limitations, this study contributes to the understanding of how VVAs can assist young adolescents with speech and social difficulties.

While the study of Zhao in [32] contributed to developing a rehabilitation strategy-assisted diagnostic feedback system, it does have some limitations. One major issue is the small sample size, which, although sufficient for verifying the feasibility of the research method, may not provide the robust data needed for comprehensive feedback results. Additionally, linking brain science data with behavioral data remains a challenge. To improve the system, future studies should increase the sample size and conduct more experiments to validate the accuracy of the feedback results. Building a comprehensive ethology and brain science database for ASD across different age groups will also be beneficial. By incorporating machine learning, they can use behavioral and brain function features as data inputs to achieve automatic identification and feedback for ASD through specific tasks. This approach will enhance the reliability and effectiveness of the rehabilitation strategy-assisted diagnostic feedback system. Zhao in [33] showed that despite its benefits, the data collection and analysis process face challenges, such as limited data due to small sample sizes and difficulty establishing correlations between brain science and behavioral data. To improve rehabilitation services, the system should expand to special user groups, integrate into daily life, and enhance behavior monitoring systems. Advanced multimodal data analysis methods can provide high-quality health services and design better rehabilitation products by deeply understanding user needs.

Looking ahead to future research, there are several promising avenues to explore, building upon the limitations identified in current studies. One key aspect is the need to involve more participants in research studies to ensure broader representation and more robust findings. By increasing the participant pool, researchers can gather diverse perspectives and better understand the varied experiences within the target population. Furthermore, it's essential to delve deeper into the implications for privacy and data protection in research involving sensitive information. As technology continues to advance, ensuring the security and confidentiality of participant data becomes increasingly critical. Future research should prioritize exploring innovative approaches to safeguarding privacy while still facilitating meaningful data collection and analysis [21].

Long-term follow-up studies are also necessary to assess the sustained impact of AI-based interventions on individuals with ASD. Standardizing methodologies and outcome measures across studies will facilitate more direct comparisons and robust conclusions. Exploring the integration of multiple AI technologies within a single intervention framework could yield more comprehensive and effective rehabilitation strategies. There's potential for the development of personalized tools tailored to the specific needs of individuals with ASD. By leveraging AI and other cutting-edge technologies, such as augmented reality, researchers can create customized interventions and support systems that address the unique challenges faced by everyone [25]. Integrating AI into interventions might enhance the effectiveness and efficiency of support services, providing personalized recommendations and adaptive learning experiences. Augmented reality offers exciting possibilities for creating immersive and interactive tools that engage individuals with ASD in therapeutic activities and social skills training. Future research in the field of ASD should focus on expanding participant involvement, addressing privacy concerns, developing personalized tools, and leveraging emerging technologies like AI and augmented reality to improve outcomes and support for individuals with ASD. By embracing innovation and collaboration, researchers can continue to advance the understanding and treatment of ASD, ultimately enhancing the quality of life for affected individuals and their families [9]. Exploring new applications of AI, such as virtual reality (VR) and augmented reality (AR), further therapeutic practices can be enhanced. These technologies may offer immersive and engaging ways to support social interaction, communication, and behavior training [28], [26]. Future research should also explore integrating AI with assistive technology interventions and reinforcement learning principles. This combination could lead to highly personalized and tailored solutions, optimizing the learning process, encouraging active participation in training and alleviating the burden of healthcare workers and families [15], [26], [14], [27].

Additionally, Investigating the ethical implications and ensuring data privacy and security will be crucial as AI becomes more integrated into therapeutic settings. Finally, fostering collaborations between researchers, clinicians, caregivers, and technology developers will be vital in creating innovative, user-centered AI solutions that meet the diverse needs of individuals with ASD. In conclusion, the integration of AI into ASD rehabilitation practices presents a significant advancement in the field. By addressing communication challenges, enhancing behavioral training, and providing comprehensive,

personalized interventions, AI-driven tools hold the potential to greatly improve the quality of life for individuals with ASD. Continued research, ethical considerations, and interdisciplinary collaboration will be key to realizing the full potential of these innovative technologies.

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