

Application of VR in Enhancing Social Competence of Children with ASD

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Abstract. Children with Autism Spectrum Disorder (ASD) commonly exhibit deficits in core social competencies, including social communication, emotional expression and cognitive comprehension, which significantly hinder their social integration and quality of life. However, traditional rehabilitation approaches have inherent limitations. Virtual Reality (VR) technology, characterized by immersion, interactivity, safety, controllability and personalized customization, offers a novel avenue for social skills intervention in ASD children. This paper systematically synthesizes the current status and evidence regarding the application of VR technology to enhance social abilities in ASD children. The study indicates that VR, through simulated social scenarios and emotional feedback training, significantly facilitates the acquisition of communication skills, emotional expression and social cognitive capacities in ASD children, effectively increasing their proactive social behaviors and reducing anxiety-driven avoidance. Feedback from parents and educators confirms that VR-based training enhances motivation and efficiency compared to traditional methods, with superior long-term skill retention outcomes. However, current research is still limited by small sample sizes, insufficient long-term tracking, high hardware costs, and underdeveloped individualized adaptation mechanisms. Furthermore, the neural mechanisms underlying VR efficacy and ethical concerns, such as data privacy, require further in-depth exploration. This paper systematically synthesizes evidence regarding the effectiveness of VR interventions and identifies existing challenges, thereby providing a theoretical foundation for optimizing clinical rehabilitation practices and supporting the sustainable development of social abilities in children with ASD.

Keywords: Virtual Reality Technology, Autism Spectrum Disorder, Children, Social Competence.

1. Introduction

Children with Autism Spectrum Disorder are mainly characterized by obvious disorders in social communication and interaction abilities. Although many children with ASD have the willingness to engage in social interaction, their social patterns often exhibit one-sidedness, making it extremely difficult to establish and maintain two-way interpersonal relationships [1]. At the communication level, most ASD children exhibit normal formal language structure, but their ability to appropriately

use and understand language in social contexts is generally underdeveloped and requires enhancement [1]. Specific manifestations include the inability to accurately recognize others' emotions, difficulty in interpreting social cues such as facial expressions and body language, and difficulty in effectively resolving social conflicts or understanding complex social concepts such as "respect" in terms of social cognition [2]. Additionally, ASD children typically present with adaptive functioning impairments, which further impact their performance in communication, social interaction, and daily living activities [3].

Deficits in the social abilities of children with ASD exert a persistent negative impact on their daily lives. Clinical observations reveal that these children commonly exhibit distinct atypical gaze patterns, such as avoiding eye contact with others [4]. This atypical gaze pattern not only impedes the normal development of language abilities but also impairs emotional perception, leaving them unable to accurately interpret and respond to others' interaction signals during social encounters [4]. This directly leads to significant difficulties for them in establishing and maintaining interpersonal relationships and actively participating in social activities [5].

More seriously, deficits in social interaction and communication often leave children with ASD vulnerable to peer rejection, which in turn triggers feelings of anxiety, inferiority, and other psychological issues [6]. What is even more worrying is that comorbidities will further exacerbate these social adaptation challenges. Statistics indicate that up to 44% of children with ASD have comorbid ADHD, while 32% experience language impairments, creating multiple overlapping difficulties [2]. These combined factors result in lifelong disability for approximately 80% of children with ASD, among whom over 80% face severe limitations in daily living skills [7].

Research shows that good social skills are the key to improving the quality of personal life, which enables individuals to better interact with people around them in daily life, participate in leisure activities and integrate into the group [6]. Therefore, ASD individuals have significant defects in social skills that not only hinder their current social participation and relationship building, but also pose a serious challenge to their lifelong independent living ability, mental health status and overall quality of life.

In recent years, growing attention has been paid to intervention research for children with ASD. Scholars have found that while traditional educational intervention methods yield certain effects, they are plagued by several issues, such as insufficient professional resources, high costs, and low child cooperation. Additionally, constructing traditional manual scenes demands significant time and effort, and specific scenarios are difficult to replicate [8]. These challenges highlight the particular importance of digital solutions based on VR and Internet technologies [5]. Furthermore, in the "14th Five-Year Plan for the Development and Improvement of Special Education", Chinese scholars specifically emphasized the integration of medical rehabilitation with information technology [2]. Due to its ability to switch between virtual and real worlds, VR technology has become a new method for helping children with ASD train their social skills. The application of digital technologies such as VR in rehabilitation training can not only solve the shortcomings of traditional training methods, but also make special education more flexible and effective, which can be said to be a trend for future development.

2. Basic overview and application advantages of VR

2.1. Definition and main characteristics of VR

VR is a technology that takes computer technology as the core, combines multimedia technology, simulation technology and sensor technology, and generates a realistic three-dimensional virtual

environment through an algorithm [9]. The system uses an intelligent helmet, VR all-in-one machine and other equipment to build an immersive interactive environment in visual, auditory and tactile channels, so that users can interact with the virtual world in real time and get feedback through natural interaction, so as to produce an experience close to the real environment [9]. VR technology has three typical characteristics: the first is immersion, which enables users to feel immersive through multisensory stimulation; The second is interactivity, which emphasizes that users can interact with the virtual environment in real time through dedicated devices; The third is imagination. This technology can break through the limitations of reality, help people develop their thinking and stimulate creativity [2]. These characteristics make VR technology show unique value in the field of special education, especially for ASD children in the cultivation of social ability.

2.2. Advantages of VR in the rehabilitation of ASD children

VR shows significant advantages in ASD rehabilitation intervention. Its core is to build a safe, controllable, repeatable and personalized training environment and provide real-time feedback data. First, VR technology can flexibly adjust stimulating factors like sound, light, and the number of people in the environment according to the needs of children with autism, creating a social scenario that is close to reality yet more gentle. This controllable environment can alleviate the uneasiness and anxiety of children brought about by external interference. Secondly, VR training allows children to control their progress, such as pausing or repeating practice at any time, which can further enhance their motivation. Building multi-role interactive dynamic drills in a VR environment not only helps children establish an understanding of social rules during training but also significantly increases their engagement. Studies have shown that interventions using mixed reality systems can increase the social participation of ASD children by 35% [10]. Additionally, VR can combine with AI to help children with autism better understand emotions. The system can detect the child's facial expressions in real-time and compare them with the emotions of virtual characters. If the child misidentifies an expression, the system will immediately provide a prompt, just like a patient teacher. Research has found that after 8 weeks of training, children's emotion recognition accuracy can improve by 42% [11]. More importantly, VR training can promote changes in neural plasticity, and fMRI evidence shows that it can activate the prefrontal amygdala neural circuit, thereby enhancing emotional regulation ability and laying the foundation for cross-scene transfer of social skills [12].

3. The application of VR in enhancing social skills

3.1. Changes in ASD children themselves

Research by Karami and other scholars has shown that using VR to train ASD patients shows significant progress in multiple aspects, not only improving daily life practice ability, but also enhancing cognitive function, emotional management and social interaction levels. It is particularly noteworthy that children show the most significant improvement in their self-care abilities. Research has found that the total score of the Daily Living Skills Questionnaire for ASD patients was significantly increased after VR training, and the completion time of tasks in each scene was significantly shortened [3].

VR training can not only enhance the basic social skills of individuals with ASD, but also effectively promote behavioral improvement, including increasing active social interaction and reducing avoidance behavior. For example, the game combining AR and VR designed by Sarker et

al. significantly enhances the joint attention of children with ASD, and this crucial social skill directly impacts individuals' ability to engage in social interactions [10]. In addition, VR intervention has also shown outstanding performance in improving cognitive function. VR games have a significantly better intervention effect on cognitive flexibility in children with ASD and have been listed as one of the effective intervention measures [13]. Improving cognitive flexibility helps individuals with ASD better adapt to changes in social situations, thereby reducing repetitive behaviors and social avoidance, and promoting more natural social engagement.

VR can help children with ASD gradually adapt to social interactions, thereby reducing anxiety and enhancing self-confidence. As shown in the study by She et al., individuals with autism showed a significant decrease in social anxiety levels after VR intervention [2]. Additionally, there was no significant difference in performance between children with autism and those with normal development in VR social gaming scenarios. This finding not only validates the adaptive advantages of VR environments but also demonstrates that VR training can effectively boost the social self-confidence of individuals with ASD [2].

3.2. Feedback from parents and educators

Feedback from parents and educators on the use of VR training for children with ASD generally shows a positive trend. The study showed that all the subjects and their guardians who participated in the training were satisfied with the content of VR rehabilitation, of which 28 subjects' willingness to continue to participate scored 6.00 ± 1.14 (full score 7), and 20 guardians clearly expressed their intention to continue to participate in the follow-up training [3]. In terms of safety, parents and teachers have highly recognized the VR training environment, demonstrating their trust in the technology. It is worth noting that most teachers hold that the effect of VR is superior to that of traditional auxiliary tools [5]. These findings indicate that VR training has not only been widely accepted by users in the field of ASD rehabilitation, but also regarded by parents and educators as an innovative intervention with development potential.

3.3. Comparison of efficacy with traditional methods

Research indicates that virtual reality (VR) is more effective than traditional approaches in assisting autistic children to enhance their social competence. Compared with conventional methods like role-playing and group therapy, VR training allows children to better learn to express emotions and communicate smoothly. Experiments have found that children trained with VR can get an average of 12.36 points in social tasks, while children trained with traditional methods only get 8.63 points. This may be because VR games are more interesting and children are more willing to participate actively, which is not as boring as traditional training [1]. Even more surprising is that the effects of VR training can also be applied to real life. Many parents and teachers have noticed that children who undergo VR training exhibit better social interactions in their daily lives. Although traditional training methods are also effective, children clearly prefer VR and are more inclined to persevere in training [5]. These findings show that VR technology can indeed bring new breakthroughs to the social training of ASD children.

4. Main limitations and challenges in current research

Current research on the application of VR in the rehabilitation of ASD children still has many limitations and practical challenges. Insufficient sample size is a widespread issue. Most studies

have a small number of participants, and some depend on public data sets, leading to restricted sample diversity and representativeness, which may undermine the reliability of the findings [2,7,13]. In terms of experimental design, the setup of the control group was not rigorous enough, and significant differences existed in the intervention protocols (such as cycle, frequency, and duration) among different studies, thereby increasing the risk of result bias [13]. In addition, the verification of long-term effects is insufficient, and only a few studies have tracked the maintenance and generalization of intervention effects [2].

There are also considerable limitations for VR technology itself. High hardware and development costs, including equipment procurement, personnel training and complex modeling technology investment, limit the popularization of technology [5]. In terms of content adaptation, existing virtual scene designs are often too similar, lacking the ability to dynamically adjust to the individual differences of ASD children, and it is difficult to achieve real personalized intervention [2]. In addition, the issue of user experience is relatively prominent. Research shows that 39.4% of the subjects experience motion sickness reactions like dizziness when using VR training. Prolonged use of the device can easily lead to discomfort, and children with comorbid tic disorders may be completely unable to adapt to the existing system [3].

Current research has a superficial understanding of the cognitive and neural mechanisms underlying VR interventions. Although VR-based training holds great potential in enhancing the social behavior of children with ASD and has become the primary basis for efficacy assessment, the evidence regarding the neural changes corresponding to these observable behavioral improvements is rather limited [14]. At present, it is still necessary to further explore the specific cognitive neural basis of the effectiveness of VR intervention [5]. Especially, how VR training affects the function of the mirror neuron system in ASD children is still a significant research gap, lacking empirical evidence.

5. Future research directions

5.1. Optimization of individualized intervention programs

ASD children show a high degree of heterogeneity in cognitive characteristics, sensory preferences and social interaction patterns, which requires that future VR intervention research must focus on personalized dynamic programs [2]. The ideal system can intelligently adjust the difficulty, interaction mode and feedback form of the VR scene according to the user's real-time operation, sensory feedback and interactive behavior. To achieve this goal, the key is to integrate artificial intelligence evaluation technology into the VR system framework [14]. Such AI modules need to automatically analyze and evaluate the differences in users' specific social cognition or sensory processing abilities, and construct a dynamic ability model. Based on this model, the system should have the ability to autonomously optimize, immediately adjust the subsequent training content and challenge goals, and form a continuous "evaluation-adjustment-re-evaluation" cycle. By following this personalized and continuously optimized rehabilitation path for each individual with ASD, the intervention outcomes are ultimately improved.

5.2. Multimodal interaction and sensory integration

ASD children often show functional defects of cross-sensory integration, which provides a key theoretical support for the clinical transformation of multimodal VR [15]. The multimodal fusion scheme can construct a dynamically evolving neurobehavioral representation map through

simultaneous collection of eye movement trajectories, speech features and brain nerve images, thus enabling the transformation of objective indicators for ASD social deficits [7]. The follow-up study should focus on the collaborative application of multiple senses, carry out systematic experiments using immersive VR scenes, and quantitatively evaluate its intervention effect on the social understanding ability of ASD patients.

5.3. Exploration of collaborative intervention models

Based on the existing research foundation, future research should focus on designing and validating an intervention program that integrates "online-offline, virtual-real, and individual-group". First, an effective mechanism should be devised to link VR social training with offline group activities [3]. Taking advantage of the safe and controllable features of VR, let children master basic social skills in the virtual environment first, and then use and consolidate these skills in real group interaction, so that the learned abilities can be really used in life. Second, establish a home-school-VR data chain: Develop a dedicated APP for parents, allowing them to see the key performance of their children in VR training in real time. The app should provide simple and clear guidance and suggestions to tell parents how to help children practice and consolidate the skills learned in VR in daily family and community activities. In addition, we can also use the latest achievements of brain science and behavior research to further study how to scientifically use the VR training platform as a supplementary tool and embed it into the existing behavior therapy and daily school teaching [14]. VR does not replace traditional methods but offers new and valuable training dimensions.

6. Conclusion

This paper systematically analyzes the research progress, core advantages and future application potential of VR technology as an innovative intervention for enhancing the social abilities of children with ASD. Comprehensive analysis indicates that VR technology, with its unique immersive experience, strong interactivity, highly safe and controllable environment and customizable scenarios, has constructed an ideal platform for social skills training for ASD children. It particularly demonstrates irreplaceable and significant advantages in simulating complex and dynamic real-world social situations, providing immediate and precise behavioral feedback, and facilitating the generalization of acquired skills to real-life settings. Empirical research provides strong evidence. At the level of skill acquisition, VR intervention can effectively improve the abilities of children with ASD, from basic communication skills to complex social cognition. There are positive changes in behavioral performance, such as a significant increase in positive social initiative and a decrease in avoidance and withdrawal behavior. At the psychological and emotional level, children's social anxiety is reduced and their confidence is enhanced after intervention. Compared with traditional rehabilitation methods, VR often exhibits greater competitiveness in stimulating children's intrinsic motivation to participate and enhancing training efficiency per unit time. However, research in this field still faces numerous challenges: Methodologically, limitations exist such as generally small sample sizes and a scarcity of long-term follow-up studies; at the technical application level, constraints include the high cost of content development, the need to optimize the user experience and adaptability of existing content, and the core challenge of implementing dynamically personalized interventions based on children's individual differences; in terms of theoretical mechanisms, the specific cognitive neural pathways through which VR interventions exert their effects require further clarification; additionally, ethical issues such as data privacy and security, potential addiction risks, and impacts on visual health must not be overlooked.

This review provides strong theoretical support and practical evidence for the application of VR in social rehabilitation for children with ASD, highlights its clinical value as an important supplement to traditional methods, and holds significant practical implications for promoting the social integration of children with ASD and alleviating family and social burdens.

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