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The Impact of Virtual Reality on the Skill Acquisition and Cognitive Development of Children and Adolescents with Autism Spectrum Disorder

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Abstract: Recent years have witnessed a growing occurrence of autism spectrum disorder (ASD) in children and adolescents. ASD is acknowledged as a neurodevelopmental disease, which can trigger serious developmental impairments and delays in language development, social and communication abilities, interest construction and behavioral patterns. Virtual reality (VR) technology is gaining increasing attention as a potential effective tool to prevent and rehabilitate ASD. Numerous studies have summarized the application of VR technology in autism developmental deficits. This review focuses on whether VR-based cognitive and performance training can hone the daily living skills, social communication capacities and academic abilities of children and teenagers diagnosed with ASD. The summary of several evidence-based studies demonstrates that VR platforms offer an innovative and efficacious option for the treatment of some deficits in autism. Despite its low cost and ease of accessibility, VR still has noteworthy limitations that need to be resolved. Future research might look into its application in other skill acquisition, correlation with brain function, adjunctive function in therapeutic treatment, and cross-cultural inquiry.

Keywords: virtual reality, autism spectrum disorder, skill learning

1. Introduction

Autism spectrum disorder (ASD) is a complex neurodevelopmental illness that lasts a lifetime and ASD sufferers might struggle with persistent difficulties in language learning, attention control and social interaction. They also present repetitive and stereotyped patterns of behavior, activities, and interests [1]. Furthermore, based on data from 8-year-olds in the United States, new epidemiologic findings indicate that the overall prevalence of autism has climbed to one in sixty-eight [2]. Therefore, with the growing incidence and considerable long-term effects of ASD on patients' daily functioning and quality of life, treatments should be developed as soon as possible after assessment and diagnosis.

While at present there is no single best 'cure' for different levels of ASD, there are several interventions that have been designed, evaluated and promoted to help individuals with autism function better. Popow et al. reviewed numerous papers on the pharmacotherapy of ASD and concluded that medication therapy may help autistic children and adolescents address behavioural and attentional issues [3]. Pharmacologic treatments could be most effective when used in conjunction with educational and behavioural interventions. As first-line treatments, various behavioral

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interventions have been shown to be beneficial for improving skills and achieving positive life outcomes. However, traditional interventions typically need to be carried out under the supervision of well-trained professionals, which means that many patients have limited access to qualified cures and services due to high costs and a shortage of specialists. In this case, significant progress has been made in creating technologies that will facilitate the implementation of these behavioral programs. Some of these technologies include artificial intelligence-driven wearable systems, robots, and Virtual Reality (VR). Among these technologies discussed and investigated by professionals, VR is considered as a valuable and promising tool for satisfying the psychosocial and educational requirements of ASD sufferers in various contexts.

The fundamental realization of VR technology is based on computer technology, which integrates 3-D graphic design, multi-media equipment, and simulation mechanisms, among other things, to produce a realistic 3-D multi-sensory experience of the virtual world with the help of computers and headsets [4]. With ongoing advances in social productivity, science, and technology, the demands for virtual reality technology in all aspects of life are increasing. VR technology has also evolved strongly, becoming a new branch of science and technology.

Over several decades, a considerable amount of literature has contributed to the efficacy of VR technology in supporting the populations diagnosed with ASD. In 2019, Park et al. summarized empirical evidence from utilizing VR-based clinical therapies for people with psychiatric disorders [5]. This paper primarily aims to briefly explain, from a general aspect, if VR technology can be employed as a potential tool for advancement in the field of clinical psychiatry. It focuses only on a few cases describing the utility of VR in the clinical treatment of numerous typical psychiatric diseases, including autism, for which the description is not extensive. Zhang et al. reviewed some of the current equipment using VR as a tool for the ASD population, mainly focusing on their social communication abilities, emotion recognition and language learning [6]. However, it did not include some literature about the impact of this technology on the daily living skills of autism populations. Many scholars have contributed to reviewing the efficacy of VR in performance training, but only a few focus on the impact of VR on the improvement in both everyday living skills and the cognitive development of people with ASD. Hence, this review aims to summarize the evidence of how VR applications improve skill learning and daily functioning in children and adolescents with ASD.

2. Daily Living Skills

Individuals diagnosed with ASD can often have difficulty in learning and managing everyday tasks because of serious deficits in motor skills and social skills caused by developmental disorders. Therefore, ASD populations need to receive a series of effective and customized training with the support and assistance of their family, caregivers and friends in developing daily living skills so that they can engage in daily life activities and adapt to society independently.

Adjorlu et al. created and tested a virtual reality head-mounted display in 2017 to assist people with autism in developing the skills needed to finish a set of shopping tasks by themselves [7]. A between-group study, involving 9 participants aged 12-15 years, was carried out to test the existence of transfer effects of the skills obtained by adolescents in simulated environments to similar real-life situations. Participants were tested on baseline data first, and then they received a post-treatment measurement after seven sessions of simulated training over ten days, with both assessments taking place in real shopping scenarios. The changes from the comparison between baseline and post-treatment data demonstrated the successful effects of the platform based on VR simulation to train daily living skills. However, the long-term transfer effects of this approach needed to be discovered. Furthermore, the experimental results are not generalizable because of the small sample size.

Similarly, Lamash et al.'s study aimed to investigate the efficacy of a program based on a virtual environment software called Virtual Action Planning Supermarket (VAP-S), to improve the

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implementation of shopping tasks among adolescents with autism [8]. 56 adolescents with ASD aged from 11 to 19 years old were engaged in the trial. Adolescents in the experiment group had to complete shopping tasks within the VAP-S environment, with the meta-cognitive strategies they learned before the experiment, while the control group underwent regular educational programs. The intervention program included an introduction and training on the VAP-S in the first session, and adolescents first learned many techniques and strategies to be familiar with the use of the VAP-S to improve the efficiency of shopping independently in the second through sixth sessions. Then they were instructed to undertake advanced shopping tasks, such as applying techniques to make a shopping list, in the last two sessions. After all these eight sessions, the findings showed that participants in the experiment group did foster their shopping abilities. It is worth noting that the control group also reported very slight improvements.

In addition to the ability to shop independently, driving skills, which provide much convenience in real-life contexts, are also essential for many people. Individuals diagnosed with ASD may have difficulty in learning to drive due to a bunch of problems, including interpreting visual signals, allocating and shifting attention and performing sequential actions. Thus, the creation and development of tailored virtual reality-based driving simulators is required to help special populations participate in driving activities.

In 2019, Bian et al. designed a VR-based driving platform called VR-based Driving Environment Adaptive Response technology (VDEAR) designed for people with ASD [9]. The difficulty of game tasks can be changed immediately depending on the player's game performance and level of engagement in this game. Specifically, the VDEAR system has three main parts, the first part is the driving task; the second part is the real-time difficulty adjustment mechanism for individuals; and the third part is the data collection module during the practice. Following the construction of the platform, the authors also conducted a study with a sample of 23 adolescents to assess the program's effectiveness. Performance improvements of all teenagers in the driving tasks were observed by the collected data. The invention further includes methods for recording data on a participant's driving performance and participation level in order to figure out whether a subject's performance is improved. Unfortunately, in a study with only one session, no significant performance improvement was found. However, this did provide a realistic option for further investigating the impacts of the long-term training sessions on individuals' driving performance and engagement to increase their confidence in driving in the future.

3. Social Interaction Capacities

Participation in social communication and interaction is a fundamental component of a person's development and life experience. Individuals can not only gain more extensive information and experiences about the world through social interaction activities but also can build their own attitudes and ways of interacting with people. At the same time, it is one of the most essential sources for helping people achieve a sense of belonging and connection to their surroundings. Autistic people face numerous obstacles as a result of social ability deficits. Deficits in social skills can cause difficulties in friendships, romantic relationships, daily life, collaborative activities, and career achievement. Therefore, social communication training is crucial for encouraging autistic children and adolescents to participate in their community, and intervention programs should be set up to aid in these domains.

A great deal of academic effort has gone into and validated the growing efficacy of VR technology for relationship building in the autism population. Kandalaft et al. created the Virtual Reality Social Cognition Training (VR-SCT) intervention, which provides young people with a dynamic rehearsal of social scenarios in order to improve their social thinking and interpersonal abilities [10]. The effectiveness of VR-SCT was investigated in a study with 8 individuals, whose findings revealed that

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following ten sessions of VR-SCT therapies, participants' aspirations and performance of social interaction in real life improved dramatically. Assessments of a series of social cognition also revealed that the autistic population could perform better in real social situations after the training of the VR-based program. Three years later, Didehbani et al. extended Kandalaft and colleagues' assessment of the feasibility of VR-SCT, examining a VR-SCT intervention with ten sessions in 30 children (aged 7-16 years) with high-functioning autism [11]. One innovative feature of this study was that each participant was matched with another peer at each sector and was observed for daily social interaction status with the peer while training social skills. This investigation found that social cognition training enhanced emotion perception and social functioning conversation abilities, which was consistent with earlier research. With the successful demonstration of these two studies, Yang and his team members also wanted to find out whether similar behaviors at the level of brain function could be honed under the operation of VR-SCT [12]. Their research, on the one hand, revealed the neurological mechanisms underlying behavioral changes and, on the other hand, investigated the connections between brain alterations and behavioral changes. As a result, it might be considered the first innovative technique to investigate the brain mechanisms of the concurrent response to specific stimulation in individuals with ASD receiving VR-SCT training. The findings demonstrated that such therapies could not only result in significant improvements in social interaction abilities but also contribute to the development of brain processes, which is a strong support for advanced social capacities.

Furthermore, some other applications using VR have proved to be plausible in strengthening the social understanding of autism. For instance, the collaborative virtual environment (CVE)-based social interaction projects have the potential to help information processing in both typical and autistic children. Traditional VR environments tend to just back up one-on-one interactions between a single person and a virtual object, without the complicated and dynamic interaction patterns of multiple people which need more cooperation and adjustment among different situations. The collaborative virtual environment, on the other hand, compensates for traditional environments' weaknesses by providing a shared virtual experience for several players, allowing them to communicate in the form of voice and text and collaborate as much as they want to complete their tasks efficiently. Zhao et al. presented the Hand-in-Hand Communication-Enhancement CVE system, the major purpose of which was to allow several players to engage in interactive games through flexible and concurrent teamwork [13]. Two players need to work together to use the tools and strategies they have learned to complete the required tasks in the three games in the program in a limited amount of time. Then 12 autistic children and 12 typical peers were matched to evaluate the capacity of this system to facilitate team activities. The results showed that, from the subjective perspective, both the children with and without ASD enjoyed the three games offered by this CVE system, and from the objective perspective, significant improvements in children's cooperation abilities were observed.

4. Academic Abilities

Apart from the above challenges in daily living skills and social communication abilities, some ASD populations may also struggle with delayed or deficient language abilities. However, compared to the abundant literature focusing on training projects underlying VR technology in social interaction practice, less emphasis has been dedicated to employing this promising technology for enhancing academic abilities, such as speech skills. Many current studies concentrate on how technology can be used in typical educational contexts to make it more accessible for children with autism to acquire knowledge and skills in traditional classrooms as well, and these issues of interest were primarily about language learning such as vocabulary, spelling and pronunciation.

Baldi, a computer-animate tutor, was designed by Bosseler and Massaro, attempting to facilitate language learning in children with ASD [14]. Two experiments were conducted to evaluate the

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effectiveness of Baldi using the Language Wizard, a computer-based language tutorial program. Specifically, in Experiment 1, children presented a significant vocabulary gaining and recalling in the one-month follow-up measurement, and in Experiment 2, the results indicated that participants could not only absorb vocabulary knowledge but also transfer what they have learned to a real-life context outside the training program. Both experiments demonstrated that children with autism did foster their language learning skills with the help of computer-mediated virtual assistants, implying that this type of support presents the potential to deliver specialized and cost-effective assistance to a broader range of sectors in the future.

The adoption of computer-assisted instruction (CAI) has been studied by several researchers and has been shown to be beneficial for enhancing autistic children's language knowledge learning. With the purpose of filling the gap that little evidence focuses on the assistive applications of CAI in word recognition learning for children and teenagers with special needs. Coleman et al. delivered a small-sample study with a multiple-conditions design to see if CAI would become a plausible equipment to help promote word identification with the employment of the Nonverbal Reading Approach (NRA) [15]. Three students were instructed firstly to learn some knowledge about the NRA, then to familiarize themselves with the CAI under the guidance from both teachers and computers and the final part was only with the CAI. The findings implied that the three participants could obtain target words when using the NRA via the CAI, which means that this technology could be developed further to help students with autism identify and learn words independently without the assistance of teachers.

Chen et al. attached importance to the practice of pronunciation as there were few previous studies investigating the use of VR-based pronunciation tutors targeted at children with ASD [16]. Their research was primarily interested in addressing whether a 3-D guide was more useful than s real human-face instructor for pronunciation training in low-functioning autism. The first eye-tracking experiment, which included 10 low-functioning children with autism and 13 typical children, discovered that most participants paid close attention to the motions of the 3-D tutor. In Experiment 2, both the human face group and the 3D group got better performance, with the 3-D group showing more progress in the production of Mandarin stop consonants and subvowels and sharp vowels. In conclusion, the study's findings imply that a three-dimensional virtual imitation intervention system is a viable alternative to multimedia articulation training for autistic children.

5. Discussion

5.1. Strengths and Limitations

The most significant advantage of VR is that it can provide safe and ideal situations in a virtual environment that might be considered risky in the real world. Additionally, VR increases enjoyment and hence boosts the quality of learning through its flexibility for controlling task difficulty. Besides, with this technology, players can receive immediate feedback, allowing them to practice based on their weaknesses and repeatedly at a level acceptable to them in order to reach the aim of improving a specific ability. Through interaction and content display in higher dimensions, VR technology may help individuals with autism accomplish more natural and easy real-time interactions with virtual objects in simulated scenarios for gaming, socializing, and other everyday activities. Due to these positive characteristics, VR is a practical tool for training and rehabilitation.

Despite these strengths, some limitations of this new technology should also be taken into account. One of the main drawbacks of VR could be the technical quality and accessibility of the equipment. To function effectively and prevent delays, errors, or malfunctions, VR needs powerful technology, such as headsets, controllers, sensors, and processors. These gadgets may not be suitable for everyone and can be costly and bulky. To ensure that VR software is user-friendly, accurate, and ethical, it must also be properly created and tested. Participants may become frustrated, confused, or even suffer

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from VR applications that are poorly designed or deployed. Another limitation is the potential physical side effects that VR users may experience. Due to the imbalance between the visual scenarios and real situations, VR may cause nausea, headaches and dizziness. These symptoms can vary between different individuals, types and lengths of the VR experience and the quality of the VR system. After using VR for a while, some people may also feel disassociated with reality. The user may not be able to function as usual as a result of these impacts.

5.2. Future Directions

Significant achievements have been made in the design and deployment of VR technology during the past years. Researchers are gradually discovering the possibilities of VR technology in assisting skill learning, particularly performance improvements of autistic people in social interaction situations. However, there is still a lot of room for future efforts. Future work can focus on expanding and improving applications, advancing technology, doing research concerning brain mechanisms and developing theoretical models. Meanwhile, the integration of VR applications with clinical research calls for particular attention and investigation. Along with the use of VR in the domain of social and entertainment to train autistic children in skill acquisition, relevant technology can also be used in the future in educational environments and clinical medical care to help atypical populations function well among several settings. Moreover, future directions could take the cross-cultural possibility of VR-based programs into consideration.

6. Conclusions

A brief summary is provided in the current review about some VR-driven applications designed for children and adolescents with ASD. The programs based on VR technology have displayed promise in alleviating autistic developmental issues and boosting skill acquisition and maturation. Most participants involved in these trials showed significant improvement in daily living skills, social communication and academic abilities in the post-treatment and follow-up assessments. Future research efforts can be directed towards addressing existing weaknesses in virtual reality, as well as expanding and enhancing technologies that have been proven to be useful. Future possibilities could also include refining and improving the design of programs that are not developmentally appropriate for the autism community, focusing on application ease accessibility and applicability in various cultural and language situations.

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