Virtual Reality Technologies and Autism Spectrum Disorder

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The worldwide rising trend of autism spectrum disorder (ASD) calls for innovative and efficacious techniques for assessment and treatment. Virtual reality (VR) technology gains theoretical support from rehabilitation and pedagogical theories and offers a variety of capabilities in educational and interventional contexts with affordable products. Applications of VR technologies can yield significant benefits provided that they are grounded in the key characteristics of the ASD population. In addressing the core impairments of ASD, and improving the current condition of autistic individuals, the unique advantages of VR for ASD therapy, and the potential of VR for investigating social interaction, could play a crucial role.

virtual reality | childhood and adolescence | autism spectrum disorder

1. Core Impairments of ASD and Its Increasing Prevalence

An impairment is considered to be core if it distinguishes the autism spectrum disorder (ASD) population from typical-developing (TD) individuals and those with other developmental delays [1]. Abundant research on ASD has identified core impairments in a variety of social aspects, including social communication and interaction, and speech and language [2]. Social communication skills cover a broad range of verbal and nonverbal abilities used in real-life and dynamic social interaction, such as emotion recognition, emotion regulation, and eye-to-eye gaze. The ASD population has difficulty understanding others' emotions through visual and/or auditory cues [3][4], fails to regulate emotions appropriately and effectively [5], engages less in direct eye-to-eye contact [6], and shows atypical viewing patterns in social contexts [7]. Speech and language skills, which are crucial for successful social interaction, are also frequently reported to be impaired in individuals with ASD. They demonstrate prosodic deficits, such as aberrant use of pitch and stress patterns [8][9], and are particularly weak in the pragmatic use of language for communication, such as poor discourse organization and maintenance [10], difficulty in understanding the speaker-listener relationship [11], and inability to conform to conversational rules [12]. It is hypothesized that these pragmatic deficits, together with emotion processing problems, are related to fundamental impairments in the domain of theory of mind [2][13], i.e., the cognitive ability to explain and predict human behaviors in terms of mental states, such as desire, belief, and intention [14][15]. These core impairments in communication and language are found to be universal in children with ASD across ages and ability levels [1][16].

Recent years have witnessed an increasing trend in the prevalence of autism in the US, China, and other countries. Recent data show that one in 59 eight-year-old children in the US is diagnosed with ASD [17]. The newest result revealed a similar prevalence in China, at around 1% [18], and in South Korea, 2.64% (95% CI =

1.91–3.37) [19]. The prevalence in various countries and regions has shown an increasing trend over time in all age groups [20][21][22], which highlights a growing need for resources to provide care for the ASD population. The expenditure on a child with ASD, covering therapies, medical care, and special education programs, is estimated to be approximately $17,000/year more than for a child without ASD [23], imposing a heavy economic burden on the family. The current intervention approaches, although fruitful in improving ASD individuals' life skills, are not always available for families, due to the high costs, and less expensive intervention paths are required to be developed to benefit families with diverse financial capacities.

2. Advantages of Incorporating VR in ASD Research and Therapy

Assistive and augmented technology, such as VR, with the aforementioned theoretical backing and various commercial products, can offer an effective and inexpensive means of practicing social skills and daily functioning both within and outside of therapy. Given the characteristics of ASD, these capabilities are particularly valuable for individuals on the autism spectrum.

Treatment on VR platforms is less stressful and would be less likely to increase anxiety or stress, problematic management of which is common in children and adolescents with ASD [24]. The social deficits associated with ASD can engender feelings of anxiety, especially in higher functioning ASD youths, who are aware of their social disability, and this overwhelming anxiety might, in turn, aggregate their social impairments [25]. For example, social anxiety resulting from unsuccessful attempts at communication and interaction may contribute to ASD individuals' avoidance of social situations and lead to further isolation from their peers [26]. This negative impact of anxiety that tends to accompany real-world social skill practice, and may reduce the effect of social communication intervention, can be minimized through the employment of VR technology, which allows children with ASD to practice their social skills in real-life contexts without fear of mistakes or rejection that they commonly encounter in real-world face-to-face exchanges [27].

VR technology can be combined with gamified approaches to increase the motivation, attention, and focus of participants with ASD. Attention-deficit/hyperactivity disorder (ADHD), characterized by symptoms of inattention and overactivity, is one of the most common comorbid disorders in people with ASD [28]. Different from TD individuals who attend preferentially to social stimuli, such as people, faces, and body movements [29], individuals with ASD show an overall reduced social attention, which becomes more severe when the stimuli have a higher social content [30]. The inattention problem often hinders the process of research or therapy that participants with ASD take part in, leaving the work of researchers and clinicians floundering. This could be resolved through the addition of a gamified VR element to current practice, since the novelty of VR, together with the playability of gamified design, could arouse among many children, as well as adults with ASD, a stronger interest in the tasks they are going to accomplish, increase their investment in the training, and improve generalization [31].

VR gamified design can promote our understanding of the lower-functioning ASD population and the support that they need. A majority of existing studies and training programs have shown promising results. However, they tend to focus on ASD individuals with average or above-average IQ, and exclude those with low-functioning ASD [32]. So further efforts are required to explore and support the ASD population at the lower end of the IQ distribution, which demands more novel and elaborate approaches in experimental and interventional design [4]. Research on lower-functioning individuals can be tricky because the tasks that are manageable for TD participants, or higher-functioning ASD participants, might imply a higher level of difficulty and demand for lower-functioning ones due to their reduced cognitive abilities, which might result in a low task completion rate. This poses great challenges for researchers and clinicians as they are unable to test whether the ability required by the specific task is intact in lower-functioning ASDs and would then hesitate to determine whether such difficulties stem from autism or mental retardation or both [33]. This situation can be ameliorated by the adoption of VR technologies, combined with a gamified design that promotes task completion by offering concrete, fascinating, and enjoyable dynamic stimuli. Previous attempts in using VR games to teach emotions, and in VR music education, have reported the ability of children with low-functioning autism to complete VR game-like intervention [32] and recorded pretty high improvement for them [34], demonstrating that VR platforms can be especially beneficial for low-functioning autism children.

It has been well-documented that VR technology can offer considerable educational benefits for children and adolescents with special needs. A substantial proportion of people suffering from ASD are in childhood or adolescence. According to the fifth edition of the DSM criteria, the age of ASD onset is “early childhood” [35], and the symptoms usually persist through the school ages and are maintained into young adulthood [36], which renders the education of young people with ASD a primary concern and an intractable undertaking. Given the nature and severity of their disability, learners with ASD require carefully-designed individualized planning to obtain educational success, which brings considerable challenges in including students with ASD in general education classrooms [37], and calls for improvement and perfection of the special education system. The educational advantages brought by VR technologies could, therefore, contribute greatly to long-term support for the ASD population and would be illuminating for educators and policymakers working on special education services for children with ASD.

Apart from the above benefits for ASD, VR technologies also show superiority as a tool for research and treatment. For research, VR-based experiments have enhanced ecological validity, which is increasingly valued in the assessment of neuropsychological research, especially in the field of ASD [38]. Ecological validity, defined as the degree to which task performance corresponds to real-world performance [39] or the degree to which task performance predicts problems in real-life settings [40], has been viewed, to some extent, to conflict with the maintaining of experimental control [41]. Researchers supporting naturalistic approaches hold that many psychological assessments that use simple and static stimuli are ecologically invalid and are unable to generalize beyond restricted laboratory settings [42], while those emphasizing precise laboratory-based control argue that the ecological research approach lacks experimental control and the internal validity that are needed for scientific progress [43]. The tension between experimental control and ecological validity could be alleviated through the integration of VR, which allows precise presentation and control of dynamic perceptual stimuli in ecologically valid scenarios, thus increasing the generalizability of the findings whilst maintaining the same level of control as laboratory-based experiments.

Intervention programs employing VR techniques allow repeated practice and exposure, which is a key element in treatment [44]. In interventions such as social communication training, it is rare that participants successfully acquire the social interaction skill after practicing it only once. Compared with other therapeutic tools that might instruct participants to learn and respond in a rote manner, VR interventions provide the opportunity for repeated practice in dynamic social exchanges [45] and help participants learn by experiencing instead of memorizing. Additionally, on VR platforms, tasks and stimuli can be presented repeatedly and consistently without fatigue [46], avoiding the problem that usually accompanies task repetition by human tutors/instructors [47].

3. Potentials of VR for Investigating Social Interaction

Among possible applications, the one that receives particular attention from ASD researchers and therapists is the VR-based investigation of social communication and interaction, where ASD individuals tend to be especially impaired. VR offers great potential for social communication research and intervention as it can provide customized authentic scenarios and interlocutors, which are essential in real-life social communication, as well as the sense of being present at the scene of communication.

The social scenarios and contexts replicated in virtual environments (VEs) can be carefully designed and controlled at the will of researchers and therapists to create whatever type of environment they want. For various research purposes, features of the real world can either be omitted, enhanced, or diminished, social relationships can be emphasized or modified, and the qualities and quantities of surrounding objects can be highlighted or weakened, increased or reduced [48]. The possible social scenarios that can be created through VR are arguably unlimited [49], including social introductions, initiating conversation, meeting strangers/friends, negotiating with a salesman, job interviews, working with co-workers, and managing conflict [44].

Virtual humanoid representations of people involved in the social scenarios, referred to as “avatars”, can be designed to serve as communicators, which carry out social communication with the user and give him or her hints on the communicational rules, and, as facilitators, which offer the user positive reinforcement upon his or her successful attempt to communicate or encourage further practice when the user makes mistakes [50]. The avatars can also be manipulated according to the requirements of researchers and clinicians; for example, the clinician’s voice can be morphed by software to sound like a young boy in order to match the avatar’s demographics [44]. Moreover, with the aid of artificial intelligence (AI), completely virtual characters can be created without the need for a therapist.

The sense of being present, which is positively correlated with the level of immersion [51], also contributes greatly to the potential of using VR for the investigation of social communication and interaction. Practical application is indispensable for the training of social communication skills, with the benefits of intervention, which are usually reduced when exposure to real-world social interactions is absent or inadequate [52]. Individuals with autism have reported a desire for more real-world practice after learning social communication skills in clinical intervention because they sometimes find it difficult to understand a social phenomenon until they see or experience it in a real-world setting [52]. Practicing a learned skill in a real-world context, and being successful in that situation, would also build confidence in people with ASD and help reduce their social anxiety [52]. Modern VR technologies and products, including surround-screen projection-based displays, like the CAVE, and HMDs, like Oculus Rift, with multisensory (e.g., visual, auditory, and tactile) congruent cues in the VEs, further enhance the sense of presence [51], and enable a fairly high level of immersion, rendering them viable tools for study and training of social communication skills.

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