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Neurocognitive training through VR and develop of Executive Functions in ASD

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Abstract

In this study we will focus on the transformative potential of neurocognitive training, particularly in the context of immersive virtual reality (VR), to promote the development of executive functions in people with ASD. This exploration will navigate current research findings by highlighting the innovative ways in which neurocognitive training, in combination with virtual reality technology, offers tailored interventions to address the unique challenges associated with executive function deficits in the population of individuals with ASD.

Keywords: ASD; Virtual reality; Executive functions; Neurocognitive training; Self Control

1. Introduction

Autism Spectrum Disorder (ASD) is characterized by a diverse range of neurodevelopmental challenges, among which deficits in executive functions stand out prominently. Executive functions, encompassing cognitive processes such as working memory, cognitive flexibility, and inhibitory control, play a fundamental role in daily functioning, learning, and social interactions. Individuals with ASD often grapple with executive function impairments, hindering their ability to navigate the complexities of everyday life (Sideraki & Drigas, 2023).

In recent years, the intersection of neurocognitive training and virtual reality (VR) technology has emerged as a promising avenue for addressing executive function deficits in individuals with ASD. This study seeks to delve into the transformative potential of neurocognitive training, with a specific focus on the immersive capabilities of virtual reality, to create tailored interventions that cater to the unique needs of individuals on the autism spectrum (Sideraki & Drigas, 2023).

Neurocognitive training, characterized by targeted exercises to enhance cognitive abilities, has shown promise in ameliorating executive function challenges in various populations. When coupled with the immersive and interactive nature of virtual reality, these interventions gain a new dimension. Virtual reality provides a simulated environment that mirrors real-world scenarios, allowing individuals with ASD to engage in activities that directly challenge and enhance their executive functions in a controlled yet realistic setting (Drigas, Mitsea, Skiannis, 2021).

This exploration aims to synthesize current research findings, shedding light on how the amalgamation of neurocognitive training and virtual reality offers a novel approach to address executive function deficits in ASD. By immersing individuals in tailored virtual experiences, this intervention has the potential to bridge the gap between abstract cognitive skills and practical application in daily life. The interactive and adaptive nature of virtual reality interventions may provide a more engaging and personalized method to enhance executive functions compared to traditional approaches (Drigas & Mitsea, 2021).

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As we navigate through the existing literature, we will unveil innovative methodologies and interventions that harness the power of neurocognitive training within immersive virtual environments. By emphasizing the transformative potential of this combined approach, we seek to contribute to the ongoing dialogue surrounding effective interventions for individuals with ASD. Ultimately, the integration of neurocognitive training and virtual reality holds promise in shaping more inclusive and impactful strategies to support the development of executive functions in the autism community.

Cncluding this indroduction, we stress the importance of all digital technologies in the field of education that have impact in brain and executing functions training. These technologies are highly effective and productive, facilitate and improve assessment, intervention, and educational procedures through mobile devices that bring educational activities anywhere [44-46], various ICTs applications that are the main supporters of education [47-52], and AI, STEM, Games and ROBOTICS [53-58] that raise educational procedures to new performance levs. Furthermore, the development and integration of ICTs with theories and models of metacognition, mindfulness, meditation, and the development of emotional intelligence [59-70], accelerates and improves educational practices and results even more, particularly children with ASD, treating domain and its practices like assessment and intervention.

2. Neurocognitive training and executive functions

Our understanding of the neural basis of executive functions in people with ASD is still evolving; several studies suggest that specific brain regions and neural circuits are involved in these processes. Interventions aimed at developing executive functions in people with ASD often include neurocognitive training often based on computer and artificial intelligence systems and behavioural interventions. Neurocognitive training has been combined with behavioural intervention and may aim to enhance neural connectivity and activation in areas related to executive functions. Computer-based cognitive training programmes have been used to improve working memory, cognitive flexibility and impulse control in people with ASD (Fishman, 2014).

The prefrontal cortex, particularly the dorsolateral prefrontal cortex (DLPFC), is crucial for the development of executive functions. Activation has been found in the PFC in individuals with DLPF during tasks involving working memory and cognitive flexibility (Just, Keller, Malave, Kana, & Varma, 2012). In addition, the anterior cingulate cortex ACC is associated with error monitoring and inhibitory control, and activation and connectivity of the ACC has been documented in individuals with ASD during tasks involving cognitive flexibility and impulse control (Shafritz, Dichter, Baranek, & Belger, 2008). Still, the basal ganglia play a role in motor control and cognitive functions. Basal ganglia dysfunction has been implicated in the repetitive stereotypic behaviors often observed in individuals with ASD (Langen, Durston, Kas, van Engeland, & Staal, 2011).

3. Cognitive flexibility and neurocognitive training

While deficits in executive functions, including impaired cognitive flexibility, are common in people with ASD, understanding the underlying neural mechanisms and developing effective interventions is complex, Neuroimaging studies have shed light on specific brain regions involved in executive functions and interventions have been designed to stimulate neurological activity in these areas, focusing particularly on cognitive flexibility (Kenworthy et al., 2014).

Neurocognitive training programmes, often computer-based, aim to stimulate neural activity in the prefrontal cortex which is a regulatory centre of mental emotions and determines an individual's responses and critical faculties (Richard & Snell, 1995). These interventions target working memory and attention, which are integral components of cognitive flexibility (Fishman, 2014). Such programs may induce neuroplasticity to enhance executive functions. In addition, behavioral interventions including neurocognitive training stimulate the ACC and other related brain regions by providing structured activities that require flexible thinking. These interventions aim to remodel neural networks associated with cognitive flexibility (Kenworthy et al., 2014).

4. Impulse control and neurocognitive training

The neural underpinnings of executive functions, and in particular impulse control with ASD, are investigated by activating specific brain regions and neurological stimulation during interventions designed to enhance impulse control and combined with computer-embedded interventions (Delmonte et al., 2012).

The prefrontal cortex, in particular the ventrolateral prefrontal cortex (VLPFC), is involved in impulse control. Altered activation patterns have been documented in the PFC in people with ASD during tasks requiring inhibitory control

(D'Cruz et al., 2016). This suggests a neural basis for deficits in impulse control in ASD. Furthermore, the islet of Reil is a cortical region involved in intuition and emotion processing, directly related to impulse control (Richard & Snell, 1995). It has been found that individuals with ASD may exhibit atypical activation in the islet during tasks requiring impulse control which highlights the role of the islet in the regulation of impulsive behaviours (Uddin et al., 2017).

Still, the striatum, part of the basal ganglia, is involved in reward processing and motor control. Dysfunction in the striatum involved in the basal ganglia may contribute to difficulties in inhibiting impulsive responses in people with ASD (Delmonte et al., 2012).

To develop impulse control, cognitive-behavioural interventions aim to stimulate neural activity in the prefrontal cortex. These interventions often include teaching strategies for self-regulation and impulse control through cognitive restructuring and behavioral analysis (Sofronoff et al., 2005). In addition, social skills training interventions focus on enhancing the ability to navigate social situations, which may include impulse control. By targeting areas such as the insula, these interventions aim to improve emotional regulation and reduce impulsive behaviors in social contexts (White, Keonig, & Scahill, 2007). Neurofeedback interventions have also been observed to include real-time monitoring of brain activity, allowing individuals to learn to regulate their neural responses. This approach has been applied to enhance self-control and reduce impulsivity in various populations, including individuals with ASD (Coben et al., 2014).

5. Problem solving and neurocognitive training

Intervention aimed at problem solving in people with ASD involves neurological stimulation of specific brain regions that occurs during interventions aimed at developing executive functions and initially involves the prefrontal cortex. More specifically, it includes the dorsolateral prefrontal cortex (DLPFC), where it is a key area for problem solving and cognitive functions (Richard & Snell, 1995). Individuals with DAP often exhibit atypical patterns of activation in the PFC during problem solving tasks (Gilbert et al, 2008; Kana et al., 2014). Subsequently, the temporal lobes, including the medial temporal lobe, are involved in memory processes that contribute to effective problem solving. Strong connectivity and activation has been observed in temporal regions in people with ASD during problem-solving tasks (Ameis et al., 2016). The default mode network (DMN) is involved in self-referential thinking and introspection, it also plays a role in problem solving. Individuals with ASD exhibit impaired DMN connectivity, affecting their ability to engage in effective problem-solving strategies (Padmanabhan et al., 2017).

Cognitive training programmes target the prefrontal cortex to enhance problem-solving skills. These programs often focus on improving working memory, cognitive flexibility, and planning skills, which are key components of effective problem solving (Eack et al., 2013). Still, ABA interventions often include strategies to enhance problem-solving skills by breaking complex tasks into smaller steps. Behavioural interventions aim to stimulate adaptive problem-solving behaviours through reinforcement and modelling (Smith, 2001). In addition, social skills training interventions can indirectly improve problem-solving skills through enhancing interpersonal skills and understanding of social cues. By targeting areas such as the prefrontal cortex, these interventions aim to improve the adaptive application of problem-solving skills in social contexts (Lerner et al., 2011).

The considerable heterogeneity in the ASD population creates challenges in developing interventions that respond to individual needs. Tailoring approaches based on each individual's specific cognitive profile can enhance the effectiveness of interventions (Lord et al., 2018). Long-term studies are needed to evaluate the lasting effects of interventions on neural plasticity and functional outcomes. Understanding whether improvements in problem-solving abilities generalize to real-world conditions is crucial for evaluating intervention success (Dawson et al., 2010).

6. Working memory and neurocognitive training

Working memory, a critical component of cognitive function, plays a pivotal role in various aspects of learning, problem-solving, and decision-making. It involves the temporary storage and manipulation of information necessary for complex cognitive tasks. As our understanding of working memory has evolved, educators and researchers have increasingly recognized its significance in shaping the learning experience. This comprehensive overview delves into the relationship between working memory and neurocognitive education, examining the implications for instructional design, interventions, and the optimization of learning outcomes.

The link between working memory and educational achievement has been extensively explored. Working memory capacity is closely associated with academic performance, particularly in areas such as mathematics, reading comprehension, and problem-solving (Alloway & Alloway, 2010). Individuals with stronger working memory capabilities tend to demonstrate more efficient learning and a heightened ability to transfer knowledge across various domains (Gathercole & Alloway, 2008).

Neurocognitive education interventions have emerged as a promising avenue for enhancing working memory and overall cognitive function. These interventions leverage insights from cognitive neuroscience to develop targeted strategies that promote neuroplasticity and cognitive growth (Klingberg et al., 2005). One prominent approach involves computerized cognitive training programs designed to specifically target working memory processes (Holmes et al., 2009). These programs often utilize adaptive tasks that challenge and progressively enhance working memory capacity.

Research has demonstrated the effectiveness of neurocognitive interventions in improving working memory and associated cognitive skills. For instance, a study by Holmes et al. (2009) reported positive outcomes in working memory and mathematical abilities following computerized training in children. The adaptive nature of these interventions allows for personalized and dynamic adjustments, catering to individual differences in working memory capacity (Klingberg, 2010).

However, it is essential to consider the nuanced nature of working memory and the need for a holistic educational approach. While targeted interventions can yield positive results, the transferability of improved working memory to real-world academic tasks requires careful consideration (Shipstead et al., 2012). Integrating working memory training within a broader neurocognitive framework that addresses executive functions and metacognition may enhance the applicability of these interventions to diverse educational contexts.

In conclusion, understanding the intricate relationship between working memory and neurocognitive education holds significant implications for educational practices. Incorporating targeted interventions that leverage neuroscientific insights can contribute to the development of cognitive skills crucial for academic success. As research in this field continues to advance, educators have the opportunity to refine instructional strategies, ultimately fostering an enriched learning environment that nurtures cognitive growth and achievement.

7. Neurocognitive training and Virtual Reality

In recent years, the integration of virtual reality (VR) technology in neurocognitive training has emerged as a pioneering approach, revolutionizing cognitive remediation strategies (Sideraki & Drigas, 2023). This innovative method holds great promise for individuals facing various neurodevelopmental challenges, such as ASD; virtual reality, with its ability to create immersive environments, provides a unique platform for targeted neurocognitive interventions. Chen and colleagues (2016) demonstrated the effectiveness of virtual reality in enhancing executive functions, including working memory and cognitive flexibility, in individuals with ASD. The immersive nature of VR allows for the creation of customized scenarios to systematically train and improve specific cognitive skills that are vital for daily functioning.

For people with ASD, virtual reality-based interventions offer a safe and controlled space to practice social interactions and adaptive behaviours. Leung et al. (2015) highlighted the importance of flexibility, impulse control and emotional regulation in social adaptation, highlighting the ability of virtual reality to simulate real-life situations and facilitate skill acquisition. This not only helps address key deficits, but also enhances overall social adaptability.

The impact of deficits in executive functions extends beyond cognitive aspects, affecting various aspects of individuals' lives. Virtual reality interventions, as proposed by de Vries and Geurts (2015), Freeman et al. (2017) and Kouklari et al. (2018), have the potential to improve quality of life and social adaptability by providing a dynamic and interactive platform for learning and skill development.

One of the strengths of virtual reality-based neurocognitive training lies in its ability to provide personalised interventions. This is in line with the understanding that executive function deficits, although prevalent in various neurodevelopmental disorders, present unique profiles. Comparative studies (Kefler et al., 2018; Sinzig et al., 2008) highlight the importance of individualized assessments and VR technology allows for the tailoring of educational programs based on individual needs.

Attention difficulties are common in individuals with ASD (Garon et al., 2008), adding complexity to the assessment and intervention process. VR, by providing a controlled and engaging environment, has the potential to capture and sustain attention, as suggested by Bertollo et al. (2019). The interactive nature of virtual reality scenarios can mitigate attentional challenges, enhancing the effectiveness of neurocognitive training.

As the field of virtual reality-based neurocognitive training continues to evolve, ongoing research is vital to explore its full potential and address potential challenges. Holmes (2009) and Coyne and Rood (2011) highlight the importance of ongoing exploration of executive function training in diverse populations and the need for longitudinal studies to evaluate the ongoing impact of VR interventions.

The study of Lindgren, Tscholl, Wang, and Johnson (2016) explored the impact of embodied interaction within a mixed reality simulation on learning and engagement. The study aimed to investigate how incorporating physical movements and interactions in a simulated environment could enhance the educational experience (Lindgren, et al., 2016).

The research employed a mixed-methods approach, utilizing a mixed reality simulation platform. Participants engaged in a learning task within the mixed reality environment, combining virtual elements with the physical world. The researchers collected quantitative data on learning outcomes and engagement levels. Additionally, qualitative data, such as participant observations and feedback, were gathered to provide a comprehensive understanding of the impact of embodied interaction on the learning process (Lindgren, et al., 2016).

The findings, as reported in Computers & Education, demonstrated that incorporating embodied interaction in a mixed reality simulation positively influenced learning outcomes and engagement. Participants who experienced the mixed reality environment exhibited increased understanding of the educational content and demonstrated higher levels of engagement compared to traditional learning methods. The combination of physical actions and virtual elements created an immersive and interactive learning experience, contributing to enhanced educational outcomes (Lindgren, et al., 2016).

The researchers highlighted the significance of integrating embodied interaction within educational simulations. They emphasized that by allowing learners to physically interact with the content, a more engaging and effective learning experience could be created. The study suggested that leveraging mixed reality technologies could have transformative effects on education by bridging the gap between abstract concepts and tangible experiences (Lindgren, et al., 2016).

Moreover, the study conducted by Bekele, Crittendon, Swanson, Sarkar, and Warren (2014), focused on the pilot clinical application of an adaptive robotic system for young children with autism. The primary aim was to investigate the potential of using a robotic intervention as a therapeutic tool for children diagnosed with autism. The researchers explored the impact of this adaptive robotic system on various aspects of social interaction and engagement among young children with autism (Bekele, et al., 2014).

The study employed a pilot clinical design to assess the feasibility and preliminary outcomes of using an adaptive robotic system in the context of autism intervention. The participants included young children diagnosed with autism spectrum disorder. The researchers implemented the adaptive robotic system in structured therapeutic sessions, closely monitoring the children's responses and interactions. The method involved systematic observation, qualitative analysis, and standardized assessments to evaluate changes in social behaviors and engagement (Bekele, et al., 2014).

The findings of the study, as reported in the Autism journal, indicated promising outcomes regarding the use of the adaptive robotic system for children with autism. The researchers observed improvements in social engagement, communication, and interaction skills among the participants. The adaptive nature of the robotic system appeared to cater to the individual needs of children with autism, fostering a positive and responsive environment for social interactions (Bekele, et al., 2014).

The study of Kenworthy, Yerys, Anthony, and Wallace (2008) conducted a study to investigate executive control in individuals with Autism Spectrum Disorders (ASD), both in laboratory settings and real-world situations. The researchers employed a combination of neuropsychological assessments, behavioral observations, and real-world functional assessments to comprehensively evaluate executive functions in individuals with ASD.

The study, published in Neuropsychology Review, revealed nuanced insights into executive control deficits in individuals with ASD. While laboratory assessments identified specific cognitive challenges related to executive functions, real-world assessments provided a more ecological perspective, showing how these deficits manifest in everyday activities. The findings suggested that executive control difficulties observed in the lab may have meaningful implications for individuals with ASD in navigating real-world scenarios (Kenworthy, et al., 2008).

In the systematic review of Drigas et al., (2023), the researchers aimed to assess the effectiveness of Virtual Reality Games (VRGs) in training meta-skills for individuals with Special Educational Needs and Disabilities (SEND). The study adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

The inclusion criteria encompassed experimental studies published after 2010, focusing on the combination of gaming with virtual reality for individuals with SEND. The selected studies were required to evaluate skills related to metacognition, emotional intelligence, and self-motivated behaviors. The research team utilized digital databases (Scopus, Science Direct, PubMed, Google Scholar) for literature search, employing keywords such as "Virtual Reality Games," "Special Education Needs and Disabilities," and "Metacognitive Skills."

Following the initial search, 1100 studies were identified, with 250 progressing to full-text screening. The researchers applied rigorous inclusion and exclusion criteria, resulting in the final inclusion of 26 studies for analysis. To assess the quality of the selected studies, the Cochrane Collaboration's Risk of Bias version 2 (ROB-2) tool was employed for randomized studies, and the Risk of Bias in Non-randomized Studies of Interventions (ROBINS-I) tool for non-randomized studies.

The systematic review revealed promising insights into the potential effectiveness of VRGs in training meta-skills for individuals with SEND. The selected studies, which incorporated VRGs as training interventions, demonstrated positive outcomes in enhancing metacognitive, socio-emotional, and motivational attributes. However, it was noted that the research landscape still lacks comprehensive knowledge about the efficacy of VRGs in populations with disabilities and learning difficulties. The analysis considered various aspects, including VRG designs, equipment, game genres, participant characteristics, duration of sessions, and main findings. The studies indicated that VR technologies, especially in the form of immersive VR environments, can provide a safe, controlled, and motivating training environment for individuals with SEND. Additionally, the use of VRGs showed promise in developing skills such as self-regulation, adaptation, emotional awareness, and social interaction.

In conclusions, this systematic review synthesized findings from 26 selected studies to investigate the effectiveness of VRGs in training meta-skills for individuals with SEND. The analysis highlighted the potential of VR technologies, particularly immersive VR environments, in addressing skill deficits related to metacognition, emotional intelligence, and self-motivation. The positive outcomes observed in the reviewed studies suggest that VRGs can offer a promising avenue for skill development among populations with special training needs. The researchers emphasized the need for further investigation to enhance understanding and optimize the use of VRGs in populations with disabilities and learning difficulties. The study contributes valuable insights to the growing body of literature on the intersection of virtual reality, gaming, and special education, paving the way for future research and interventions aimed at promoting social inclusion and skill acquisition for individuals with SEND.

8. Discussion

In conclusion, the fusion of neurocognitive training with virtual reality represents a paradigm shift in cognitive rehabilitation. The immersive and interactive nature of virtual reality not only addresses deficits in executive function, but also provides a flexible platform for personalized interventions, making it a promising avenue for improving the lives of individuals with neurodevelopmental challenges.

In addition, the incorporating adaptive robotic systems in interventions for young children with autism holds promise, paving the way for further research and development in the use of technology to enhance social and communication skills in individuals with autism spectrum disorder (Bekele, et al., 2014).

The study contributes valuable insights into the potential of embodied-interaction mental reality simulations as a powerful tool for educational improvement, highlighting the importance of multisensory experiences in the learning process. This research lays the foundation for further exploration of innovative approaches to education that leverage technology to create immersive and effective learning environments. The importance of bridging the gap between laboratory assessments and real-world function when investigating executive control in individuals with ASD is highlighted. Using a multifaceted approach, there is a need to understand how executive function deficits affect individuals both in controlled environments and in their daily lives.

9. Materials and Methods

MethodsThis study will undertake a comprehensive review of existing literature to explore the transformative potential of neurocognitive training, particularly when combined with immersive virtual reality (VR) technology, in promoting the development of executive functions among individuals with Autism Spectrum Disorder (ASD). The methodology will involve systematic identification, selection, and synthesis of relevant research articles, reviews, and studies pertaining to the intersection of neurocognitive training, virtual reality, and executive functions in ASD populations.A structured search strategy will be employed to identify relevant literature from electronic databases such as PubMed, PsycINFO, Web of Science, and Google Scholar. Keywords including "Autism Spectrum Disorder," "ASD," "Virtual Reality," "Executive Functions," and variations thereof will be used in combination with Boolean operators to ensure comprehensive coverage of relevant studies.

Studies included in the review will meet the following criteria: (1) focus on neurocognitive training interventions or virtual reality interventions targeting executive functions, (2) involve participants diagnosed with Autism Spectrum Disorder, (3) report outcomes related to executive function development or improvement, (4) written in English, and (5) published in peer-reviewed journals or scholarly sources. Studies will be excluded if they do not meet the aforementioned inclusion criteria, are duplicates, or are not available in full-text format. Additionally, studies focusing solely on non-ASD populations or unrelated interventions will be excluded.Two independent reviewers will screen titles and abstracts of identified studies based on the inclusion and exclusion criteria. Full-text articles of potentially relevant studies will then be retrieved and assessed for eligibility. Any discrepancies will be resolved through consensus or consultation with a third reviewer.

Data Extraction: Relevant data from selected studies will be extracted using a standardized data extraction form. Key information to be extracted includes study design, participant characteristics, intervention details, outcome measures, and main findings related to executive function development in individuals with ASD.

- Computer with internet access for literature search and retrieval.
- Reference management software (e.g., EndNote, Zotero) for organizing and managing citations.
- Standardized data extraction form for systematic data collection.
- Reporting guidelines (e.g., PRISMA) for systematic reviews to ensure transparency and rigor in reporting findings.

10. Results and Discussion

The results of this study revealed significant insights into the transformative potential of neurocognitive training through virtual reality (VR) in promoting the development of executive functions among individuals with Autism Spectrum Disorder (ASD). Through a comprehensive review of existing literature, several key findings emerged:

10.1. Neurocognitive Training and Executive Functions in ASD

Neurocognitive training interventions, particularly those targeting executive functions, have shown promise in addressing cognitive challenges in individuals with ASD. These interventions often focus on enhancing working memory, cognitive flexibility, impulse control, problem-solving, and attention.Studies have highlighted the involvement of specific brain regions, including the prefrontal cortex (PFC), anterior cingulate cortex (ACC), basal ganglia, and islet of Reil, in executive function processes. Dysfunction in these regions has been associated with executive function deficits observed in ASD.Neurocognitive training programs aim to stimulate neural activity in these regions, promoting neuroplasticity and enhancing executive function abilities.

10.2. Virtual Reality and Executive Function Development

The integration of virtual reality technology into neurocognitive training interventions has emerged as a promising approach to address executive function deficits in ASD.

Virtual reality offers immersive and interactive environments that simulate real-world scenarios, providing individuals with ASD opportunities to practice and improve executive function skills in a controlled yet realistic setting.Studies have demonstrated the effectiveness of virtual reality-based interventions in enhancing executive functions, including working memory, cognitive flexibility, impulse control, and problem-solving, among individuals with ASD.

10.3. Tailored Interventions and Personalized Approaches

Virtual reality-based neurocognitive training allows for personalized interventions tailored to individual cognitive profiles and needs. This personalized approach enhances the effectiveness of interventions by addressing specific executive function deficits in each individual.The interactive nature of virtual reality environments engages individuals with ASD and sustains attention, mitigating attentional challenges commonly observed in this population.Adaptive robotic systems and mixed reality simulations have also shown promise in providing tailored interventions for individuals with ASD, fostering social interaction, communication, and engagement.

10.4. Educational Implications

The incorporation of virtual reality and embodied interaction simulations into educational settings holds promise for enhancing learning experiences and promoting cognitive growth among individuals with ASD.Virtual reality-based educational interventions can bridge the gap between abstract concepts and tangible experiences, providing immersive and effective learning environments.Leveraging mixed reality technologies and adaptive robotic systems can enrich educational practices, fostering social inclusion and skill acquisition for individuals with ASD.

10.5. Future Directions and Research Opportunities

Future research should explore the long-term effects and generalizability of virtual reality-based neurocognitive training interventions in individuals with ASD Longitudinal studies are needed to evaluate the lasting impact of interventions on neural plasticity, functional outcomes, and real-world adaptation Further investigation into the efficacy of virtual reality-based interventions in diverse populations with neurodevelopmental disorders and learning difficulties is warranted.

11. Conclusions

The findings of this study underscore the transformative potential of integrating neurocognitive training with virtual reality technology to address executive function deficits in individuals with ASD. By leveraging immersive and interactive environments, virtual reality-based interventions offer tailored and personalized approaches to enhance executive function skills, including working memory, cognitive flexibility, impulse control, and problem-solving.The interactive nature of virtual reality environments engages individuals with ASD in meaningful ways, providing opportunities for practice and skill development in a safe and controlled setting. Moreover, the incorporation of adaptive robotic systems and mixed reality simulations further enriches educational practices, fostering social interaction, communication, and engagement among individuals with ASD.While the findings highlight the promising outcomes of virtual reality-based interventions, several avenues for future research and development are identified. Longitudinal studies are needed to evaluate the sustained impact of interventions on neural plasticity and functional outcomes over time. Additionally, further exploration into the efficacy of virtual reality-based interventions in diverse populations with neurodevelopmental disorders and learning difficulties can inform the development of inclusive and impactful strategies.

In conclusion, the integration of neurocognitive training with virtual reality technology represents a paradigm shift in cognitive rehabilitation for individuals with ASD. By providing tailored and personalized interventions, virtual reality-based approaches hold promise for promoting the development of executive functions and enhancing overall quality of life for individuals with ASD. Continued research and innovation in this area are essential to maximize the potential benefits of virtual reality-based interventions and advance the field of neurodevelopmental interventions.

Compliance with ethical standards

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Disclosure of conflict of interest

The Authors proclaim no conflict of interest.

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