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Virtual Reality Applications in Children with Down Syndrome: A Traditional Review

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ABSTRACT:
Down syndrome is a genetic disorder caused by trisomy of the 21st chromosome. Children with down syndrome may have balance and coordination disorders, abnormal movement patterns, decreased muscle tone and delays in motor development compared to typically developing peers. Various rehabilitation methods such as sensory integration, neurodevelopmental therapy and vestibular stimulation are used to treat these motor skill problems. However, one of the most important difficulties in the rehabilitation process is the lack of motivation, which negatively affects the process.
In recent years, virtual reality-based rehabilitation approaches have been increasingly used to increase children's participation and make therapy more engaging. Their interactive and game-based structure strengthens intrinsic motivation in children, makes the process of achieving therapeutic goals more enjoyable, and supports long-term engagement. The literature has shown that virtual reality applications have positive effects on numerous parameters, such as muscle strength, range of motion, coordination, attention span, problem-solving skills, and motor control. Furthermore, virtual reality applications simulate daily tasks, enabling high-repetition functional movements, thus contributing to the motor learning process. The app's usability in the home environment provides a significant advantage in maintaining therapy continuity. All these features of virtual reality offer a potential contribution to the participation and development of children with down syndrome in therapy.
However, although the use of virtual reality technology has been proposed during the therapeutic management of children with down syndrome, studies have generally focused on other neurological disorders such as autism spectrum disorder, attention deficit and hyperactivity disorder, and cerebral palsy. In this review study, the aims of using virtual reality therapies in children with down syndrome were discussed and their effects on gross motor functions such as balance, coordination, speed, agility as well as fine motor functions based on upper extremity skills were evaluated.
Keywords: *Down syndrome; virtual reality; augmented reality; motor skills*

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INTRODUCTION

Down syndrome (DS) is a genetic condition caused by chromosomal abnormalities and occurs in approximately 1 in 700 to 1 in 1,000 live births. This condition is one of the most common genetic causes of intellectual disability (Oster-Granite et al., 2011). Cytogenetically, it is divided into three main groups: trisomy 21, translocation, and mosaic type (Bull, 2020). Trisomy 21 is the most common type, seen in approximately 95% of individuals with DS. It occurs due to an error in cell division known as nondisjunction during meiosis I. Translocation accounts for 5% of affected individuals. Mosaic type DS is the least common type, occurring in ~2% of all individuals with DS (Antonarakis, 1998; Morris et al., 2012). As a result of a chromosomal abnormality, neurodevelopmental delays are often accompanied by vision and hearing problems, cognitive problems, obesity, heart and respiratory system problems (Pikora et al., 2014). Children with DS have impaired

balance and coordination, abnormal movement patterns, decreased muscle tone and delayed motor development compared to typically developing children (Lauteslager, 2004). Decreased postural tone, inadequate postural reaction, joint hypermobility and sensory problems play an important role in delayed motor development (das Neves Cardoso et al., 2015). In addition, these problems may cause delay in mental, emotional and social development (Wang et al., 1995). For this reason, as soon as DS is diagnosed, a comprehensive evaluation process should be initiated in all developmental areas, appropriate intervention methods should be determined and lifelong rehabilitation processes should be followed (Määttä et al., 2011). Exercise and traditional rehabilitation interventions have been shown to aid motor skill development in children and adults with DS, and even improve the quality of motor responses after intervention (SILVA & Ferreira, 2001). Motor coordination is considered the interaction of the musculoskeletal, nervous, and sensory systems to produce accurate and balanced dynamic movements (Balaban et al., 2009). The higher the level of coordination complexity of a particular motor skill, the higher the level of coordination required for effective performance (Gallahue et al., 2013; Kiphard, 1974).

Children with DS are more dependent on feedback on motor responses than their typically developing peers. They often take longer to perform the movement because they need more time to process the feedback (Martins et al., 2013). In a study, it was reported that individuals with DS had low movement speed and slow reaction times (Sacks & Buckley, 2003). It has been observed that reaction time and movement speed can be improved with regular training. Sensory integration, neurodevelopmental therapy and vestibular stimulation are some effective rehabilitation methods for treating problems in gross and fine motor skills in children with DS (Uyanik et al., 2003). Nevertheless, one of the most significant challenges in the DS rehabilitation process is the lack of motivation, which negatively impacts the rehabilitation process. Virtual Reality-based (VR-based) therapy is one of the most promising developments in rehabilitation technology that can be used clinically to improve strength, range of motion, coordination, attention span, problem solving, decision making, balance and postüre (Snider et al., 2010). VR-based rehabilitation applications have been proven to be effective in increasing children's motivation and self-efficacy (Reid, 2002). VR systems integrate computer software and hardware into a user-computer interface, promoting multi-sensory stimulation and user interaction, thereby creating real-time simulations (Perez-Marcos, 2018). It also provides sensory-motor training by providing feedback about the body and activating the motor and perceptual areas of the brain (Adamovich et al., 2009). VR systems allow the user to practice high-quality movements and high repetitions by simulating a real-life task. In order to achieve motor learning, VR systems can help target functional movements of the whole body or a single extremity. The implementation of these activities is promising as they may increase the child's motivation during therapy and can be used as part of the child's home therapy programs (Ghafar & Abdelraouf, 2017). Although VR technology has been recommended for educational and rehabilitative purposes for children with DS, most existing studies have investigated its application for children with neurodevelopmental disorders such as cerebral palsy, autism spectrum disorder and attention deficit hyperactivity disorder (Pinar-Lara, 2024). Research specifically examining the utilization of VR for the rehabilitation of children with DS remains scarce in the current literature. In this review, the purposes of using VR therapies in children with DS were reviewed. The effects of VR on fine motor function based on gross motor function and upper extremity skills such as balance, coordination, speed, agility in children with DS were described.

Virtual Reality Applications for Gross Motor Function in Children with Down Syndrome

Motor control and balance problems are common physical disorders in individuals with DS. One of the main contributing factors is muscle hypotonia, and the inadequate strengthening of muscles negatively affects both motor control and balance. This decrease in muscle tone causes movements to be

less controlled and slower, which makes motor coordination difficult (Umar et al., 2021). In addition, ligamentous laxity leads to decreased joint stability, making balance even more difficult. This laxity prevents the development of motor skills, especially walking and standing (Finbråten et al., 2015). At a neurological level, myelination delays in individuals with DS slow down the speed of signals sent to brain structures that control motor skills and balance. This leads to delays in motor planning and execution, making it difficult to maintain balance (Wu & Li, 2020). In individuals with DS, the vestibular and proprioceptive systems may also be negatively affected. This leads to inadequate access to proprioceptive and vestibular information critical for maintaining balance, which may result in over-reliance on visual cues (Uyanik & Kayihan, 2010). In addition, motor learning processes develop more slowly in individuals with DS. Learning and implementing new movements and developing motor planning strategies may take time. This may hinder independence in daily life activities and the development of motor skills (Valentini et al., 2021). All these factors are fundamental factors affecting motor coordination and balance in individuals with DS and play an important role in understanding the physical development processes of these individuals. Traditional rehabilitation approaches have been used to address these problems in DS. However, the integration of innovative and engaging interventions may further improve treatment outcomes (Shelton & Malow, 2021).

VR is utilized as a tool to enhance motor coordination and balance abilities in children with DS. Although research on this subject is limited, existing studies suggest that VR training can positively influence motor functions in these children. In the study by Wuang et al., A total of 105 children with Down syndrome, aged between 7–12 years, were randomly assigned to standard occupational therapy (SOT), Wii-based virtual reality interventions (VRWii), or a control group. Both intervention groups showed significant improvements in sensorimotor functions compared to controls, with the VRWii group achieving greater gains in motor skills, visual-motor integration, and sensory integration. The results of this study show that virtual reality using Wii game technology is beneficial in developing the sensory-motor functions of children with DS (Wuang et al., 2011). The study indicated that VR training helped children become more independent in their daily life activities by improving their balance skills. It was emphasized that such interventions could yield more successful results when used in addition to traditional rehabilitation methods. In a study conducted by Gómez-Alvárez et al., the effects of VR-based therapy in children with DS were examined in the context of an unblinded randomized controlled trial conducted in a special education school. The participants were children aged between 6–12 years. In the study, one group exercised with the Nintendo Wii Fit Balance Board and sports video games (Snowboard, Penguin Slide, Super Hula Hoop, Heading Soccer ve Ski Jumping) for 10 sessions (5 weeks, twice a week, 20 minutes each session), while the control group continued their daily routine. (Gómez Álvarez et al., 2018). As a result of the study, they found statistically significant results in static balance in the VR group in closed-eye assessments. Another advantage of VR is that it provides sensory-motor activation. VR environments provide children with various motor tasks, allowing them to receive more sensory and motor feedback in completing these tasks. Yunus et al. conducted a randomized controlled trial with 20 children with Down syndrome, aged 9–18 years, who were randomly assigned to treatment and control groups. The treatment group received sensory-motor virtual reality therapy twice a week for four weeks, while the control group did not receive any intervention. Following the intervention, the treatment group demonstrated significant improvements in Pediatric Balance Scale and Timed Up and Go Test (TUG) scores. Sensory integration was achieved through VR games designed to simultaneously stimulate visual, auditory, and proprioceptive systems (Yunus, 2024). These games required children to integrate multiple sensory inputs while coordinating their motor responses, thereby improving both static and dynamic balance. Moreover, VR therapy enhances neuroplasticity by providing repetitive, task-specific, and engaging sensory-motor stimulation. Through these enriched environments, children's brains form

new neural pathways and strengthen existing ones, which supports motor learning and promotes long-term improvements in balance and functional independence. The study concludes that VR therapy is an effective method for improving sensory integration and balance training in children with Down syndrome. In a study conducted by Memon et al., it was shown that both VR and traditional exercise interventions had a positive effect on static and dynamic balance in individuals with DS (Memon et al., 2024). However, it was observed that the group receiving the VR intervention showed a more significant improvement in static balance compared to the traditional exercise group. In the study by Suarez-Villadat et al., VR and conventional physical therapy programs were compared in terms of their effects on dynamic balance and muscle endurance in adolescents with DS (19 female and 30 males; average age, 14.19 ± 2.06 years). The VR group engaged in 60-minute sessions, three times per week over 20 weeks, using Nintendo Wii Fit sports video games, totaling 60 sessions. The control group participated in a traditional physical therapy regimen focused on motor and coordination exercises. Dynamic balance was evaluated using the TUG test, while muscle endurance was measured with the 30-Second Chair Stand Test. The findings indicated that VR-based interventions provided greater improvements in both dynamic balance and muscle endurance compared to conventional therapy (Suarez-Villadat et al., 2023). Similarly, Rahman et al. conducted a study examining the effects of VR and traditional physical therapy on functional balance in children with DS, including participants aged 8–12 years from both genders.The VR group received traditional physical therapy exercises combined with three sports video games using the Nintendo Wii Fit Balance Board. The treatment was performed 6 times per week for 6 weeks, for a total of 36 sessions. Each session lasted 60 minutes. The control group received a traditional physical therapy program that included strengthening, walking, and stair climbing exercises. Functional balance was assessed using the Bruininks-Oseretsky Motor Skills Test (BOT-2), and VR was found to be more effective in improving functional balance compared to traditional physical therapy (Rahman & Rahman, 2010). These results demonstrate the potential of VR as a promising balance training tool for balance problems in individuals with DS. Studies have highlighted that VR application is more effective in improving motor functions and balance, especially when applied as an adjunct to a traditional physical therapy program. Changes in the musculoskeletal system and motor skills in DS affect physical abilities such as speed and agility (Ulrich et al., 2001). Problems such as low muscle tone and loss of muscle strength observed in DS can directly negatively affect the coordination and speed of movements (Connolly & Michael, 1986). Additionally, deficits in abilities such as balance and proprioceptive awareness may limit agility (Zolghadr et al., 2025). These effects result from a combination of both genetic factors and physiological and environmental elements in the individual's developmental process (Giuriato et al., 2025).

Studies on the development of speed and agility skills in individuals with DS using VR show that this technology is an effective tool (Lin & Wuang, 2012; Reis et al., 2017). Lin et al. found that the implementation of strength and agility training with the help of VR improved motor skills in individuals with DS during adolescence. In the study, children aged 13–18 years in the exercise group participated in a strength and agility program using both virtual and traditional methods for 6 weeks. According to the results of this study, it was emphasized that strength and agility performance could be improved more effectively with combined virtual and traditional methods (Lin & Wuang, 2012). Similarly Reis et al. compared the effects of VR and daily care routines on functional balance in children with DS, including participants aged 10–14 years from both genders.The VR group was given 4 sessions per week for 4 weeks, 16 sessions in total, using the river videos games using the Xbox 360 and Kinect sensor. The control group continued their daily care routine. Each session lasted a maximum of 20 minutes. As a result of the study, it was stated that VR-based tools were effective in developing children's balance, coordination and speed skills In this study, participants made visible improvements in their motor performance with VR-supported activities (Reis et al., 2017). Studies in the literature show that

virtual reality plays an important role in the development of motor skills and that VR can contribute to the development of speed, agility and motor skills in individuals with DS. However, it is also emphasized that this technology should be adapted to the specific needs of individuals.

Virtual Reality Applications for Fine Motor Function in Children with Down Syndrome

Individuals with DS show deficits in multiple areas such as physical and motor function. Body composition and muscle strength are vital parameters for children's gross motor, fine motor and functional performance (Beqaj et al., 2018). Upper extremity function is generally associated with motor coordination, dexterity, muscle strength and sensitivity (Padia et al., 2023). Manual dexterity provides the precision, speed, and coordination of upper extremity movements for a task, while grip and pinch strength provide quantitative measures of upper extremity integrity (Choi, 2015). It has been shown that the development of gross and fine motor skills in children with DS is both slower and more impaired than in normally developing children (Volman et al., 2007). In a study conducted by Sinaga et al., scores of 9-12 year old children with DS and typically developing children on the Nintendo Wii game were compared and significant differences were found in fine motor skill scores. It was reported that fine motor skills of children with DS were weaker than those of normal children (Sinaga et al., 2016). Most intervention programs to develop fine motor skills include exercises or activities that use the hands, sensory integration therapy, and neurodevelopmental therapy (Chen et al., 2014; Jobling & Cuskelly, 2006). However, a limited number of studies have shown that VR therapy is effective in upper extremity motor skills in children with DS. In one study, an 8-week intervention was administered to a 12-year-old child with DS using a game system that included Nintendo Wii rehabilitation software (Berg et al., 2012). The child was instructed to use the Nintendo Wii at least four times a week, with each session lasting at least 20 minutes. Assessments were conducted before and after the intervention using the second edition of the BOT-2. The participant showed improvement in hand dexterity and upper extremity coordination scores on the BOT-2.

A study by Wuang et al. compared VRWii with SOT in 7- to 12-year-old children with DS (Wuang et al., 2011). A total of 105 children were randomly allocated to receive either SOT or VRWii, whereas an additional control group comprising 50 participants did not undergo any intervention. Each intervention group participated in one-hour sessions twice a week for 24 weeks. According to the study's results, the VRWii group achieved the greatest improvements in BOT-2 fine motor subtests and the visual-motor integration test compared to the SOT and control groups. It was noted that VRWii could be used in addition to other proven successful rehabilitation interventions in the treatment of children with DS. In another study, 45 children with DS, aged 9 to 14, were divided into three groups: a control group, a motor skills exercise group, and a computer game intervention group (Hashemi & Arabameri, 2019). The intervention groups participated in 40-minute sessions, three days a week for 10 weeks, to monitor the development of fine motor skills. At the end of the study, it was observed that both the computer games and motor skills training programs improved fine motor skills in children with DS. However, no significant difference was found between the two intervention groups. This was attributed to the possibility that virtual interventions could capture children’s interest more effectively and that computer games might have a more motivating aspect.

Current studies indicate that VR therapy is an effective intervention for improving upper extremity motor skills in children with DS. VR therapy can be used alongside existing methods to further enhance upper extremity functions in children with DS.

CONCLUSION

In conclusion, VR therapy is an innovative and effective method that can be used to improve the motor skills of children with DS. These therapies provide significant improvements in children's motor coordination, balance, speed, agility and upper extremity motor skills. However, the existing literature suffers from several limitations, including small sample sizes, short intervention periods,

methodological heterogeneity, and the lack of standardized VR protocols specific to children with DS. Furthermore, the lack of long-term follow-up in most studies makes it difficult to assess the sustainability of therapeutic gains. To address these shortcomings, future research should be supported by large-scale randomized controlled trials, develop VR-based gaming models specific to DS, and comprehensively evaluate long-term effects on motor, cognitive, and psychosocial outcomes. Furthermore, exploring how VR applications can be effectively integrated with traditional rehabilitation approaches will provide valuable insights into clinical practice.

Conflict of Interest

No conflict of interest was declared by the authors.

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