NEUROSCIENCE RESEARCH NOTES

OPEN ACCESS | SYSTEMATIC REVIEW ISSN: 2576-828X

The role of virtual reality in the rehabilitation of individuals with Down Syndrome

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Received: 9 July 2025; **Accepted:** 5 January 2026; **Published:** 30 June 2026
Edited by: Pike See Cheah (Universiti Putra Malaysia, Malaysia)
Reviewed by: Huang Tan (Second Affiliated Hospital of Zunyi Medical University, China); Priyadharshini Kumar (Saveetha Institute of Medical and Technical Sciences)
https://doi.org/10.31117/neuroscirn.v9i1.484

ABSTRACT: Down Syndrome or Trisomy 21, is a genetic disorder resulting from an extra copy of chromosome 21, leading to intellectual disability, physical abnormalities, and a range of health complications. It is the most common chromosomal aneuploidy and has an increasing global prevalence. Individuals with DS often face developmental delays, congenital heart defects, and reduced muscle tone. Emerging rehabilitation methods, including Virtual Reality, have shown promise in enhancing cognitive and motor functions by providing interactive, engaging environments. This study aims to evaluate the effectiveness of Virtual reality in enhancing the physical, cognitive and social outcomes among individuals with Down syndrome. A comprehensive literature review in accordance with PRISMA-ScR was conducted using databases such as PubMed, Google Scholar, and ScienceDirect, focusing on full-text articles from 2019-2024. Seven studies, based on inclusion and exclusion criteria, that examined the role of virtual reality in the rehabilitation of individuals with Down syndrome were included in the analysis. This study shows that virtual reality effectively improves motor skills, balance, cognitive function, and motivation in children with Down syndrome. Regular, controlled use of VR offers a dynamic and engaging therapy option, with better balance and coordination outcomes than traditional methods. Evidence supports the use of virtual reality in rehabilitating children with Down syndrome, showing improvements in motor skills, balance, cognition, and independence. Interactive, game-based VR boosts engagement and motivation, leveraging neuroplasticity for meaningful progress.

Keywords: Virtual reality, Down syndrome or trisomy 21, Quality of life, Physical therapy or physiotherapy, Rehabilitation.

1.0 INTRODUCTION

Down syndrome (DS) was first described in 1866 by John Langdon Down, a British physician. Dr Down observed certain similarities: they have broad, flat faces, thick tongues, small noses, narrow palpebral fissures, obliquely placed eyes, and round, extended cheeks.

There are various terms used to describe DS, but trisomy 21 is currently the most common variant (Wajuihian, 2016). The extra copy will depend on the variant that causes the abnormality in the body. DS is commonly diagnosed with chromosomal abnormalities and congenital aneuploidy in infants, which causes physical and mental developmental delay. The main clinical feature of DS is intellectual disability, which affects their cognition and learning and is mainly caused by DS. DS is present across all races, religions, nationalities, and socioeconomic levels (Wajuihian, 2016). The lifetime prevalence of DS increases as the global population grows. As of 2013, ~1 in every 779 babies born had DS. The annual birth rate of DS is 1.4/1000 live births in India (Mohamed et al., 2019; Beshay et al., 2019). Despite this, the survival rate has increased in the last 50 years from <50% in the 1990s to 95% in the early 2000s, with a life expectancy of 60 years (Mohamed et al., 2019). In each human, there are 23 pairs of chromosomes in egg and sperm cells. Humans have 22 pairs of non-sex chromosomes and a pair of sex chromosomes (XX, XY). During the migration stage of meiosis, incomplete separation of chromosomes will result in 24 chromosomes in an egg or sperm, while other cells have 23 chromosomes.

The presence of three copies of chromosome 21 is called *trisomy.* There are three main steps in meiotic division, namely, *pairing, recombination,* and *chromosomal segregation.* If an abnormal gamete merges with a normal gamete, the resulting embryo will have 47 chromosomes instead of 46 chromosomes. These abnormal developments lead to intellectual, physical, and medical abnormalities in people with DS. Trisomy 21 is the most common type of DS (95% of cases). The error will be either in the sperm or the egg. Advanced maternal age is one of the major risk factors of Trisomy 21. Mosaicism is one of the least common types of DS, which occurs in 1%-2% of people. In mosaic type, some cells have the normal two copies of chromosome 21, while abnormal cells have 3 copies. Mosaic is not an inherited condition like Trisomy 21, and the clinical features can be mild depending on the proportion of trisomic cells. Translocation happens before fertilisation, in which an extra copy of chromosome 21 breaks and the extra part of the chromosome will attach to the other chromosome during cell division. Unlike trisomy 21, where there are three copies of chromosome 21, in translocation, the total chromosome count remains 46 because the additional chromosome is fused to another chromosome. DS caused by translocation can be inherited from either parent. Approximately 4% of people have DS due to translocation (Pal A et al., 2026) DS is characterised by declines in cognitive abilities and multiple bodily systems, especially the musculoskeletal, neurological, and cardiovascular systems. Brachycephaly (small head or skull shape), a round face, almond-shaped eyes due to epicanthic fold of the eyelid and oblique palpebral fissure, small ears, flat nasal bridge, macroglossia, physical inactivity and poor nutrition (Mailani et al., 2024). According to Paul and Ellapen (2019), regular exercise and physical activity in DS patients improve cardiometabolic risk factors by reducing body fat. Shields and Taylor (2010) and Gupta and Singh (2011) explain that strengthening exercises such as circuit training, basic plyometric drills, and swimming will improve muscle strength, thereby enhancing activities of daily living, reducing insulin resistance, and improving cardiometabolic factors in diabetic patients. The article concludes that regular exercise will improve the health of DS individuals by improving their aerobic capacity, muscle strength, proprioception, and postural stability (Paul et al., 2019).

While traditional exercise improves several physical and functional abilities, Virtual reality (VR) introduces a novel, interactive approach to achieve similar or even greater outcomes. VR is defined as "the use of interactive simulations created with computer hardware and software to present users with opportunities to engage in environments that appear to be and feel similar to real-world objects and events" (Asadzadeh et al., 2021). It is a replication of an environment that will stimulate the person's presence and allow them to interact. VR also provides sensory experiences such as sight, hearing, touch, and smell (Baqai et al., 2019). It is a new rehabilitation method that has attracted considerable interest among physiotherapists (Leghari et al., 2023). VR has been shown to enhance cognitive abilities by providing immersive, engaging environments that improve attention, memory, and problem-solving skills. Studies have demonstrated significant cognitive benefits, highlighting VR's potential as an effective therapeutic tool. VR and remote sensing are new technologies developed in the field of physiotherapy. During the physiotherapy session, the system will sense the body motion and evaluate the physical therapy outcome. With tailored games, the user will be motivated for a sustainable level of exercise (Postolache et al., 2019).

Thus, this study aims to determine which therapeutic approaches in virtual reality programmes are effective for DS, to analyse the results, and to describe the outcome measures used in DS. This will help to determine how VR can enhance physical, cognitive, and social outcomes for individuals with DS, therefore contributing to their overall well-being and independence.

2.0 METHODOLOGY

2.1 Research question

How does virtual reality affect the physical, cognitive and social outcomes among individuals with Down syndrome?

2.2 Study design

This scoping review is conducted in adherence to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses for Scoping Reviews (PRISMA-ScR) Guidelines and Databases and information sources.

2.3 Databases and information sources

After obtaining approval from the SRB and the Ethical Committee, a comprehensive literature search was conducted on an electronic database using a search strategy. The databases used for the scoping review were PubMed, Google Scholar, and ScienceDirect. The search focused on full-text articles published in English between 2019 and 2023.

2.4 Search strategy

A comprehensive literature search was conducted using electronic databases including PubMed, Google Scholar, and ScienceDirect. The search focused on full- text articles published in English between 2019 and 2024. Relevant keywords and Boolean operators were used to identify studies related to the topic in PubMed, Google Scholar and ScienceDirect, including “virtual reality” OR “VR” OR “augmented reality,” “Down syndrome” OR “trisomy 21,” “quality of life” OR “QoL,” and “physical therapy” OR “physiotherapy” OR “rehabilitation.”

2.5 Study selection

A single reviewer conducted a literature search across different databases. The eligibility of the trials was assessed independently by two reviewers. Any discrepancies that arose were resolved through discussion. A third reviewer was available for consultation in case of unresolved disagreement.

2.6 Eligibility criteria

Articles were included if they met the following inclusion criteria: a) studies involving participants aged 6-15 years, b) studies published between 2019-2024, c) articles that used Virtual reality as the active intervention; d) randomized controlled trials (RCTs), cross- sectional studies, and case studies; and e) only English and full-text articles were included in the study. Articles were excluded if they met the following Exclusion criteria: a) studies in which conditions such as Cerebral palsy, Autism, Stroke were included; b) studies that include children less than 6-15 years of age; and c) articles in which Virtual reality was used as a passive intervention.

2.7 Procedure

A total of 495 articles were retrieved from Google Scholar, PubMed, and ScienceDirect, and 426 were removed because they addressed conditions other than DS. Then, 69 articles were screened, of which 35 were from Google Scholar and 34 duplicates were removed from PubMed (17) and ScienceDirect (17). 35 articles were sought for retrieval; 23 were not retrieved. Later, 12 articles were assessed for eligibility, of which 5 were excluded. The study selection process followed the PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses for Scoping Reviews) framework, as shown in Fig. 1. Finally, 7 articles were selected for the study, as shown in **Table 2.**

Table 1. Risk of bias appraisal using critical appraisal checklist for quasi- experimental studies.

Author and Year	1	2	3	4	5	6	7	8	9	10	Overall Appraisal
Gaber et al., 2024	+	+	+	+	+	-	+	+	+	+	Include
Yunus et al., 2024	+	+	+	+	+	+	+	+	+	+	Include
Ghouri et al., 2024	+	+	+	+	+	-	+	+	+	+	Include
Leiton- Muñoz et al., 2023	+	+	+	+	+	-	+	+	+	+	Include
Valencia- Jiménez et al., 2023	+	+	+	+	+	-	+	+	+	+	Include
Da Cruz Netto et al., 2020	+	+	+	+	+	+	+	+	+	+	Include
Torres- Carrión et al., 2019	+	+	+	+	+	-	+	+	+	+	Include

Legend: +=Yes,–=No

Table 2. Included articles.

Title & Year	Type of Study	Age	Methods	Outcome measure	Conclusion
Developing independent skills using a virtual reality-based training program for children with Down Syndrome (Gaber, 2024)	Quasi-experimental study	8-12 years old	Eighteen children were randomly divided into 3 groups and received a VR-based training program (Addie Model) consisting of 50 sessions (20 minutes each, 3 times a week for 4 months).	Independence Skills Scale (ISS) for motor skills: It consists of 38 items with 4 dimensions, such as eating, drinking, dressing and undressing and personal hygiene and self-care.	The study concludes that VR effectively develops independence skills in children with moderate DS, enhancing participation, focus, and engagement in activities.
The effect of sensory-motor virtual reality on balance in children with clinical Down Syndrome (Yunus et al., 2024)	Randomised controlled trial	9-18 years old	Twenty participants were randomly divided into two groups: the treatment group (SenMor's VR) for 2 sessions a week over 4 weeks, and the control group (no treatment)	a) Pediatric balance scale (PBS): static balance b) Timed up and go (TUG) test: dynamic balance	The study concludes that there is an observable positive impact of SenMor VR on static and dynamic balance in children.
Effect of virtual reality on static and dynamic balance among individuals with Down syndrome (Ghouri et al., 2024)	Quasi-experimental study	6-9 years old	24 participants were randomly assigned to two groups: Group A received 30-minute VR sessions using Nintendo Wii/Fit, and Group B received traditional therapy.	Pediatric Balance Scale (PBS): 14 items, each with a score from 0-4, with a maximum score of 56. Rhomberg Test for balance: Feet apart with eye open, eye closed, followed by feet together	The studies conclude that both VR and traditional exercises improve balance, but VR showed greater improvement in static and dynamic balance.
Effects of virtual reality training in the postural control of children with Down syndrome: a case series (Leiton-Muñoz et al., 2023)	Case series	6-9 years old	Five participants meeting the criteria underwent NWBB sessions twice weekly for 25 minutes over 9 weeks, without any other treatments.	Time Up and Go (TUG) test: The subject sits, stands, walks 3 meters, turns, and returns to sit as quickly as possible. The One Leg Standing (TOLS): the subject will raise one leg to 900 hip flexion as long as possible.	The study concluded that a 9-week NWBB program improves postural control and functional balance of children with DS.

Effect of an intervention based on a multisensory environment for proprioception assessment in children with Down Syndrome: case study (Valencia-Jiménez et al., 2023)	Case study	7-12 years old	Three participants received 12 weekly 30-minute game sessions, with PPT used in the first and last sessions to assess proprioception, muscle tone, and motor skills.	a) Berg scale b) Psychomotor Profile Test (PPT) for motor skills c) Game platform analysis for cognitive function: left-right game for hands, left-right game for feet, the catcher game, Whack-A-Mole game	The study found the MSE-based intervention effective in improving motor and balance behaviour and enhancing visual, somatosensory, and vestibular feedback.
Memorisation of daily routines by children with Down syndrome assisted by a playful virtual environment (Da Cruz Netto et al., 2020)	Experimental study	10-19 years old	The 30 subjects are randomly divided into 2 homogenous groups: Experimental group (15) and control group (15)	Daily routine memorisation test (DRMT): a weekly reminder of a typical daily household routine t to be completed by children and parents.	The study found that children in the EG showed improved action sequencing. Customised VR games like “Nossa Vida enhanced learning and motivation in children with disabilities.
Improving cognitive visual-motor abilities in individuals with Down Syndrome (Torres-Carrión et al., 2019)	Experimental study	Cognitive age >5 years old	Six participants were divided into two groups: three received TANGO:H with gestures, and three had regular classroom activities.	Illinois Test for Psycholinguistic Aptitude (ITPA): to evaluate psycholinguistic function involved in communication in various areas of learning. It consists of 12 subtests	The study found that TANGO:H yielded positive results in stimulating cognitive visual-motor skills in individuals with DS.

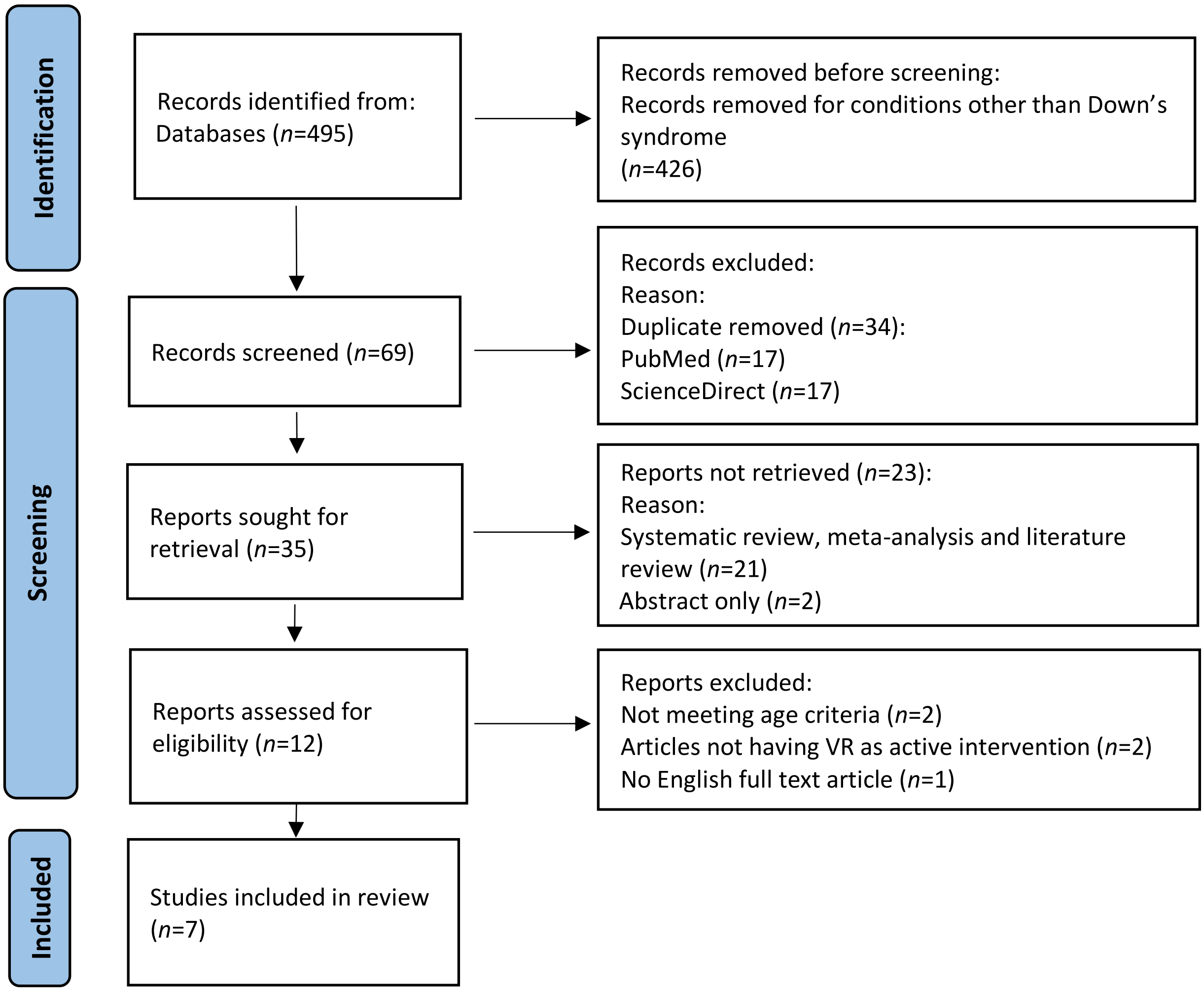

Figure 1. PRISMA flowchart

3.0 RESULT

The findings from seven research articles collectively highlight the significant role of VR in the rehabilitation of individuals with DS. These studies consistently demonstrate that VR-based interventions yield positive outcomes, particularly in enhancing cognitive functions, motor skills, and balance-related abilities in children with DS. The use of VR and multisensory-based therapeutic approaches has proven effective not only in improving physical capabilities such as coordination, postural control, and fine motor skills, but also in fostering motivation, engagement, and active participation during therapy sessions. Importantly, the regular, structured implementation of VR in therapeutic settings has consistently promoted functional movement and balance, establishing VR as a valuable tool for both physical and cognitive-motor development. These immersive technologies provide an enriched, interactive environment that supports personalised and adaptive rehabilitation, making therapy more appealing and less monotonous for children.

4.0 DISCUSSION

This scoping review explores the role of virtual reality in the rehabilitation of individuals with DS. Findings suggest that virtual reality can improve motor skills, balance, cognitive function, and motivation in children with DS. The study included various outcome measures, including the Illinois Test for Psycholinguistic Aptitude (ITPA), Daily Routine Memorisation Test (DRMT), Berg scale, Psychomotor Profile Test (PPT), Game Platform Analysis, Time Up and Go (TUG), The One-leg standing (TOLS), Pediatric Balance Scale (PBS), Rhomberg Test, and Independence Skill Scale (ISS). Virtual Reality (VR) will be effective based on the principle of neuroplasticity, which encourages the brain to adapt and learn various activities essential in day-to-day life for children with DS (Gaber, 2024).

The findings of this study align with prior research demonstrating the effectiveness of VR interventions in improving motor and cognitive functions in individuals with DS. Yunus et al., in a randomised controlled trial, demonstrated significant improvements in balance, as measured by the PBS and TUG scores, among participants who received a sensorimotor VR intervention. This improvement was attributed to the stimulation of the vestibular and proprioceptive systems -two key components for maintaining postural equilibrium, which supports balance enhancement through mechanisms of neural plasticity that strengthen motor pathways and improve overall balance coordination in individuals with DS (Yunus et al., 2024). Similarly, Ghouri et al. (2024) reported positive outcomes in static and dynamic balance using VR, with significant gains observed in PBS and Romberg test scores in the experimental group, further reinforcing the role of vestibular and proprioceptive input in balance training which will promote the refinement of motor responses and proprioceptive accuracy through experiential learning and feedback-mechanism. Gaber (2024) also provided evidence on the benefits of VR in developing independent skills among children with DS. The study showed that the VR group exceeded other intervention groups on ISS scores, suggesting that interactive VR environments offer a safe and realistic environment for practicing daily living skills through simulation of real-life activities, children can rehearse essential routines and behaviors, reinforcing their learning through repetition and positive reinforcement in a gaming setting. These findings support the use of VR as an effective tool for encouraging independence in this population (Gaber, 2024). Moreover, Jimenez et al. and Munoz et al. explored VR and multisensory interventions in smaller case-based studies, reporting improvements in proprioception and motor behavior (PPT) and postural control (TUG), respectively (Leiton-Muñoz et al., 2023; Valencia-Jiménez et al., 2023). Although Munoz et al. noted no change in TOLS, the authors emphasized the central nervous system's capacity for neuroplasticity allows in responding to stimuli that promote motor learning through repeated sensory involvement (Leiton-Muñoz et al., 2023).

Cognitive benefits of VR interventions were also supported by Netto et al., who found significant improvements in memorization of daily routines, measured using DRMT. This outcome was connected to the activation of the hippocampal system-an area critical for memory formation, which plays a key role in spatial memory and cognitive development (Da Cruz Netto et al., 2020). In addition, Carrion et al. highlighted enhancements in cognitive visual- motor abilities using Kinect-based interventions, confirming the potential of VR to support visual-motor integration (Torres-Carrión et al., 2019). Overall, these studies collectively demonstrate the benefits of VR in improving balance, motor skills, cognitive function, and motivation among individuals with DS. By engaging vestibular and proprioceptive, cognitive, and emotional systems, VR encourages neuroplastic changes that facilitate better motor control and balance. Also, the use of personalised, game-based environments supports both cognitive and physical development and makes therapy both more effective and more enjoyable for children. These findings reinforce the value of VR as an innovative and effective therapeutic modality in pediatric rehabilitation for DS.

5.0 CONCLUSIONS

The availability of evidence underlines the role of VR in the rehabilitation of individuals with DS, especially children. The evidence shows that VR contributes significantly in the improvement of motor skills, balance, cognitive function, proprioception, and daily-living independence. The combination of interactive, game-based VR involves children effectively, promoting their participation and motivation while using the principles of neuroplasticity to allow functional improvement. However, VR holds significant ability to transform the therapeutic landscape by providing engaging, effective, and personalised intervention for individuals with DS.

6.0 LIMITATIONS

Lack of good-quality randomised controlled trials on VR-based therapy in DS. Less evidence is available on the long-term benefits of VR-based therapy. Inconsistent outcome measures make it difficult to compare results. Limited focus on cognitive outcome, which is equally important in DS rehabilitation.

7.0 SUGGESTIONS

Future research should focus on high-quality randomised controlled trials for clear and appropriate evidence of its effectiveness. Additionally, studies should be conducted to investigate the long-term effects of VR. Lastly, attention should be given to cognitive outcomes, such as memory and attention, as they are crucial for the overall development of children with DS.

Acknowledgements: No funding was received for this study.

Author Contributions: MM and PAK conceived and designed the idea and methodology; MM and MAKA analysed data; MM and PAK wrote the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

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