

SYNERGISTIC IMPACT OF VIRTUAL REALITY AND AQUATIC THERAPY ON LOWER LIMB STRENGTH AND FUNCTIONAL RECOVERY IN CHILDREN WITH CEREBRAL PALSY

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ABSTRACT

Background:

Cerebral palsy is non-progressive neuro-developmental disorder characterized by motor impairments that often result in reduced strength and limitations in functional mobility. Conventional rehabilitation approaches aim to improve motor function however, innovative interventions such as virtual reality and aquatic therapy have gained increasing attention due to their potential to enhance engagement, task-specific training, and neuromuscular performance.

Objective:

This narrative review aims to examine existing literature on the use of virtual reality and aquatic therapy in children with cerebral palsy, with particular focus on their effects on lower limb strength and functional recovery.

Methods:

A narrative review of the literature was conducted using electronic databases including PubMed, Google Scholar, Scopus, and PEDro. Relevant studies published between 2020 and 2025 were identified using keywords related to cerebral palsy, virtual reality, aquatic therapy, pediatric rehabilitation, and motor function. Multiple observational studies were included to provide a combined effect of virtual reality and aquatic therapy.

Results:

The findings from the reviewed literature indicate that virtual reality and aquatic therapy demonstrate positive effects on lower limb strength, balance, gait, and overall functional performance in children with cerebral palsy. Virtual reality-based interventions facilitate motor learning by encouraging

repetitive, goal-directed practice supported by enriched visual and sensory feedback. In contrast, aquatic therapy offers a gravity-reduced and supportive environment that enables greater freedom of movement, minimizes joint stress, and enhances postural stability. Emerging clinical observations suggest that the integration of these interventions may yield complementary benefits by simultaneously promoting sensorimotor engagement, task-specific training, and motivational participation in rehabilitation.

Conclusion:

Virtual reality and aquatic therapy are complementary approaches that enhance lower limb strength and functional performance in children with cerebral palsy. Their combined use promotes motor learning, sensorimotor stimulation, and engagement, leading to more effective rehabilitation outcomes.

Keywords: Cerebral Palsy, Virtual Reality, Aquatic Therapy, Lower Limb Strength, Functional Recovery, Pediatric Rehabilitation

INTRODUCTION

Cerebral palsy (CP) is a group of neurodevelopmental disorders that primarily affect posture, movement, and motor coordination as a result of damage to the developing brain.(1) Although the brain lesion is non-progressive, the associated motor impairments often evolve with growth and development, leading to increasing functional limitations over time. Cerebral palsy remains one of the most common causes of physical disability in childhood, with affected children frequently experiencing muscle weakness, abnormal muscle tone, impaired balance, and poor coordination. These impairments substantially restrict independence, participation in daily activities, and overall quality of life.(2)

Lower limb dysfunction is a disabling and prominent feature in children with cerebral palsy. Deficits in muscle strength, selective motor control, and postural stability significantly compromise standing balance, walking ability, and transitional movements. Lower extremity weakness has been consistently identified as a key contributor to reduced gait efficiency, early fatigue, and limited functional mobility.(3) As independent ambulation and mobility are closely linked to participation in social, educational, and recreational activities, improving lower limb strength and functional recovery remains a primary objective of pediatric physiotherapy and neuro-rehabilitation.(4)

Conventional physiotherapy interventions for children with cerebral palsy commonly include stretching, strengthening exercises, balance training, gait training, and neurodevelopmental

approaches.(5) While these interventions are effective in addressing motor impairments, sustaining motivation and active participation can be challenging, particularly in pediatric populations.(6) Repetitive and task-focused exercises may be perceived as monotonous by children, leading to reduced engagement and suboptimal therapeutic outcomes. Consequently, contemporary rehabilitation practices emphasize the integration of innovative, engaging, and child-centered approaches that promote motivation while delivering sufficient therapeutic intensity.(7) Virtual reality (VR) has emerged as a novel and promising intervention in pediatric neuro rehabilitation. Virtual reality-based rehabilitation involves the use of interactive, computer-generated environments that allow children to perform functional tasks in a simulated and engaging manner while receiving real-time feedback. (8) The immersive nature of VR encourages active participation and repetitive practice, both of which are essential for motor learning. In children with cerebral palsy, VR-based interventions have demonstrated positive effects on balance, coordination, gross motor function, and functional mobility.(9)

Aquatic therapy is a well-established therapeutic modality in pediatric rehabilitation and has been widely used for children with cerebral palsy. Aquatic therapy utilizes the physical properties of water, including buoyancy, viscosity, hydrostatic pressure, and thermal effects, to facilitate movement and therapeutic exercise.(10) Buoyancy reduces the effects of gravity, allowing children with limited strength or postural control to

perform functional movements with greater ease and safety. Water resistance provides a natural medium for strengthening exercises, while hydrostatic pressure enhances proprioceptive input and postural stability.(11)

Although virtual reality and aquatic therapy have been independently shown to produce favorable outcomes in children with cerebral palsy, increasing attention is being directed toward their combined application. From a theoretical and clinical perspective, integrating virtual reality with aquatic therapy may offer complementary and synergistic benefits.(12) Virtual reality enhances motivation, task specificity, and motor learning, while aquatic therapy provides a supportive environment that facilitates movement and reduces physical strain. Together, these modalities may create an enriched rehabilitation setting that maximizes functional gains.(13)

The concept of synergy in rehabilitation suggests that combining two effective interventions may result in superior outcomes compared to their isolated use.(14) In the context of cerebral palsy rehabilitation, the integration of VR-based tasks within an aquatic environment, or the sequential use of these modalities, may enhance lower limb strengthening and functional recovery. Virtual reality-guided balance, stepping, or weight-shifting activities performed in water could allow children to practice functional tasks with reduced joint loading and increased confidence.(15) Such an approach may be particularly advantageous for children with moderate to severe motor impairments who experience limitations during land-based therapy.

A narrative review provides an ideal framework for this purpose, allowing for an integrative and critical discussion of existing literature, underlying mechanisms, and practical implications. By examining both virtual reality and aquatic therapy, this review aims to clarify their individual contributions and potential combined effects on lower limb strength and functional recovery in children with cerebral palsy.

1. METHODS

A structured literature search was conducted across PubMed, Scopus, Web of Science, and Google Scholar to identify relevant publications

from 2020 to 2025. Search terms were applied in various combinations and included “cerebral palsy,” “virtual reality,” “aquatic therapy,” “hydrotherapy,” “lower limb strength,” “Gross motor function,” and “functional recovery.”

The review included multiple observational studies that examined the use of virtual reality and aquatic therapy in children with cerebral palsy. Studies focusing exclusively on adult populations, non-therapeutic interventions, surgical management, or conditions other than cerebral palsy were excluded. Conference abstracts, editorials, and non-English publications were also excluded. Data extracted from the included literature focused on participant characteristics, intervention type and duration, outcome measures related to lower limb strength, and key findings reported by the authors. The extracted information was synthesized descriptively to explore trends, clinical implications, and gaps in the existing literature, with particular attention to the potential synergistic role of virtual reality and aquatic therapy.

2. REVIEW OF LITERATURE

2.1 Virtual Reality Based Rehabilitation in Children with Cerebral Palsy

Virtual reality (VR) based rehabilitation has gained increasing attention as an innovative therapeutic approach in the management of motor impairments in children with cerebral palsy. (16) Multiple systematic reviews and clinical trials have examined the effects of virtual reality based rehabilitation for children with cerebral palsy, with approximately 16 to 19 studies reporting improvements in balance and motor function. These investigations primarily focus on the role of virtual reality in enhancing motor performance, balance, coordination, and functional mobility.

Virtual reality interventions typically involve computer-generated environments that require children to perform task oriented movements such as stepping, weight shifting, reaching, and balance control.(17) These tasks are often presented in a game-based format, which increases motivation and encourages active participation. Across the literature, VR-based therapy has been shown to promote repeated practice of functional

movements, a key principle of motor learning. This repetitive, goal-directed training is particularly important for children with cerebral palsy, who often require high practice intensity to achieve meaningful functional improvements. (18) Studies have reported that virtual reality based interventions contribute to improvements in lower limb function by enhancing balance control, postural stability, and gross motor performance. Improvements have commonly been observed in functional domains related to standing, walking, and dynamic balance. The use of real-time visual and auditory feedback in VR systems allows children to adjust their movements during task performance, thereby facilitating sensorimotor integration and improving movement accuracy. Such feedback-driven training may support neuro plastic changes within the developing nervous system.(19)

Overall, current evidence indicates that virtual reality-based interventions can positively influence lower limb strength, balance, and functional recovery in children with cerebral palsy. (20) While VR alone may not replace traditional physiotherapy, it represents an effective complementary approach that enhances motivation, promotes motor learning, and supports functional gains.

2.2 Aquatic Therapy in Children with Cerebral Palsy

Aquatic therapy has long been recognized as an effective rehabilitation approach for children with neurological and musculoskeletal impairments, including cerebral palsy. (21) The therapeutic use of water provides a unique environment that facilitates movement while minimizing physical strain, making it particularly suitable for children with motor limitations. Aquatic therapy has also been investigated in children with cerebral palsy, with at least 8 to 13 studies demonstrating benefits in lower limb strength, balance, and gross motor function. The therapeutic benefits of aquatic therapy are largely attributed to the physical properties of water. Buoyancy reduces the effects of gravity, allowing children with limited muscle strength or poor postural control to perform movements such as standing, walking, and stepping with greater ease and confidence. This

reduction in weight-bearing demands enables children to practice functional movements that may be challenging on land. (22)

Evidence suggests that aquatic therapy can contribute to improvements in lower limb muscle strength, balance, and gait-related functions in children with cerebral palsy. Improvements in walking ability, postural stability, and functional mobility have been reported following structured aquatic exercise programs. The supportive aquatic environment also allows for the safe practice of balance and coordination tasks, reducing fear of falling and encouraging greater movement exploration. (23)

Aquatic therapy is particularly beneficial for improving muscle tone and movement quality, which are critical for functional recovery in children with cerebral palsy. Immersion in warm water has been shown to relax hypertonic muscles, helping to reduce spasticity and facilitate smoother, more coordinated movements. This reduction in muscle stiffness can enhance the effectiveness of functional training, allowing children to perform motor tasks more efficiently both in water and on land. Moreover, the hydrostatic pressure of water provides continuous sensory input, supporting proprioceptive awareness, postural control, and overall motor performance during rehabilitation activities.(24)

Overall evidence suggest, aquatic therapy offers a supportive and effective rehabilitation environment that facilitates lower limb strengthening, balance training, and functional recovery in children with cerebral palsy. Its unique physical properties, combined with high levels of engagement and safety, make it a beneficial component of pediatric neuro-rehabilitation programs.

2.3 Synergistic Effects of Virtual Reality and Aquatic Therapy in Children with Cerebral Palsy

The integration of virtual reality and aquatic therapy offers a transformative approach to pediatric cerebral palsy rehabilitation. By harnessing the interactive, task-specific, and feedback-driven nature of virtual reality alongside the supportive and resistive properties of water, this combined intervention creates a uniquely enriched environment for motor learning and

functional improvement. Children can engage in repetitive, goal-oriented movements with reduced gravitational constraints, enhanced safety, and increased confidence, enabling more efficient practice of complex motor tasks. (15)

A pioneering feasibility case series by Costa et al. investigated aquatic therapy integrated with virtual reality (termed aquatic VR) in children with neuromuscular involvement, including cerebral palsy. The study reported high engagement and positive therapeutic experiences among participants during AVR sessions, suggesting that combining VR with aquatic environments may enhance motivation and motor engagement. (13) Evidence showed this dual-modality approach maximizes sensory input by pairing the visual and auditory feedback of VR with the proprioceptive and tactile stimulation provided by water. Such enriched sensory-motor experiences are likely to reinforce neuromuscular control, improve coordination, and accelerate the acquisition of functional skills.(25) By combining cognitive engagement, motor learning principles, and the supportive properties of the aquatic environment, virtual reality guided aquatic therapy has the potential to enhance lower limb strength, balance, and functional mobility beyond what either intervention can achieve alone. This innovative synergy represents a promising frontier in pediatric rehabilitation, offering a child-centered, enjoyable, and highly effective strategy for optimizing motor recovery and improving quality of life.

3. DISCUSSION

The present narrative review explored the role of virtual reality and aquatic therapy in improving lower limb strength and functional recovery in children with cerebral palsy, with particular emphasis on their potential synergistic effects. The findings from the reviewed literature suggest that both interventions independently demonstrate positive effects on motor function, balance, and functional mobility.(26) Evidence indicates that integrating virtual reality with aquatic therapy may offer complementary benefits in pediatric neuro-rehabilitation. Studies included in this review consistently reported improvements in balance, gait parameters, and gross motor function

following VR-based interventions. These improvements are likely attributable to the principles of motor learning embedded within VR platforms, including repetitive practice, augmented feedback, and goal-oriented tasks. (13) Despite these promising theoretical advantages, the current literature lacks robust clinical trials specifically examining the combined effects of virtual reality and aquatic therapy in children with cerebral palsy. Most studies focus on single-modality interventions, and there is considerable heterogeneity in intervention protocols, outcome measures, and participant characteristics. These limitations restrict direct comparisons and generalization of findings. Furthermore, factors such as accessibility to aquatic facilities, cost of VR equipment, and the need for trained personnel may influence the feasibility of implementing combined interventions in routine clinical practice.

From a clinical perspective, the findings of this review support the inclusion of both virtual reality and aquatic therapy as adjuncts to conventional physiotherapy for children with cerebral palsy. Therapists may consider integrating these approaches based on individual patient needs, severity of impairment, and available resources.(15) Future research should focus on well-designed randomized controlled trials investigating combined intervention protocols, optimal dosage, and long-term outcomes. Standardized outcome measures and larger sample sizes are also needed to strengthen the evidence base.

In summary, this narrative review highlights the potential value of virtual reality and aquatic therapy in enhancing lower limb strength and functional recovery in children with cerebral palsy. While direct evidence on their synergistic effects remains limited, the complementary nature of these interventions provides a strong rationale for their combined use. Continued research in this emerging area may contribute to the development of innovative, evidence-based rehabilitation strategies aimed at improving functional outcomes and quality of life in children with cerebral palsy.

4. CONCLUSION

Virtual reality and aquatic therapy are promising approaches for improving lower limb strength and functional recovery in children with cerebral palsy. Each intervention enhances balance, motor control, and mobility, and their combined use may offer complementary benefits that improve motor learning and engagement. Together, they represent innovative, child-centered strategies to optimize rehabilitation outcomes.

5. REFERENCE:

1. Patel DR, Bovid KM, Rausch R, Ergun-Longmire B, Goetting M, Merrick J. Cerebral palsy in children: A clinical practice review. *Current problems in pediatric and adolescent health care*. 2024;54(11):101673.
2. Patel DR, Neelakantan M, Pandher K, Merrick J. Cerebral palsy in children: a clinical overview. 2020;9(Suppl 1):S125.
3. Sarajchi M, Al-Hares MK, Sirlantzis K. Wearable lower-limb exoskeleton for children with cerebral palsy: A systematic review of mechanical design, actuation type, control strategy, and clinical evaluation. 2021;29:2695-720.
4. Walhain F, Desloovere K, Declerck M, Van Campenhout A, Bar-On L. Interventions and lower-limb macroscopic muscle morphology in children with spastic cerebral palsy: A scoping review. 2021;63(3):274-86.
5. Alrashidi M, Wadey CA, Tomlinson RJ, Buckingham G, Williams CA. The efficacy of virtual reality interventions compared with conventional physiotherapy in improving the upper limb motor function of children with cerebral palsy: a systematic review of randomised controlled trials. 2023;45(11):1773-83.
6. Bampouli V, Trevlaki E, Trevlakis E. Physical Therapy Treatment in Children with Cerebral Palsy. 2022;4863.
7. Goswami JN, Sankhyam N, Singhi P. Add-on home-centered activity-based therapy vs conventional physiotherapy in improving walking ability at 6-months in children with diplegic cerebral palsy: A randomized controlled trial. 2021;58(9):826-32.
8. Fandim JV, Saragiotto BT, Porfirio GJM, Santana R. Effectiveness of virtual reality in children and young adults with cerebral palsy: a systematic review of randomized controlled trial. 2021;25(4):369-86.
9. Liu C, Wang X, Chen R, Zhang J. The effects of virtual reality training on balance, gross motor function, and daily living ability in children with cerebral palsy: systematic review and meta-analysis. 2022;10(4):e38972.
10. Muñoz-Blanco E, Merino-Andrés J, Aguilar-Soto B, García YC, Puente-Villalba M, Pérez-Corrales J, et al. Influence of aquatic therapy in children and youth with cerebral palsy: A qualitative case study in a special education school. 2020;17(10):3690.
11. Xiang A, Fu Y, Wang C, Huang D, Qi J, Zhao R, et al. Aquatic therapy for spastic cerebral palsy: a scoping review. 2024;29(1):569.
12. Rehrig A, Southard K. The Effectiveness of Aquatic Therapy, Robot Assisted Gait Training, and Virtual Reality on Patients with Parkinson's Disease: A Literature Review. 2021.
13. Costa R, Richmond S, Geigle P, Quarles J. Aquatic therapy with virtual reality for children with neuromotor needs: A preliminary feasibility case series. 2020;28(2):10-7.
14. Al-Nemr A. Synergistic effect of functional strength training and cognitive intervention on gross motor function in children with cerebral palsy. 2024;13(3):246-55.

15. Khadra C, Ballard A, Paquin D, Cotes-Turpin C, Hoffman HG, Perreault I, et al. Effects of a projector-based hybrid virtual reality on pain in young children with burn injuries during hydrotherapy sessions: A within-subject randomized crossover trial. 2020;46(7):1571-84.
16. Lopes JBP, Duarte NdAC, Lazzari RD, Oliveira CSJJob, therapies m. Virtual reality in the rehabilitation process for individuals with cerebral palsy and Down syndrome: A systematic review. 2020;24(4):479-83.
17. Abbas JR, O'Connor A, Ganapathy E, Isba R, Payton A, McGrath B, et al. What is virtual reality? A healthcare-focused systematic review of definitions. 2023;12(2):100741.
18. Demers M, Fung K, Subramanian SK, Lemay M, Robert MTJJSJG. Integration of motor learning principles into virtual reality interventions for individuals with cerebral palsy: systematic review. 2021;9(2):e23822.
19. Kilcioglu S, Schiltz B, Araneda R, Bleyenheuft YJJSJG. Short-to long-term effects of virtual reality on motor skill learning in children with cerebral palsy: systematic review and meta-analysis. 2023;11(1):e42067.
20. Kaliyaperumal AB, Sekar K, Manickavelu P, Senthilmurugan S. Effect of Muscle Energy Technique and Stabilization Exercise on Forward Neck and Rounded Shoulder for Elite Swimmers. Indian Journal of Physiotherapy & Occupational Therapy Print(ISSN 0973-5666) and Electronic-(ISSN 0973-5674). 2023;17(1):1-6.
21. Tapia C, Constanzo J, González V, Barria RMJDN. The effectiveness of aquatic therapy based on the Halliwick concept in children with cerebral palsy: A systematic review. 2023;26(6-7):371-6.
22. Mujawar MMJRms, kineziterapija, ergoterapija. A systematic review of the effects of aquatic therapy on motor functions in children with cerebral palsy. 2022;2(27):51-67.
23. Ogonowska-Slodownik A, Güeita-Rodriguez J, Skomorowska K, Morgulec-Adamowicz NJJJoD, Development, Education. Effects on function and enjoyment of aquatic therapy in children with cerebral palsy: A pilot study in a special education school. 2025;72(5):924-33.
24. Sameeha S. Effects of aquatic therapy in children diagnosed with cerebral palsy: literature review. 2023.
25. Kraus K, Kraus N, Shtepa O. Synergetic effects of network interconnections in the conditions of virtual reality. 2021.
26. Melo RS, Carneira CSF, Rezende DSA, Guimarães-do-Carmo VJ, Lemos A, de Moura-Filho AGJPo. Effectiveness of the aquatic physical therapy exercises to improve balance, gait, quality of life and reduce fall-related outcomes in healthy community-dwelling older adults: A systematic review and meta-analysis. 2023;18(9):e0291193.