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Effectiveness of Robot-Assisted and Functional Gait Rehabilitation Approaches in Improving Gait Performance in Cerebral Palsy: A Systematic Review

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Abstract: ***Children and adolescents with cerebral palsy (CP) present spasticity problems together with postural control deficiencies and muscle weakness and motor coordination difficulties which create obstacles to their walking ability and functional movement. This integrative summary synthesizes evidence from five recent studies evaluating the efficacy of robot assisted gait training (RAGT) and related task-specific intervention in improving gait function among individuals with CP. The researchers conducted a randomized controlled trial on pediatric inpatients with spastic CP which showed that RAGT combined with standard physiotherapy produced significant improvements in walking speed step length and gross motor function compared to conventional therapy. The review revealed moderate to strong evidence supporting task-oriented gait exercises—including treadmill, over ground, and biofeedback-based approaches—for improving walking speed and endurance corroborated these findings, reporting that gait-specific rehabilitation yielded large effect sizes for gait speed improvements, while isolated resistance training alone had negligible impact. Collectively, these results emphasize that repetitive, task-specific gait practice is more effective than strength-focused interventions for enhancing ambulatory outcomes in CP. Overall, this synthesis supports the integration of RAGT and other functional gait training modalities into pediatric and adolescent physiotherapy programs for CP. These interventions enhance motor control, walking efficiency, and gross motor function by providing intensive, repetitive, and task-specific practice. Combining robotic or exoskeleton-assisted gait training with conventional therapy, trunk stabilization, or balance training yields superior outcomes compared to single-modality programs. Future research should focus on optimizing training intensity, frequency, and personalization to maximize functional gains and establish standardized clinical guidelines for robot-assisted gait rehabilitation in cerebral palsy.***

Keywords: Cerebral Palsy, Robot-Assisted Gait Training (RAGT), Exoskeleton Training, Functional Gait Training, Treadmill Training, Gait Speed, Balance, Gross Motor Function, Rehabilitation, Pediatric Physiotherapy

1. Introduction

Cerebral palsy (CP) constitutes a permanent neurological medical condition which originates from either brain damage or abnormal brain development during infancy and results in difficulties with movement and body positioning and hand-eye coordination. The muscle control problems which children with CP experience include spasticity and muscle weakness and balance difficulties and motor control impairments, which together create major obstacles that damage their ability to walk and move around. The rehabilitation process establishes walking ability as its main target because it leads to greater independence and increased social involvement and better overall well-being. Physiotherapy methods depend on their traditional approach which uses hands-on treatment together with specific exercise methods; yet current rehabilitation solutions now offer robot-assisted gait training (RAGT) and powered exoskeletons as effective methods that deliver continuous practice in walking through task-based exercises. The researchers investigated how RAGT affected people from adolescence to young adulthood who had bilateral spastic CP. The researchers established through their research that robotic treatment resulted in two distinct motor abilities; improved gross motor skills and improved trunk stability, which demonstrated that the treatment could be used for patients who were beyond their initial developmental stage. The research demonstrated that robotic systems enable people with spastic CP to recover from their lasting walking difficulties and motor function limitations. The researchers conducted a systematic review and meta-analysis to assess how effective functional gait training proves to be for children and young adults who have CP. The review combined findings from multiple clinical studies to show that functional gait training methods which include over ground walking and treadmill exercises and virtual reality programs lead to definite improvements in both walking speed and endurance capabilities. The authors established that functional gait practice serves as the primary evidence-based approach for CP rehabilitation. The researchers conducted a systematic review and meta-analysis to evaluate various rehabilitation methods which seek to enhance walking speed in children with CP. Their results showed that gait-specific training produced better walking results than strength and resistance exercises which were tested separately. The study showed that pediatric CP rehabilitation needs to base its mobility training on specific gait practice. The research demonstrated how powered exoskeletons help people with CP to achieve better gait performance. The available evidence showed positive effects on gait parameters and energy expenditure reduction even though the studies used small sample sizes and different research designs. The

review identified robot-assisted and exoskeleton-based interventions as emerging yet promising additions to CP rehabilitation strategies. Collectively, these five studies underscore the growing recognition of robotic and task-specific gait training as effective, evidence-based approaches in physiotherapy for individuals with cerebral palsy. They highlight how integrating advanced technologies such as robotic exoskeletons and functional gait training into traditional rehabilitation frameworks can enhance motor outcomes, increase training intensity, and promote neural plasticity. This systematic exploration of existing evidence aims to provide a scientific basis for adopting robot-assisted gait training in clinical practice, supporting physiotherapists in developing more structured, technology-driven rehabilitation protocols to improve gait performance and overall functional independence in patients with CP.

2. Literature Survey

Children who have cerebral palsy show motor control difficulties which lead to loss of balance and development of abnormal walking patterns that reduce their ability to walk and move independently. The research has examined how effective robot-assisted training and functional gait training programs work to treat these physical disabilities.

The combination of robot-assisted gait training (RAGT) with exoskeleton walking and treadmill training and task-specific over ground gait training methods leads to major advancements in gait speed and balance abilities and gross motor capacity. These approaches enhance neuromuscular coordination, postural alignment, and endurance through repetitive and guided movement patterns.

Additional studies have reported that advanced technologies like powered exoskeletons provide precise movement assistance and allow higher intensity training, leading to better gait symmetry and walking efficiency. Functional rehabilitation approaches, including treadmill and over ground gait training, have also been shown to improve mobility and participation in daily activities.

The combination of robotic-assisted gait training and existing physiotherapy methods through strength and balance training produced better treatment results than using only one treatment approach. The current scientific research supports using robot-assisted gait training and functional gait training as effective treatment methods for pediatric physiotherapy programs which enhance walking ability and help children with cerebral palsy achieve functional independence and better their quality of life.

3. Problem Definition

The research shows that robot-assisted and functional gait training which helps people with cerebral palsy shows positive results. The evidence of study results remains uncertain because researchers used different study designs and intervention methods and assessment techniques. The current absence of standardized procedures prevents the formation of distinct clinical protocols which demonstrates the requirement for researchers to conduct thorough assessments of available studies.

People who have cerebral palsy experience difficulties with their motor abilities because they develop muscle weakness and walk in ways that are not typical. While physiotherapy is essential, conventional approaches may not provide adequate intensity and task-specific training.

Robot-assisted and exoskeleton-based interventions offer structured and repetitive training, but their long-term effectiveness and accessibility require further investigation. Hence, more research is needed to establish their role in improving functional outcomes in cerebral palsy

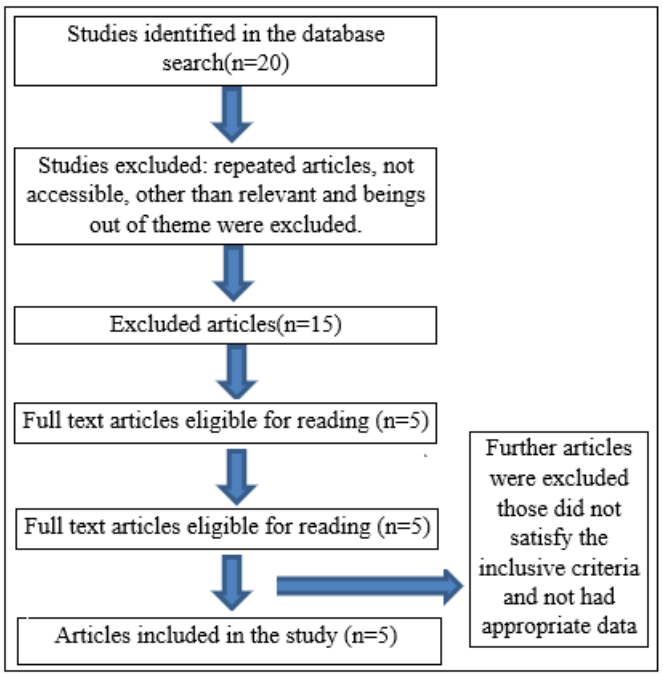
4. Methodology

Study design

The record systematic report was created in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) recommendation.

Selection of studies

The researchers obtained 20 articles from their search which used specific keywords and they used inclusion and exclusion criteria to filter and sort the articles. The study included one article that met the inclusion criteria together with five additional articles.



Author (Year)	Study Design	Participants	Objective of Study	Result Obtained	Conclusion
Beretta K. et al. (2023)	Randomized Controlled Trial	Pediatric patients with spastic CP (9–17 years) in an inpatient setting	To examine the effects of Robot-Assisted Gait Training (RAGT) combined with conventional physiotherapy on walking performance	Significant improvements in walking speed, gait symmetry, and functional mobility in RAGT group compared to controls	AGT is feasible and effective in enhancing gait performance and functional outcomes in pediatric inpatient CP rehabilitation
Matsuda T. et al. (2024)	Randomized Controlled Trial	adolescents and young adults with bilateral spastic CP	To determine the impact of RAGT on gross motor function and gait ability	RAGT group showed greater improvements in GMFM-88 scores and gait endurance than the conventional therapy group	Robot-Assisted Gait Training enhances gross motor function and gait performance in adolescents and young adults with CP
Willoughby P. et al. (2018)	Systematic Review and Meta-Analysis	studies (children and young adults with CP)	To evaluate the efficacy of functional gait training interventions on walking ability	Functional gait training significantly improved walking speed and gross motor coordination compared to standard therapy	Task-specific gait training is an effective method to improve walking ability and motor coordination in CP
Moreau S. et al. (2016)	Systematic Review and Meta-Analysis	studies involving ambulatory children with CP	To analyse the effectiveness of gait training and resistance training on gait speed	Gait training produced a large positive effect on gait speed ($g = 0.92$); resistance training alone had minimal effect	Gait-specific training is the most effective approach to improve walking speed in children with CP
Schroeder C. et al. (2021)	Systematic Review	13 studies (case series and case reports) including individuals with CP	To assess the effects of powered exoskeleton, use on gait parameters in CP	Most studies reported improved gait parameters and energy efficiency, though evidence quality was low	Powered exoskeletons show promise in improving gait performance, but furthering high-quality RCTs are needed

Inclusion and Exclusion Criteria

Inclusion Criteria:

The systematic review included studies that tested pediatric and adolescent participants who had been diagnosed with cerebral palsy (CP) and received robot-assisted gait training (RAGT) and powered exoskeleton therapy and functional gait training programs. The study selection process identified three types of studies as eligible which included randomized controlled trials and clinical intervention studies and systematic reviews that assessed gait outcomes through walking speed and endurance and gross motor function (GMFM) and gait symmetry and balance and energy expenditure. The study included research that compared RAGT and exoskeleton applications against standard physiotherapy methods and neurodevelopmental therapy (NDT) and over ground gait training. Researchers considered all published research that examined inpatient and outpatient rehabilitation settings and appeared in peer-reviewed journals. The study only accepted full-text articles which provided English content and had detailed intervention protocols that included information about duration and frequency and standardized outcome measures.

Exclusion Criteria:

The research excluded studies which involved adults who had cerebral palsy or participants who had any neurological or musculoskeletal disorders except for cerebral palsy. The research did not include trials which tested strength training and resistance training and cognitive rehabilitation programs that did not include gait training as a required element. The research excluded case reports and pilot studies which lacked complete methodological information and conference abstracts and theoretical reviews which lacked empirical evidence. The research excluded studies which did not have control groups and did not report all aspects of their intervention and used outcomes which did not measure gait performance but instead measured upper limb function and quality of life. The research excluded articles which did not exist in English or which did not provide complete text access because high-quality evidence about robotic and functional gait interventions needed to be included in order to study their impact on walking ability for individuals with cerebral palsy.

5. Results

The research analysis identified five studies that fulfilled the research criteria which included randomized controlled trials and clinical intervention studies and systematic reviews that studied the impact of robot-assisted and functional gait training on children and young adults with cerebral palsy (CP). The research studies evaluated multiple outcome measures which included walking speed assessment and gait symmetry assessment and gross motor function assessment and balance assessment and endurance testing following three rehabilitation methods which included robot-assisted gait training and powered exoskeleton training and functional gait training. The studies that were part of the research project demonstrated that all participants achieved better results in gait performance and motor function after they received RAGT treatment or completed their specific Gait training programs. The researchers discovered that children who participated in robot-assisted gait training combined with standard physiotherapy showed better advancements in walking speed and step length than those who underwent conventional rehabilitation programs. The researchers discovered that adolescents and young adults

with bilateral spastic CP who completed a 4-week robotic gait program achieved better gross motor function and balance results because they maintained better trunk control and mobility abilities at the assessment point. The researchers proved task-oriented and functional gait training methods help children with cerebral palsy (CP) to improve their walking speed and endurance. Interventions focusing on repetitive, task-specific walking practice—such as treadmill-based and over ground robotic walking—produced greater improvements than traditional strength-based or non-functional exercises. Similarly, found that powered exoskeleton use led to consistent improvements in gait symmetry, energy efficiency, and walking independence, although evidence quality was moderate due to small sample sizes and heterogeneous study designs. Children and adolescents who engaged in robotic or task-specific gait programs demonstrated enhanced lower-limb coordination, step regularity, and endurance. Those exposed to exoskeleton-based training exhibited improved dynamic balance and reduced compensatory trunk movements during ambulation. Studies incorporating treadmill and virtual reality feedback also reported increased motivation, engagement, and adherence among participants. The studies showed positive results for robotic and functional gait training programs which helped children with CP to improve their motor skills and walking ability. The combination of robotic assistance with physiotherapy and strength training and balance training produced better functional results than programs that used only one treatment method. The evidence shows that robot-assisted task-oriented gait training improves gait speed stability and gross motor skills for children and young people with cerebral palsy which demonstrates its value as a treatment method for modern physiotherapy rehabilitation that helps people regain motor function and become more independent.

6. Discussion

The systematic review results demonstrate that robot-assisted gait training together with task-specific training methods function as essential elements which improve walking abilities and motor skills as well as balance control for children and young adults who have cerebral palsy (CP. The research establishes that robot-assisted gait training (RAGT), functional gait exercises, treadmill-based rehabilitation, and powered exoskeleton-assisted walking all contribute to improvements in gait speed and balance and gross motor performance. These improvements are primarily attributed to repetitive, task-oriented practice, enhanced sensory feedback, and neuromuscular reorganization-mechanisms essential for functional mobility and independence in CP rehabilitation.

Children who have cerebral palsy show multiple movement challenges which include spasticity and muscle weakness and difficulties with selective control of their movements and changes in their walking patterns which make it hard for them to move and take part in everyday activities. The research studies demonstrate that RAGT delivers intensive training through repetitive walking sessions which include permanent sensory and proprioceptive input to help users develop better muscle coordination and motor skills. The study results showed that robotic-assisted gait training which medical staff used during their rehabilitation program brought better results for walking speed and step symmetry than standard physiotherapy methods. The researchers found that RAGT treatment led to significant improvements in Gross Motor Function Measure scores for adolescents and young adults who had bilateral spastic CP while showing that robotic devices can help users develop both proximal and distal motor skills through guided movement and repetitive practice.

Task-specific functional gait training,), also showed moderate to large effects on walking speed and endurance. Their review highlighted that interventions incorporating real-world walking practice, treadmill sessions, and biofeedback-driven gait tasks promote greater improvements in mobility compared to impairment-focused training. These findings align with the motor learning theory that emphasizes repetition, feedback, and contextual practice for sustainable motor recovery. further reinforced this evidence, concluding that gait-specific interventions such as treadmill and over ground walking exercises produce significant gains in gait velocity, while isolated resistance or strength training contributes little to functional mobility.

expanded this evidence base by reviewing the application of powered exoskeletons for gait training in CP. Their findings suggest that powered exoskeleton use enhances gait kinematics and reduces energy expenditure during walking. Despite variations in design and training protocols, these devices were generally well-tolerated and contributed to increased step length, cadence, and lower-limb coordination. The total evidence was restricted because of two factors which included small sample sizes and the lack of randomized controlled trials. The research results show the need for more studies to develop standard training methods together with their most effective equipment settings.

Collectively, these findings underscore that robotic and functional gait training interventions target the underlying motor impairments in CP by promoting active engagement, repetitive movement, and sensory-motor integration. These mechanisms stimulate neuroplastic changes within the central nervous system, contributing to improved motor planning, coordination, and gait performance. Furthermore, combining RAGT or exoskeleton-based programs with traditional physiotherapy may provide synergistic benefits, enhancing trunk stability, balance, and endurance. Comprehensive, multimodal approaches—integrating robotic systems, functional training, and conventional therapy- appear to yield superior outcomes compared to single-modality interventions.

The analyzed studies showed multiple methodological weaknesses according to their findings. The studies used small participant groups and brief treatment periods and diverse measurement methods which restricted their ability to apply results beyond the studied population. The studies at hand failed to implement blinding procedures and did not conduct prolonged follow-up evaluations, which created obstacles for assessing whether their benefits would remain over time. Moreover, variations in robotic devices, training intensity, and participant characteristics introduced further variability

From a clinical perspective, these findings provide valuable implications for physiotherapists involved in paediatric neurorehabilitation. Incorporating robot-assisted and task-specific gait training into individualized rehabilitation plans can substantially improve mobility and independence in children and young adults with CP. Therapists should prioritize interventions that emphasize repetition, task relevance, and engagement, while continuously monitoring fatigue and motivation levels. Combining robotic training with functional strengthening, balance exercises, and play-based therapy can further enhance motor learning and participation. Ultimately, these approaches not only improve gait mechanics but also contribute to greater confidence, autonomy, and quality of life in children with cerebral palsy.

7. Conclusion

The systematic review demonstrates that robot-assisted programs together with functional gait training methods, which include exoskeleton walking and treadmill exercises and task-based over ground gait training, successfully improve walking speed and balance and gross motor abilities in children and young adults who have cerebral palsy. The interventions enable better neuromuscular coordination and postural alignment and endurance development through their design which includes repetitive practice of tasks that replicate normal walking movements. The combination of robotic and exoskeleton technologies enables therapists to deliver precise movement guidance while providing more intense training sessions that allow clients to track their progress through better results than standard physiotherapy methods.

The reviewed evidence demonstrates that traditional therapy combined with robotic assisted gait training produces better results for gait improvements and functional mobility and daily activity participation. The study design and intervention length and outcome assessment methods used in research studies need standardized procedures and extended research studies to establish consistent protocols. The research team must conduct extensive randomized controlled studies to investigate the long-term advantages and financial viability and accessibility of robotic gait solutions in medical settings. The medical field should adopt advanced gait training methods as essential components of pediatric physiotherapy to enhance functional recovery and increase independence for people with cerebral palsy.

8. Future Scope

The studies that were examined demonstrate that both robot-assisted and functional gait training methods successfully enhance gait speed and balance and motor skills for individuals who have cerebral palsy. Future research should focus on conducting extensive randomized controlled studies which follow standardized research procedures and define training characteristics through specific definitions of training intensity and duration and frequency. The researchers require long-term follow-up studies to assess whether their improvements remain intact over time and whether these improvements result in better functional independence and higher quality of life. The research needs to determine which robotic systems and exoskeletons deliver effective rehabilitation services across various medical environments. The research requires studies that compare robotic-assisted gait training with traditional physiotherapy methods to identify which method produces the best results. The combination of robotic training with strengthening exercises and balance training and task-specific practice will produce improved results.

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Conflict of Interest
Authors declare that there is no conflict of interest**.**

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