

Effect of Lower Limb Weighted Treadmill Training on Strength and Range of Motion in Children with Spastic Diplegia: A Randomised Controlled Trial

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ABSTRACT

Introduction: Children with spastic diplegia commonly present with reduced muscle strength and limited joint mobility, particularly in the hip and ankle, which adversely impacts gait efficiency and functional mobility. Although treadmill training is widely utilised in paediatric neurorehabilitation, incorporating additional resistance through Lower Limb (LL) weights may enhance the muscular engagement. However, evidence supporting its effectiveness in improving strength and Range Of Motion (ROM) remains limited.

Aim: To determine the effectiveness of LL weighted treadmill training on hip flexor and ankle dorsiflexor muscle strength and joint ROM in children with spastic diplegia.

Materials and Methods: This randomised controlled trial was conducted at the outpatient Department of Paediatric Physiotherapy Unit, Justice KS Hegde Charitable Hospital and Kapikad Community Rehabilitation Centre, Mangaluru, Karnataka, India from March 2025 to March 2026. A total of 26 children with spastic diplegia were randomly allocated to an intervention group and a control group. The intervention group received treadmill training with added LL weights in addition

to conventional physiotherapy, whereas the control group underwent conventional physiotherapy alongside treadmill training without additional weights. The intervention was carried out over six weeks. Outcome measures included assessment of hip flexor and ankle dorsiflexor muscle strength and joint ROM using dynamometer and goniometer respectively. A paired t-test was utilised to evaluate significant changes between pre- and post-test measurements within each group, while an unpaired t-test was used to determine significant differences between the two groups. The level of significance was set at p-value <0.05.

Results: Both groups showed improvements following the intervention. However, the intervention group demonstrated greater improvement in muscle strength (p-value <0.05) and active ROM (p-value <0.05) compared to the control group. No statistically significant changes were observed in passive ROM in either group.

Conclusion: The LL weighted treadmill training combined with conventional physiotherapy significantly improved muscle strength and active ROM in children with spastic diplegia. This combined approach may serve as an effective adjunct to rehabilitation strategies aimed at optimising functional abilities.

Keywords: Cerebral palsy, Joint range of motion, Loaded treadmill training, Muscle strength, Resistance training

INTRODUCTION

Cerebral Palsy (CP) represents a group of permanent, non-progressive disorders affecting movement and posture, resulting from disturbances in the developing brain [1,2]. Rather than a single diagnostic entity, CP encompasses a wide spectrum of clinical manifestations that evolve with age. The condition was first described by William Little who associated perinatal complications such as birth asphyxia with motor impairments, thereby laying the foundation for understanding its neurological basis [2]. The global prevalence of CP ranges from 1.5 to 3.0 per 1000 live births, with notable geographic variations. High-income countries have reported a gradual decline in prevalence, approaching approximately 1.6 per 1000 live births, likely due to advancements in perinatal care, in contrast middle and low- income countries continue to report high prevalence rates, nearing 3 per 1000 live births [2]. In India, the pooled prevalence is estimated at approximately 2.95 per 1000 children, reflecting a substantial clinical and societal burden [3].

The aetiology of CP is multifactorial involving a complex interplay of prenatal, perinatal and postnatal factors [1,2]. Spastic CP is the most prevalent subtype affecting approximately 80% of cases, which primarily affect the LLs, leading to significant limitations in gait and functional mobility [4]. Children with spastic CP typically present with a combination of muscle weakness, reduced ROM, impaired selective motor control, and increased muscle tone, which

collectively contributes to inefficient and abnormal movement pattern [5,6]. Among the impairments, deficits at the ankle joint are particularly significant due to its essential role in gait. Adequate ankle dorsiflexion and plantar flexor control are required for forward propulsion and smooth progression during walking. However in children with CP, plantar flexor spasticity combined with dorsiflexor weakness often leads to equinus posture and toe walking [7]. In addition, proximal muscle weakness, especially of hip flexors, further limits the limb advancements during the swing phase. Increasing evidence indicates that muscle weakness is a key determinant of functional limitation in CP, which arises from a combination of altered neural mechanisms and structural changes in the muscle tissues, underscoring the need for interventions that specifically target strength deficits [8].

Evidence indicates that muscle weakness plays a major role than spasticity in limiting the motor function, leading to a shift in rehabilitation approaches from spasticity management to strength training [7]. Strengthening interventions have been shown to be safe and beneficial in improving muscle force production, neuromuscular activation, and functional outcomes in children with CP [9]. Concurrently, treadmill training is widely utilised as task-specific intervention that facilitates repetitive and rhythmic stepping in a controlled, weight-bearing environment, thereby enhancing gait performance and balance [10].

Compared with over ground walking on a stationary surface, treadmill training provides a continuously moving surface and allows walking velocity to be controlled, promoting repetitive and rhythmic stepping. However, treadmill walking may also alter the biomechanical characteristics of gait, with differences reported in spatiotemporal parameters and lower-limb joint kinematics compared with over ground walking [11].

Recent rehabilitation approaches have emphasised the integration of resistance principles into functional training. The addition of external loads, such as ankle weights during treadmill walking, introduces increased mechanical demand that can augment muscle activation, particularly during the swing phase. This may facilitate the neuromotor adaptation and improve coordination between proximal and distal muscle groups, including the hip flexors and ankle dorsiflexors, which are critical for effective gait [7]. Previous studies indicate that weighted gait training enhances muscle strength and gait performance in neurological disorders [10,12].

Although previous studies have investigated treadmill training with external loading in children with CP [7,12,13], evidence regarding its specific effects on muscle strength and joint ROM in children with spastic diplegia remains limited [12].

In particular, the effects of LL weighted treadmill training on the strength of the hip flexors and ankle dorsiflexors, which play important roles in LL advancement during gait, together with active and passive ROM, have not been adequately established. Therefore, the present study aimed to determine the effects of LL weighted treadmill training on hip flexor and ankle dorsiflexor muscle strength and hip flexion and ankle dorsiflexion joint ROM in children with spastic diplegia, compared with treadmill training without additional lower-limb loading.

MATERIALS AND METHODS

This single-blinded randomised controlled trial was conducted between March 2025 and March 2026. It included 26 children with spastic diplegic CP from Justice KS Hegde Hospital of Nitte (Deemed to be University) and Kapikad Community Rehabilitation Centre, Mangaluru, Karnataka, India. The study was approved by the Institutional Ethics Committee (IEC) of Nitte Institute of Physiotherapy, Nitte (Deemed to be University), Deralakatte, Mangaluru, Karnataka, India (NIPT/IEC/2025/2432; approved on 11-01-2025). Written informed consent was taken from the parents. The trial was prospectively registered with the Clinical Trial Registry-India (CTRI/2025/05/087697). This study was conducted and reported in accordance with the CONSORT 2010 guidelines.

Sample size calculation: The sample size was estimated based on a previous study conducted by Wagdy E et al., considering the mean difference of 0.45 in ankle dorsiflexor strength and pooled SD of 0.31 between the control and experimental groups. With a 5% level of significance and a statistical power of 95% for two-tailed test [12], the required sample size was calculated to be 13 participants per group, resulting in a total sample size of 26, using nMaster Software version 2.0. Participants were selected using convenience sampling.

Inclusion criteria: Children of either gender aged 5 -12 years, diagnosed with spastic diplegia, classified as Gross Motor Function Classification System (GMFCS) levels I-II and having Modified Ashworth Scale (MAS) grades 0-1+ were included in the study. The GMFCS is a five-level classification system used to classify gross motor function and functional mobility in children with CP, with Level-I representing the least and Level-V the greatest limitation [14]. The MAS is a clinical scale used to assess resistance to passive movements associated with increased muscle tone [15]. Participants were also required to follow simple verbal instructions.

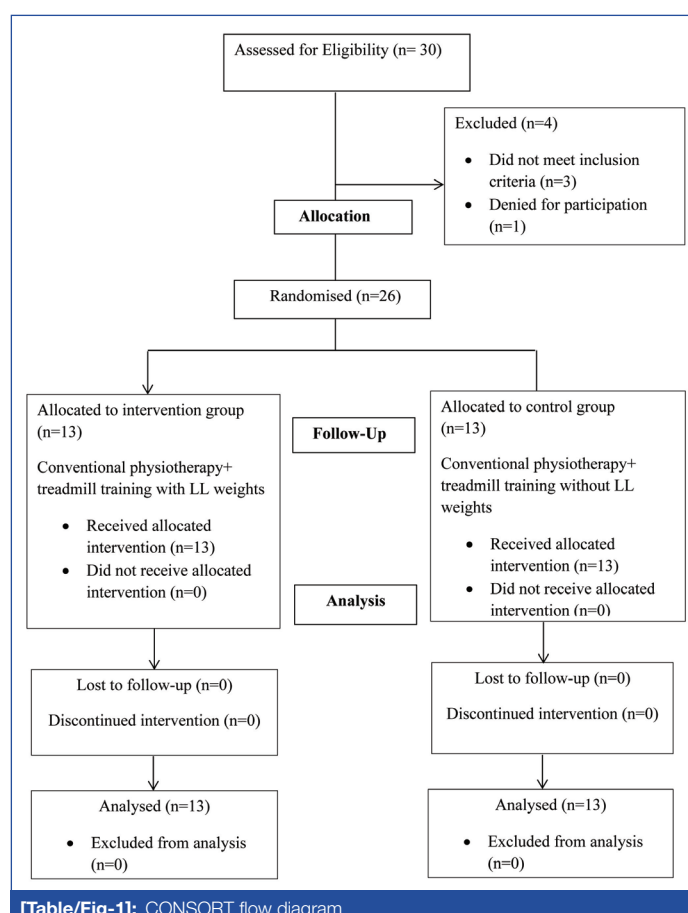
Exclusion criteria: Children with recurrent seizures, cardiovascular disease, auditory or visual impairments, fixed deformities of upper

and lower extremities, or those who had received botulinum toxin injections within last six months were excluded from the study.

Of the 30 children screened, four were excluded; one due to recurrent seizures, two for not meeting the diagnostic criteria and one declined participation. Therefore, 26 eligible participants were enrolled in the study.

Randomisation

Participants were randomly allocated in a 1:1 ratio to the intervention and control groups using simple randomisation. The random allocation sequence was generated using www.random.org by an individual separate from the primary investigator. The primary investigator enrolled the eligible participants and allocated them equally to the two groups [Table/Fig-1]. Allocation concealment was ensured using Sequentially Numbered, Opaque, Sealed Envelopes (SNOSE). The envelopes were opened after enrolment to reveal the group allocation. The outcome assessor was blinded to group allocation throughout the study. Due to the nature of the intervention, blinding of the participants was not feasible. Additionally, parents were instructed not to reveal the treatment allocation.



[Table/Fig-1]: CONSORT flow diagram.

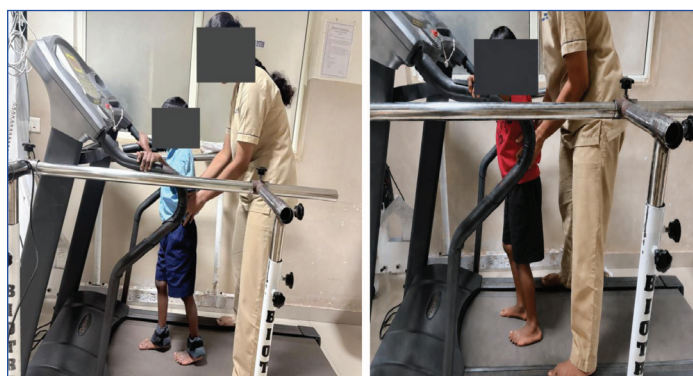
Procedures

Both the intervention and control groups received conventional physiotherapy and treadmill training as part of their treatment program. In addition, the intervention group received treadmill training combined with LL weights. Each session lasted 55 minutes, consisting of 35 minutes of physiotherapy and 20 minutes of treadmill training and was conducted four times/week for six weeks.

Baseline demographics including age, gender, Body Mass Index (BMI), MAS and GMFCS were recorded for all participants, prior to intervention. Baseline assessments also included measurements of hip flexor and ankle dorsiflexor muscle strength, as well as active and passive ROM of hip flexion and ankle dorsiflexion. The interventions were administered by the primary investigator, while the outcome assessments were performed by an independent physiotherapist, who remained blinded to the group allocation.

Intervention Group Treatment

The intervention group received conventional physiotherapy comprising stretching exercises, supported standing, balance training, squatting to standing activities, and gait training in different environments and directions [10]. Treadmill training was performed with zero degree inclination, with the treadmill speed individually adjusted for each participant within a range of 0.8-2.0 km/h, according to their comfortable walking speed. The speed was not progressively increased during the intervention; however, it varied between participants based on their individual walking ability and tolerance. Each session consisted of a 3-minute warm-up, 15 minutes of treadmill walking and a 2-minute cool-down. Participants were instructed to stop walking immediately if they felt pain, fainting, or shortness of breath, while walking on the treadmill [12]. Furthermore, resistance training was provided by attaching weights corresponding to 60% of LL mass around the anterior aspect of both the ankles using velcro straps to improve the muscle strength. The 60% loading was selected based on previous research by Simão CR et al., reporting more pronounced changes in LL kinematics with this loading level. The additional load was intended to increase mechanical demand on the LL musculature and provide strengthening stimulus during treadmill walking [16]. The LL mass was calculated using the Jensen's age based equation, in which foot ($0.00015 \times \text{age} + 0.0187$), leg ($0.00122 \times \text{age} + 0.3809$) and thigh ($0.00364 \times \text{age} + 0.06634$) masses were determined. Based on this calculation, 60% of LL mass was placed bilaterally during treadmill training [Table/Fig-2a] [13].



[Table/Fig-2]: (a) Treadmill training with Lower Limb (LL) weights; (b) Treadmill training without Lower Limb (LL) weights.

Control Group Treatment

The control group received the same conventional physiotherapy and treadmill training protocol as the intervention group, but without the application of additional ankle weights during treadmill training [Table/Fig-2b].

Outcome Measures

Isometric strength: Isometric strength of the hip flexors and ankle dorsiflexors was measured with baseline dynamometer using the 'make test'. The procedure was explained and a practice trial was provided before testing. Participants maintained the limb in a fixed position against examiner-applied resistance. Three trials were recorded for each muscle group with adequate rest intervals, and a verbal encouragement was provided to ensure maximal effort [17]. Each contraction was maintained for 5-6 seconds.

Hip flexors: Participants positioned in supine with the hip flexed to 90° , knee relaxed and ankle supported, and the dynamometer placed on the anterior thigh just proximal to the knee [18,19].

Ankle dorsiflexors: Participants were seated with hip at 90° , knee at 30° and the foot in neutral position, with the dynamometer placed proximal to the metatarsophalangeal joints [20].

Active and Passive Range of Motion (ROM): A standard universal goniometer was used to assess the active and passive ROM of hip flexion and ankle dorsiflexion in both LLs. All

measurements were performed by same assessor with proper stabilisation. Three readings were taken and the mean value was recorded.

Hip flexion: The child was positioned in supine lying, with the contralateral limb stabilised and the test knee maintained in a flexed position. The goniometer was aligned at greater trochanter with the stationary arm aligned towards anterior superior iliac spine and movable arm towards lateral femoral epicondyle. The child performed active hip flexion for AROM, while the therapist passively moved the limb to an end range for PROM.

Ankle dorsiflexion: The child was positioned in supine lying, with the knee maintained in an extended position. The goniometer was aligned at the lateral malleolus, with the stationary arm aligned towards fibula and movable arm parallel with fifth metatarsal. The child actively dorsiflexed the ankle for AROM and for PROM therapist passively moved the ankle to end range with subtalar joint maintained in neutral [21].

STATISTICAL ANALYSIS

The collected data were analysed using descriptive and inferential statistical methods. Statistical analysis was performed using Statistical Package for the Social Sciences (SPSS) Software version 23.0 (IBM Corp., Armonk, NY, USA). The normality of continuous variables was assessed using the Shapiro-Wilk test. Categorical variables were summarised as frequencies and percentages, while continuous variables were expressed as mean $\pm$ Standard Deviation (SD). Baseline characteristics including age, gender, BMI, GMFCS and MAS were compared between the intervention and control groups. Independent t-test was used for continuous variables, whereas Fisher's exact test was applied for categorical variables. Pre- and postintervention comparisons of hip flexor and ankle dorsiflexor muscle strength and ROM within each group were analysed using paired t-test. Between groups comparisons were performed using unpaired t-test. A p-value <0.05 was considered statistically significant.

RESULTS

The baseline characteristics of the study participants [Table/Fig-3] shows that the mean age was 7.08 ± 2.40 years in the intervention group and 8.08 ± 2.84 years in the control group, with no significant difference between groups (p-value = 0.342). Mean BMI was 13.32 ± 1.52 kg/m² in the intervention group, whereas the control group had a mean BMI of 15.70 ± 2.93 kg/m², which was also not significantly different (p-value = 0.056). The gender distribution was also comparable between the groups, with no statistically significant difference.

Parameters	Category	Intervention (n=13)	Control (n=13)	Total (n=26)	p-value
Age (years)	Mean $\pm$ SD	7.08 ± 2.40	8.08 ± 2.84	—	0.342
BMI (kg/m ²)	Mean $\pm$ SD	13.32 ± 1.52	15.70 ± 2.93	—	0.056
Gender, n (%)	Female	7 (53.8)	8 (61.5)	15 (57.7)	0.690
	Male	6 (46.2)	5 (38.5)	11 (42.3)	

[Table/Fig-3]: Baseline demographics of intervention and control group.

*BMI: Body mass index; SD: Standard deviation; †Independent t-test was used for age and BMI, and Fishers-exact test was used for gender, p>0.05- Not statistically significant

GMFCS levels and MAS grades were comparable between groups, with no statistically significant differences, indicating baseline homogeneity [Table/Fig-4].

All participants completed the planned 24 sessions, with no loss to follow-up or missed sessions. No adverse events were reported in either group throughout the intervention period.

At baseline, there were no statistically significant between-group differences in hip flexors or ankle dorsiflexors muscle strength (p-value >0.05). Following the intervention, the between-group analysis demonstrated statistically significant differences in favour.

	Category	Intervention	Control	Total	p-value
GMFCS	Level I	4 (30.8)	3 (23.1)	7 (26.9)	0.690
	Level II	9 (69.2)	10 (76.9)	19 (73.1)	
MAS	Grade 0	4 (30.8)	2 (15.4)	6 (23.1)	0.619
	Grade 1	3 (23.1)	3 (23.1)	6 (23.1)	
	Grade 1+	6 (46.2)	8 (61.5)	14 (53.8)	

[Table/Fig-4]: Baseline characteristics of intervention and control group.

*Fishers-exact test, p>0.05- Not Significant; GMFCS: Gross motor functional classification system; MAS: Modified Ashworth Scale

Hip Flexor and Ankle Dorsiflexor Strength

Within-group analysis using the paired t-test demonstrated statistically significant improvements in hip flexor and ankle dorsiflexor strength on both sides in both the intervention and control groups [Table/Fig-5]. At baseline, there were no statistically significant between-group differences in hip flexors or ankle dorsiflexors muscle strength (p-value >0.05). Following the intervention, the between-group analysis demonstrated statistically significant differences in favour of the intervention group for hip flexor and ankle dorsiflexor strength bilaterally (p-value <0.001) [Table/Fig-5]. The negative between-group mean differences reflect greater increases in postintervention strength in the intervention group, as the mean difference was calculated as preintervention minus postintervention. The corresponding 95% confidence intervals did not cross zero, supporting the statistical significance of these between-group differences. Thus, the intervention group demonstrated a greater improvement in lower-limb muscle strength than the control group.

Parameter-Strength				Mean±SD	Mean difference	SD of difference	95% Confidence Interval of the Difference		Effect size	Within group comparison using Paired t-test	Between group comparison using Unpaired t-test
							Lower	Upper		p-value	p-value
Hip flexors	L	Intervention	Pre	2.16±1.0	-0.66	0.19	-0.78	-0.54	0.927	<0.001	<0.001
			Post	2.82±1.14							
		Control	Pre	2.15±0.92	-0.23	0.11	-0.3	-0.16	0.824	<0.001	
			Post	2.38±1.0							
	R	Intervention	Pre	2.15±1.11	-0.65	0.2	-0.77	-0.52	0.917	<0.001	<0.001
			Post	2.8±1.23							
		Control	Pre	2.23±0.96	-0.27	0.09	-0.33	-0.21	0.897	<0.001	
			Post	2.5±1.04							
Ankle dorsiflexors	L	Intervention	Pre	1.18±0.67	-0.42	0.17	-0.53	-0.32	0.872	<0.001	<0.001
			Post	1.61±0.8							
		Control	Pre	1.1±0.29	-0.09	0.08	-0.14	-0.05	0.615	0.001	
			Post	1.19±0.31							
	R	Intervention	Pre	1.16±0.76	-0.44	0.16	-0.53	-0.34	0.896	<0.001	<0.001
			Post	1.6±0.83							
		Control	Pre	1.18±0.4	-0.08	0.08	-0.13	-0.04	0.548	0.002	
			Post	1.26±0.42							

[Table/Fig-5]: Comparison of strength of Hip flexors and Ankle dorsiflexors on both left and right-sides.

*SD: Standard deviation; L: Left; R: Right; †Within-group p-values were obtained using the paired t-test; between-group p-values were obtained using the unpaired t-test. Mean difference = pre-test - post-test; negative values therefore indicate an increase in the post-test value. p<0.05 was considered statistically significant and p <0.01- Highly significant. The effect size shown is the effect size reported for the within-group change

Hip flexion and Ankle dorsiflexion Active Range of Motion (ROM)

Both groups demonstrated significant within-group improvements in active hip flexion and ankle dorsiflexion [Table/Fig-6]. The intervention group showed significant improvements across all assessed AROM measures, while the control group also demonstrated significant changes.

At baseline, there were no significant between-group differences in hip flexion and ankle dorsiflexion AROM (p-value >0.05). The between-group analysis demonstrated statistically significant differences in favour of the intervention group for hip flexion and ankle

dorsiflexion AROM on both sides (p-value <0.001) [Table/Fig-6]. The negative mean differences indicate greater increases in AROM in the intervention group, and the corresponding confidence intervals excluded zero. These findings demonstrate that the intervention group achieved greater gains in active lower-limb mobility compared with the control group.

Hip flexion and Ankle dorsiflexion Passive Range of Motion (ROM)

No statistically significant within-group changes were observed in hip flexion or ankle dorsiflexion PROM in either group (p-value >0.05) [Table/Fig-7]. Consistent with these findings, the between-group analysis revealed no statistically significant differences in PROM for hip flexion or ankle dorsiflexion. The confidence intervals for the between-group differences included zero, indicating that the observed changes in PROM did not differ significantly between the groups.

Between Group Comparison

Overall, the between-group treatment effects were statistically significant for all assessed strength and AROM outcomes, consistently favouring the intervention group. In contrast, none of the PROM outcomes demonstrated a statistically significant between-group difference. The findings therefore indicate that the addition of lower-limb weights to treadmill training was associated with greater improvements in active muscle performance and active ROM, while no additional between-group benefit was demonstrated for passive ROM.

DISCUSSION

The study showed no statistically significant difference in the baseline demographic characteristics (age, gender, BMI, GMFCS and MAS) in both the groups (p-value >0.05), indicating that both groups were comparable at baseline. Similarly, preintervention measures of muscle strength and both active ROM and passive ROM were comparable across groups. This homogeneity at baseline ensures internal validity of the study and supports the postintervention differences.

The findings of the present study demonstrated significant improvements in muscle strength and AROM in both groups, with

Parameter-AROM				Mean±SD	Mean difference	SD of difference	95% Confidence interval of the difference		Effect size	Within-group using Paired t-test	Between group comparison using unpaired t-test
							Lower	Upper		p-value	p-value
Hip flexors	L	Intervention	Pre	101.46±4.99	-4.85	1.14	-5.54	-4.16	0.951	<0.001	<0.001
			Post	106.31±4.55							
		Control	Pre	95.69±4.09	-2.62	1.26	-3.38	-1.85	0.823	<0.001	
			Post	98.31±3.92							
	R	Intervention	Pre	100.54±6.12	-5.62	0.87	-6.14	-5.09	0.978	<0.001	<0.001
			Post	106.15±5.6							
		Control	Pre	95.54±5.03	-3.0	1.22	-3.74	-2.26	0.867	<0.001	
			Post	98.54±4.72							
Ankle dorsiflexors	L	Intervention	Pre	9.15±3.11	-1.31	0.95	-1.88	-0.74	0.674	<0.001	<0.001
			Post	10.46±2.73							
		Control	Pre	8.69±2.02	-0.54	0.78	-1.01	-0.07	0.343	0.028	
			Post	9.23±2.05							
	R	Intervention	Pre	8.77±2.8	-1.62	0.96	-2.2	-1.03	0.754	<0.001	<0.001
			Post	10.38±2.43							
		Control	Pre	9.15±2.12	-0.54	0.88	-1.07	-0.01	0.290	0.047	
			Post	9.69±2.5							

[Table/Fig-6]: Comparison of Active Range of Motion (AROM) of hip flexion and ankle dorsiflexion on both left and right-sides.

*SD: standard deviation; L: left; R: right; *Within-group p-values were obtained using the paired t-test; between-group p-values were obtained using the unpaired t-test. Mean difference = pre-test - post-test; negative values therefore indicate an increase in the post-test value. The p <0.05 was considered statistically significant and p <0.01 - Highly significant. The effect size shown is the effect size reported for the within-group change

Parameter-PROM				Mean±SD	Mean difference	SD of difference	95% Confidence interval of the difference		Effect size	Within group comparison using Paired t-test	Between group comparison using Unpaired t-test
							Lower	Upper		p-value	p-value
Hip flexors	L	Intervention	Pre	114.69±5.2	0.0	0.0	0.0	0.0	—	1.000	1.000
			Post	114.69±5.2							
		Control	Pre	108.23±5.07	0.0	0.0	0.0	0.0	—	1.000	
			Post	108.23±5.07							
	R	Intervention	Pre	114.15±5.27	0.0	0.0	0.0	0.0	—	1.000	1.000
			Post	114.15±5.27							
		Control	Pre	108.92±4.75	0.0	0.0	0.0	0.0	—	1.000	
			Post	108.92±4.75							
Ankle dorsiflexors	L	Intervention	Pre	15.31±2.5	0.0	0.0	0.0	0.0	—	1.000	0.063
			Post	15.31±2.5							
		Control	Pre	13.69±3.07	-0.08	0.28	-0.24	0.09	0.077	0.337	
			Post	13.77±3.11							
	R	Intervention	Pre	14.31±3.15	0.0	0.0	0.0	0.0	—	1.000	1.000
			Post	14.31±3.15							
		Control	Pre	14.23±2.92	0.0	0.0	0.0	0.0	—	1.000	
			Post	14.23±2.92							

[Table/Fig-7]: Comparison of Passive Range of Motion (ROM) of hip flexion and ankle dorsiflexion on both left and right-sides.

*SD: Standard deviation; L: left; R: right; *Within-group p values were obtained using the paired t-test; between-group p values were obtained using the unpaired t-test. Mean difference = pre-test - post-test; negative values therefore indicate an increase in the post-test value. p <0.05 was considered statistically significant. "—" indicates that an effect size was not calculated where the pre- and post-test values were identical

greater improvement observed in the intervention group. In contrast, PROM didn't show significant changes in either group (p-value >0.05). These findings indicate that treadmill training combined with LL weights may provide an additional stimulus for improving active muscle performance and joint movement in children in spastic diplegia.

The greater improvement in muscle strength in the intervention group may be explained by the additional external resistance provided during treadmill training. The applied load increased the mechanical demand placed on the lower-limb muscles during a repetitive, task-specific activity, thereby providing an additional strengthening stimulus. This interpretation is supported by previous research, investigating treadmill training with ankle loading in children

with CP, which has reported improvements in muscle strength and functional outcomes [12,22]. However, muscle activation and motor-unit recruitment was not directly assessed in the present study; therefore, these mechanisms cannot be confirmed and should be considered possible explanations rather than direct findings. The findings are consistent with previous evidence on loaded treadmill training. Wagdy E et al., reported improvements in ankle dorsiflexor strength and balance following treadmill training combined with ankle weights in children with spastic CP (p-value <0.05) [12]. Similarly, Alotaibi A et al., reported improvements in gait-related outcomes following loaded treadmill training in children with spastic diplegic CP (p-value=0.047) [22]. Simão CR et al., also reported changes in hip flexion during the swing phase following

additional ankle loading during treadmill walking (p -value =0.001) [13]. These findings provide support for the use of external loading to increase the challenge of task-specific gait training.

The improvement in AROM, particularly hip flexion and ankle dorsiflexion, may reflect enhanced voluntary motor control following repetitive, gait specific practice. Unlike PROM, AROM requires voluntary muscle activation and active control of the joint. Therefore, the greater improvement in AROM observed following loaded treadmill training may indicate that the intervention enhanced the participants' ability to actively produce the required movement during gait. This finding was consistent with Lorentzen J et al., who reported that increased mechanical demand during treadmill based intervention can improve active ankle mobility and reduce movement stiffness in children with CP (p -value <0.001) [23].

In contrast, PROM did not significantly improve in either group. This finding is clinically important because it indicates that the improvements in active movement were not accompanied by measurable changes in passive joint mobility. PROM is influenced by the extensibility of the muscle-tendon unit and other passive joint structures; therefore, active repetitive gait training may not provide a sufficient or sustained stimulus to produce measurable changes in passive mobility. Previous evidence suggests that interventions specifically involving sustained stretching or positioning may be more appropriate when the primary treatment goal is to modify passive ROM [24]. Thus, the absence of PROM improvement in the present study may explain why improvements were observed in active movement and strength but not in passive joint mobility.

Overall, the findings suggest that LL weighted treadmill training may offer an additional benefit over treadmill training alone for improving muscle strength and AROM in children with spastic diplegia. However, the intervention should not be interpreted as a treatment for limitations in passive joint mobility. Where PROM restrictions are clinically relevant, interventions specifically targeting passive mobility and tissue extensibility may need to be incorporated alongside task-specific strengthening and gait training.

Limitation(s)

Although the required sample size was achieved, the relatively small sample, convenience sampling, and single-centre recruitment may limit the generalisability of the findings. Blinding of participants and treating physiotherapist was not feasible, which may have introduced performance bias. Spasticity was assessed only at baseline and was not reassessed postintervention, therefore, changes in muscle tone and their potential influence on the study outcomes could not be determined. The absence of long term follow-up and functional outcome measures limits assessment of sustainability and functional significance of observed effects. Future research should focus on larger and more diverse populations, long-term follow up and the inclusion of functional outcome measures, while also exploring optimal resistance progression and the integration of loaded treadmill training with other rehabilitation strategies.

CONCLUSION(S)

Treadmill training combined with LL weights and conventional physiotherapy significantly improved muscle strength and active ROM in children with spastic diplegia. However, no significant improvement was observed in passive ROM, suggesting that additional interventions targeting soft-tissue extensibility may be required. The findings indicate that loaded treadmill training may be feasible adjunct to conventional physiotherapy for improving muscle strength and active ROM in children with spastic diplegia.

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REFERENCES

- [1] McIntyre S, Goldsmith S, Webb A, Ehlinger V, Hollung SJ, McConnell K, et al. Global prevalence of cerebral palsy: A systematic analysis. *Dev Med Child Neurol.* 2022;64(12):1494-506. Doi: 10.1111/dmcn.15346.
- [2] Sadowska M, Sarecka-Hujar B, Kopyta I. Cerebral palsy: Current opinions on definition, epidemiology, risk factors, classification and treatment options. *Neuropsychiatr Dis Treat.* 2020;1505-18. Doi:10.2147/NDT.S235165.
- [3] Jindal P, Macdermid JC, Rosenbaum P, Direzze B, Narayan A, Nayak SL. Treatment and rehabilitation of children with cerebral palsy in India: A scoping review. *Dev Med Child Neurol.* 2019;61(9):1050-60. Doi: 10.1111/dmcn.14211.
- [4] Vitrikas K, Dalton H, Breish D. Cerebral palsy: An overview. *Am Fam Physician.* 2020;101(4):213-20.
- [5] Youn PS, Cho KH, Park SJ. Changes in ankle range of motion, gait function and standing balance in children with bilateral spastic cerebral palsy after ankle mobilization by manual therapy. *Children.* 2020;7(9):142. Doi: 10.3390/children7090142.
- [6] Conner BC, Remec NM, Michaels CM, Wallace CW, Andrievic E, Lerner ZF. Relationship between ankle function and walking ability for children and young adults with cerebral palsy: A systematic review of deficits and targeted interventions. *Gait Posture.* 2022;91:165-78. Doi: 10.1016/j.gaitpost.2021.10.024.
- [7] El-Negmy EH, Ahmed HI, Amina SH, Khaled AO. Effect of ankle weight during gait training on dorsiflexors strength in hemiparetic children. *Med J Cairo Univ.* 2019;87:3619-24. Doi: 10.21608/MJCU.2019.69905.
- [8] Shin HI, Sung KH, Chung CY, Lee KM, Lee SY, Lee IH, et al. Relationships between isometric muscle strength, gait parameters, and gross motor function measure in patients with cerebral palsy. *Yonsei Med J.* 2016;57(1):217-24. Doi: 10.3349/ymj.2016.57.1.217.
- [9] Elanagar RK. Effects of plyometric exercises on muscle-activation strategies and response-capacity to balance threats in children with hemiplegic cerebral palsy. *Physiother Theory Pract.* 2022;38(9):1165-73. Doi: 10.1080/09593985.2020.1833389.
- [10] Sherief AE, Gazya AA, Abd El Gafaar MA. Integrated effect of treadmill training combined with dynamic ankle foot orthosis on balance in children with hemiplegic cerebral palsy. *Egypt J Med Hum Genet.* 2015;16(2):173-79. Doi: 10.1016/j.ejmhg.2014.11.002.
- [11] Grecco LA, Zanon N, Sampaio LM, Oliveira CS. A comparison of treadmill training and overground walking in ambulant children with cerebral palsy: Randomized controlled clinical trial. *Clin Rehabil.* 2013;27(8):686-96. Doi: 10.1177/0269215513476721.
- [12] Wagdy E, Adel Ahmed AM, Mohammed Hassan M, Ahmed Kamal O, Aziz MA, Mouhamed HA. Effect of treadmill training combined with ankle weight on balance in spastic cerebral palsied children: A randomized controlled trial. *SPORT TK.* 2024;13(Suppl 1):4. Doi: 10.6018/sportk.605581.
- [13] Simão CR, Regalado IC, Spaniol AP, Fonseca DO, Ribeiro TD, Lindquist AR. Immediate effects of a single treadmill session with additional ankle loading on gait in children with hemiparetic cerebral palsy. *Neuro Rehabilitation.* 2019;44(1):9-17. Doi: 10.3233/NRE-182516.
- [14] Palisano R, Rosenbaum P, Walter S, Russell D, Wood E, Galuppi B. Development and reliability of a system to classify gross motor function in children with cerebral palsy. *Dev Med Child Neurol.* 1997;39(4):214-23. Doi: 10.1111/j.1469-8749.1997.tb07414.x.
- [15] Bohannon RW, Smith MB. Interrater reliability of a modified Ashworth scale of muscle spasticity. *Phys Ther.* 1987;67(2):206-07.
- [16] Simão CR, Galvão ÉR, Fonseca DO, Bezerra DA, Andrade AC, Lindquist AR. Effects of adding load to the gait of children with cerebral palsy: A three-case report. *Fisioterapia e Pesquisa.* 2014;21(01):67-73. Doi: 10.1590/1809-2950/470210114.
- [17] Thompson N, Stebbins J, Seniorou M, Newham D. Muscle strength and walking ability in diplegic cerebral palsy: Implications for assessment and management. *Gait Posture.* 2011;33(3):321-25. Doi: 10.1016/j.gaitpost.2010.10.091.
- [18] Van den Beld WA, Van der Sanden GA, Sengers RC, Verbeek AL, Gabreëls FJ. Validity and reproducibility of hand-held dynamometry in children aged 4-11 years. *J Rehabil Med.* 2006;38(1):57-64. Doi: 10.1080/16501970510044043.
- [19] Crompton J, Galea MP, Phillips B. Hand-held dynamometry for muscle strength measurement in children with cerebral palsy. *Dev Med Child Neurol.* 2007;49(2):106-11. Doi: 10.1111/j.1469-8749.2007.00106.x.
- [20] Lidbeck C, Tedroff K, Bartonek Å. Muscle strength does not explain standing ability in children with bilateral spastic cerebral palsy: A cross sectional descriptive study. *BMC Neurol.* 2015;15(1):188. Doi: 10.1186/s12883-015-0441-y.
- [21] Norkin CC, White DJ. Measurement of joint motion: A guide to goniometry. 5th ed. Philadelphia: F.A.Davis; 2016.
- [22] Alotaibi A, Ibrahim A, Ahmed R, Abualait T, Jamal M. Comparative effects of partial body weight-supported and loaded treadmill training on motor performance in children with cerebral palsy: A randomized clinical Trial. *Medicina.* 2025;61(7):1125. Doi: 10.3390/medicina61071125.

- [23] Lorentzen J, Kirk H, Fernandez-Lago H, Frisk R, Scharff Nielsen N, Jorsal M, et al. Treadmill training with an incline reduces ankle joint stiffness and improves active range of movement during gait in adults with cerebral palsy. *Disabil Rehabil*. 2017;39(10):987-93. Doi: 10.1080/09638288.2016.1174745.
- [24] Hoffman RM, Corr BB, Stuber WA, Arpin DJ, Kurz MJ. Changes in lower extremity strength may be related to the walking speed improvements in children with cerebral palsy after gait training. *Res Dev Disabil*. 2018;73:14-20. Doi: 10.1016/j.ridd.2017.12.005.

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