European Review for Medical and Pharmacological Sciences 2024; 28: 2117-2126

The effect of upper limb loading with external weights on gait and trunk control in ambulatory children with spastic hemiplegic cerebral palsy: a randomized controlled trial

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Abstract. – OBJECTIVE: Children with hemiplegic cerebral palsy (CP) are typically ambulant with high motor functioning levels but with gait asymmetry and a greater risk of instability and falling. Physiotherapy is considered the core part of CP rehabilitation due to the risk of neurosurgery and the side effects of drug interventions. Although growing evidence has looked at the effect of upper limb loading during walking in many populations, such interventions in children with CP remain unexplored yet. The purpose of this study was to investigate if loading the upper limbs with external weights could improve walking speed, trunk control, and balance in ambulatory children with hemiplegic CP.

PATIENTS AND METHODS: The following outcome measures were recorded at baseline and six weeks after the intervention: gait speed [10-Meter Walk Test (10 MWT)], trunk control [Trunk Control Measurement Scale (TCMS)], and balance [Pediatric Balance Scale (PBS)]. Multiple 2 (groups) x 2 (time-points) mixed analysis of variance models (ANOVAs) were used for analysis.

RESULTS: Both groups showed a significant improvement ($p < 0.001$) in 10 MWT, TCMS, and PBS scores post-intervention. However, the magnitude of change in the outcome measures was higher in the intervention group (10 MWT = 0.59 m/s, TCMS = 10.41, PBS = 9.35) compared to the control group (10 MWT = 0.37 m/s, TCMS = 6.43, PBS = 4.68).

CONCLUSIONS: This study demonstrated that although both control and intervention groups showed improvements in terms of gait speed, trunk control, and balance, the intervention group that had upper limb loading showed higher significant improvements. Clinicaltrial.gov ID: NCT05444387.

Key Words:
Hemiplegic cerebral palsy, Upper limb loading, Gait speed, Trunk control, Balance.

Introduction

Cerebral palsy (CP) is a collection of sensory and motor disorders, as well as postural disorders, caused by non-progressive injury to the immature brain[1,2]. It can be classified according to the topographical presentation as monoplegia, hemiplegia, diplegia, and quadriplegia[2]. These obvious motor difficulties are frequently accompanied by cognitive disturbances and other neurologic difficulties[3]. CP is considered the most prevalent mobility disorder in children, with an average frequency of 3 per 1,000 live births worldwide and a high prevalence of 60 to 150 per 1,000 among preterm infants who are born weighing less than 1,500 g[4]. Hemiplegic CP accounts for 21% to 40% of all cases of CP[5,6].

Children with hemiplegic CP are typically ambulant with high motor functioning levels [Gross

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Motor Function Classification System (GMFCS) I/II] but with a gait asymmetry and a greater risk of instability and falling[7]. They show deviations in their spatiotemporal gait parameters. Their gait is asymmetric, as manifested by a shorter stance phase on the affected side compared to the unaffected side. In addition, these children have slower walking speeds and a more supported gait, with a longer double support phase (when both feet are in contact with the ground) than typically developing children[8,9]. There are four connected neuromuscular impairments present in children with spastic CP: muscle weakness, spasticity, short muscle-tendon length, and impaired selective motor control.

Children with spastic CP have poor trunk control owing to weak trunk muscle strength, altered neural control, and inadequate position sense[10,11]. Impaired trunk control in children with spastic CP is associated with balance dysfunction[12,13]. Balance is considered an important aspect of performing daily activities such as standing, walking, sitting, standing from a sitting position, and rambling activities. Children with CP appear to rely on 'guard' arm posture as a compensation strategy to maintain balance while walking compared to newly walking toddlers. The hand position of children with unilateral CP is more elevated and anterior, and their upper arm is rotated more posteriorly than typically developing children[14].

There is no cure for CP[15]. The World Health Organization (WHO) considers limb movement function as the main rehabilitation goal in children with CP[16]. Keeratisiroj et al[17] deem that walking capacity training of children with CP needs to be taken seriously. Physiotherapy is considered the core part of the rehabilitation of children with CP due to the risk of neurosurgery and the side effects of drug interventions[18,19].

Many studies[20-26] looked for the effects of facilitating and exercising the upper limbs on gait and balance; however, according to our knowledge, no studies investigated the effects of adding external weights on the upper limb on gait, trunk control, and balance in children with hemiplegic CP. The purpose of this study was to investigate if loading the upper limbs with external weights could improve walking speed, trunk control, and balance in ambulatory children with hemiplegic CP. We hypothesized that loading the upper limbs with external weights would improve gait speed, trunk control, and balance in ambulatory children with hemiplegic CP.

Patients and Methods

Study Design

This was an experimental, participant-blinded, randomized controlled trial. The procedures of the current study were approved by the Research Ethics Committee Boards of the College of Health Sciences at the University of Sharjah (number: REC-21-06-09-01-S) and the Ministry of Health and Prevention in the UAE (MOHAP/DXB-REC/ONN/No. 105/2021). The study was registered at clinicaltrial.gov (NCT05444387).

All parents were given a summary of the evaluation and treatment methods, after which they signed an informed consent form authorizing the child's participation stating, "I hereby consent to permit my child to take part in this study, and I agree that the information collected about my child from this study may be used for future studies. Participation of my child is voluntary, and I may withdraw him/her from the study at any time without any consequences. I know who to contact if I have any questions about the study in general".

Participants

Inclusion criteria for children were: (1) a diagnosis of hemiplegic CP, (2) age between six and eight years of both genders, as it has been found that children with CP walk independently between 3 and 5 years of age if they achieve the gross motor skills in the first two years (e.g., rolling and sitting without support)[27]. (3) The level of gross motor function is between level I and level II according to the GMFCS, (4) the degree of spasticity according to the Modified Ashworth Scale ranges between grade 1 and grade 2, (5) adequate cognitive and linguistic abilities (e.g., working memory, attention, and concentration) required to follow the therapist directions and instructions, (6) cooperative children and (7) Arabic or/and English speakers. On the other hand, children were excluded if they had any orthopedic surgery or spasticity-altering procedures in the previous 12 months or visual, auditory, vestibular, and perceptual deficits.

Fifty-two children with hemiplegic CP were recruited. Nine children were excluded for not meeting the eligibility criteria, four declined to participate, and the remaining thirty-nine were randomly assigned to two groups (control group and intervention group). During rehabilitation, five children did not receive allocated treatment. After rehabilitation, one child was lost to follow-up. The data of seventeen (n = 17) participants in the intervention group and sixteen (n = 16) participants in the control group were analyzed. The flowchart of the study is described in Figure 1.

Randomization

The sample size was determined using data from previously published studies[28,29] that investigated children with CP with similar age groups (5-18 years) compared to our participants (6-8 years).

All children with spastic hemiplegic CP were randomly assigned to two groups: the control group (balance exercises, stretching exercises, strengthening exercises, partial body weight support treadmill training, and gait training exercises) and the intervention group (same treatment in addition to upper limb loading) by a block randomization method. Randomization was stratified according to age (6-7 years or 7-8 years). For each stratum, the allocation sequence was generated from a random number generator with assignments sealed in sequentially numbered opaque envelopes. Following enrollment, a participant was assigned to a group by opening the next envelope. This process was administrated by an independent person not involved in the training programs.

Outcome Measures

Primary outcome measure

Self-selected gait speed during the 10-Meter Walk Test (10 MWT) was used. Each child was asked to walk on a 14 m walkway at a self-selected, comfortable speed. Measurements were obtained for the 10 m distance in the center of the walkway, while the remaining 2 m acceleration

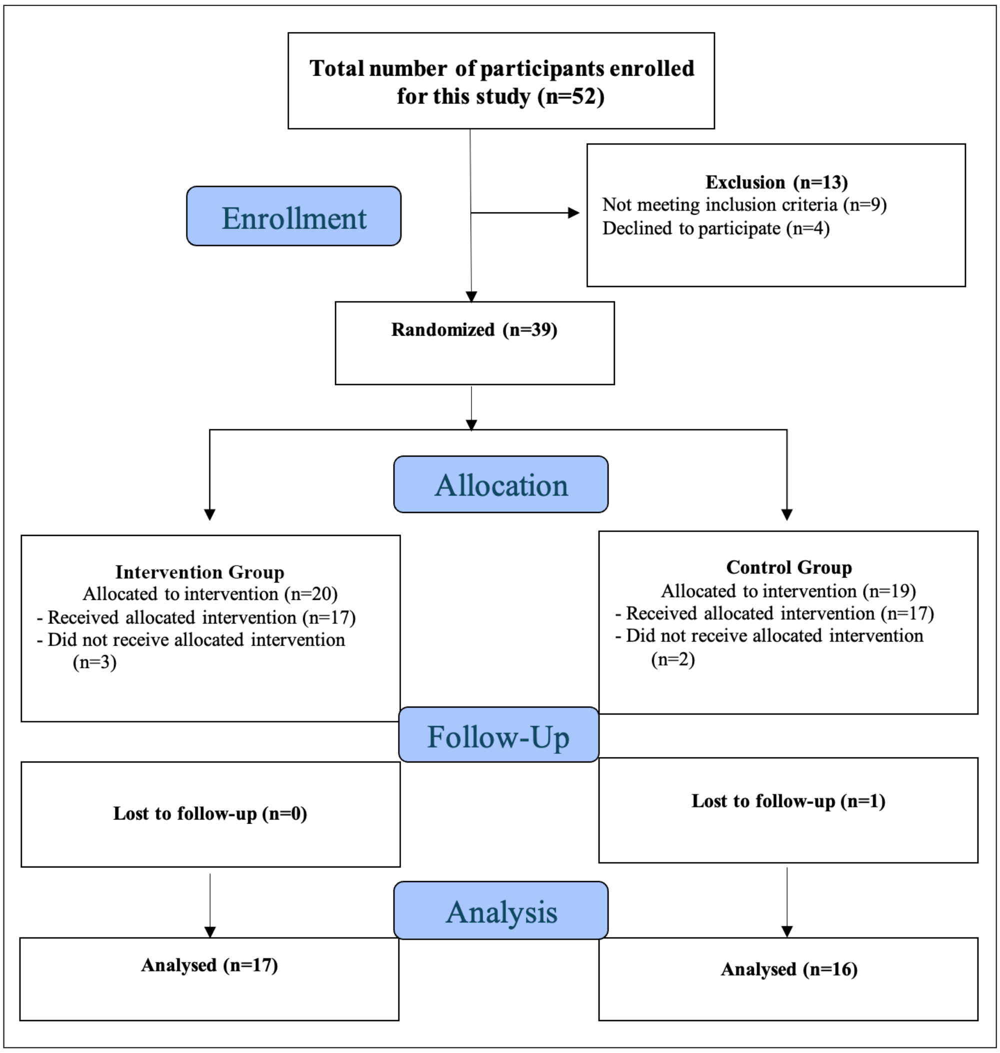

Figure 1. The flow of participants through the study.

and deceleration areas were excluded[30]. The 10 MWT was performed three times, and the average value was used. The participants were using their usual footwear and splints during the test. This test is valid[31] and has a great intra-rater and inter-rater reliability[32].

Secondary outcome measures

(1) Trunk Control Measurement Scale (TCMS) measures two main components of trunk control during functional activities: 1- being a stable base of support, and 2- being an actively moving body segment. Therefore, the scale consists of two sections: static sitting balance and dynamic sitting balance. The total scale contains 15 items. All items are scored on a two-, three- or four-point ordinal scale and administered bilaterally in case of clinical relevance. The total score of the TCMS ranges from 0 to 58, with a higher score indicating a better performance. TCMS helps in differentiating between children who are independent in self-care and mobility and those who are not[33]. It is valid[34] and reliable[35].

(2) The Pediatric Balance Scale (PBS) is valid[36] and reliable[37]. It is a widely used instrument for examining children with CP who have difficulty maintaining standing balance. It is made up of 14 three-dimensional components that include standing, sitting, and postural adjustments. Each item is graded on a scale of 0 to 4, with a higher score indicating greater balance[38].

All primary and secondary outcome measures were used twice for each child, at baseline and post-treatment (after six weeks).

Intervention

Children in the control group received balance exercises, stretching exercises, strengthening exercises, partial body weight support treadmill training, and gait training exercises for 60 minutes, and children in the intervention group received the same training program given to the control group with additional loading of the upper limbs (30 mins maximum for loading of the upper limb). Both groups received two sessions per week with at least one day in between for six consecutive weeks. The literature[39,40] has reported positive effects from training protocols consisting of 2 or 3 training sessions each week for between 6 and 12 weeks in children with CP and central gait impairments. The upper limb loading was administered during partial body weight support treadmill training, which was given for a maximum of 30 minutes and finished earlier if the child asked to stop or if the child stopped stepping[41]. A motorized treadmill with a minimum speed of 0.1 km/h was used (Gait Keeper mini: Mobility Research, Inc., Lillehøjvej, Silkeborg, Denmark). Partial body weight support was provided by a walking harness that provided full contact at the pelvis and trunk without limiting hip movement and the harness was attached to a mobile hoist[28] (Light Gait: Mobility Research, Inc., Tempe AZ, USA). Body weight support was systematically reduced, walking speed was progressively increased over the training period, upright standing posture was emphasized, and normal kinematic components of the gait cycle were facilitated during the training session[28,39,40].

To implement upper limb loading, external weights of 1 lb were wrapped around both wrists during partial body weight support treadmill training. The weight was tested on the child in the first session according to a pilot study in which children can keep holding a load for one minute without a definite change of standing balance[42,43].

Statistical Analysis

Descriptive statistics were used to identify each variable's mean and standard deviation. The Shapiro-Wilk test was used to check for the normal distribution of variables. An independent *t*-test was used to compare the age, height, and weight of participants in both groups, while the Chi-squared test was used for between-group comparison of gender, degree of spasticity score, GMFCS level, and side of hemiplegia. Finally, a mixed-model analysis of variance (ANOVA) was used to compare the means of the study and control groups in terms of all outcome measures. Post hoc analysis of significant findings was done using the Bonferroni correction. A threshold of $p < 0.05$ was used to determine statistical significance. The Statistical Package for Social Sciences (SPSS) software [SPSS 21 (IBM Corp., Armonk, NY, USA)] was used to perform all the statistical analyses.

Results

Thirty-three children with hemiplegic CP (23 boys and 10 girls) were recruited for this randomized controlled study. All demographic data were normally distributed. As illustrated in Table I, the independent *t*-tests showed no significant difference between the control and the intervention groups at baseline in terms of age, height, and weight (age, $p = 0.281$; height, $p = 0.611$; and weight, $p = 0.820$). Additionally, the Chi-squared

Table I. Participants' characteristics.

Variables	Intervention Group n=17	Control Group n=16	*p*-value
Mean ± SD			
Age (years)	6.97 ± 0.45	7.71 ± 0.53	0.281[a]
Height (cm)	114.96 ± 8.53	116.16 ± 7.36	0.611[a]
Weight (kg)	21.06 ± 3.86	21.81 ± 3.71	0.820[a]
N (%)			
Gender (male/female)	13 (76.5%)/4 (23.5%)	10 (62.5%)/6 (37.5%)	0.383[b]
Degree of spasticity (1/+1/2)	6 (35.3%)/7 (41.2%)/4 (23.5%)	6 (37.5%)/7 (43.8%)/3 (18.8%)	0.945[b]
Gross Motor Function Classification System (level I/level II)	9 (52.9%)/8 (47.1%)	10 (62.5%)/6 (37.5%)	0.579[b]
Side of hemiplegia (right/left)	13 (76.5%)/4 (23.5%)	11 (68.8%)/5 (31.3%)	0.619[b]

Data are illustrated as mean ± standard deviation and frequency (%), [a]refers to Independent *t*-test, [b]refers to Chi-square test. *p*-value is significant at < 0.05.

tests showed no significant differences between groups based on the number of participants categorized by gender, degree of spasticity, GMFCS levels, and the side of hemiplegia (gender, $p = 0.383$; degree of spasticity, $p = 0.945$; GMFCS levels, $p = 0.579$; and side of hemiplegia, $p = 0.619$).

There was a significant interaction between groups (intervention *vs.* control) and time (pre- *vs.* post-intervention scores) in the mixed-model ANOVA for 10MWT ($p = 0.007$), TCMS ($p < 0.001$), and PBS ($p < 0.001$). The main effects of groups and time were not interpreted as there was a significant interaction between groups and time. Both groups showed an increase in the post-intervention mean values of all outcome measures compared to the pre-intervention scores. Post-hoc within-group comparisons showed that the post-intervention means of 10MWT, TCMS, and PBS were significantly higher than the pre-intervention scores for both groups ($p < 0.001$) with a higher mean difference in the intervention group (10MWT = 0.59 m/s, TCMS = 10.41, PBS = 9.35) compared to the control group (10MWT = 0.37 m/s, TCMS = 6.43, PBS = 4.68) as illustrated in Table II.

Discussion

The present study was conducted to investigate the effects of upper limb external weights on gait, trunk control, and balance in children with spastic hemiplegic CP. The results of the current study showed a significant improvement in gait speed, trunk control, and balance measured after six weeks in children who were treated with and without loading the upper limbs with external weights. However, greater improvements were noticed in the group treated with loading the upper limbs with external weights.

Gait Speed

The improvement in gait speed recorded by the intervention group was anticipated in many previous studies[21,44,45] that identified that involving the upper limbs in rehabilitation positively reflects on gait parameters in people with neurological conditions. Loading the upper limbs with external weights during walking increases the total arm-swing amplitude and pelvic rotation, leading to an increase in cadence, stride length, and swing phase, therefore, a higher gait speed[44].

There was a higher significant improvement in pre- to post-comparison of gait speed in the intervention group in this study. This finding comes in line with a study[44] that was done on patients with Parkinson's disease in which gait patterns with and without arm weights placed on the distal forearm were compared using a three-dimensional motion capture system, and a higher walking speed was found when walking with additional arm weights than without arm weights.

Loading the upper limbs during walking contributes to an increase in step length and cadence of the hemiparetic side[45]. Furthermore, a similar finding in gait speed was found in hemiplegic stroke survivors when a study[45] compared the over-ground preferred walking speed with and without loading the upper limbs.

Table II. Comparison of pre-intervention and post-intervention outcome measures of the intervention and control groups.

Variables	Groups	Pre	Post	Pre-Post-Intervention comparison		Mean difference (95% CI) in change scores between groups	Interaction (groups*phases)[a]	
		Mean ± SD	Mean ± SD	*p*-value	Mean difference (95% CI)		*p*	F (df)
10-Meter Walk Test (m/s)	Intervention group N = 17	0.53 ± 0.10	1.12 ± 0.31	< 0.001	0.59 (0.48, 0.70)	-0.22 (-0.37, -0.06)	0.007	8.22 (1.31)
	Control group N = 16	0.54 ± 0.13	0.92 ± 0.22	< 0.001	0.37 (0.26, 0.48)			
Trunk Control Measurement Scale	Intervention group N = 17	34.17 ± 2.92	44.58 ± 3.22	< 0.001	10.41 (9.48, 11.34)	-3.97 (-5.31, -2.63)	< 0.001	36.67 (1.31)
	Control group N = 16	34.18 ± 3.27	40.62 ± 3.03	< 0.001	6.43 (5.47, 7.39)			
Pediatric Balance Scale	Intervention group N = 17	35.17 ± 3.02	44.52 ± 2.91	< 0.001	9.35 (8.24, 10.46)	-4.66 (-6.25, -3.07)	< 0.001	35.80 (1.31)
	Control group N = 16	35.50 ± 2.96	40.18 ± 3.83	< 0.001	4.68 (3.54, 5.82)			

[a]Results of 2*2 (group*time) mixed-model analysis of variance.

A higher significant improvement in the intervention group could be attributed to an improvement in interlimb coordination. The engagement of the upper limbs eased the swinging motion of the arms, resulting in a decrease in the angular momentum around the vertical axis and consequently reducing the vertical ground reaction moment. Reduction in the vertical ground reaction moment is likely to be accompanied by decreased energy consumption of legs, and therefore faster walking[46,47]. Our study findings come in line with the Hussein et al[21] study, which used arm cycle as a treatment for children with hemiplegic CP and found an improvement in interlimb coordination in addition to an increase in the angular displacement of the lower limb joints (hip, knee, and ankle) and a concomitant improvement of the arm swing.

Trunk Control and Balance

Importantly, in improving the gait speed, there were recorded improvements in trunk control and balance in children with hemiplegic CP. Rationally, this could be attributed to the dependency of the functional activities on the stability of the trunk to carry out the movements of the upper and lower extremities[48]. According to neurodevelopmental principles, movements of extremities are controlled in a proximodistal fashion with the trunk, where the trunk has a vital role in movement control of the extremities and further development of balance and functional mobility[49,50].

In addition to that, there has been a significant correlation between trunk control measured by TCMS and balance measured by PBS in children with spastic CP[48]. An explanation for the higher improvement in trunk control and balance recorded in the intervention group could be the neurologic reorganization in the motor cortex. When both arms are loaded and moved during walking, the "template" generated by the undamaged hemisphere may provide normal motor plans to assist in restoring the movement pattern of the hemiplegic side[51]. In the study by Luft et al[52], bilateral repetitive arm training over six weeks induced changes in the movement-related cortical activation patterns in chronic stroke survivors. This suggested cortical reorganization in the form of increased recruitment in sensorimotor areas of the contralesional hemisphere (precentral gyrus, postcentral gyrus) and in the ipsilateral cerebellum, and patients with such changes, arm function improved. These improvements in the cerebellum and arm function could lead to improvement in balance, which comes in line with the significant balance improvement measured in the intervention group of this study.

Significant improvement in gait speed, trunk control, and balance of both intervention and control groups manifested by an increase in the interlimb coordinated stability might be due to the same gait training program given to both groups, as gait training might improve muscle strength around the knee joint which attributed in the increasing balance that played an important role in improving the children's function[53]. Furthermore, gait training might stimulate the sensorimotor system toward regaining normal function by facilitating weight-bearing to improve limb alignment[39].

Limitations

Our study has some limitations, each of which will lead to a future investigation. First, the lack of follow-up assessment might have had important effects on the sustainability of the treatment effect in children with hemiplegic CP. Second, CP has a highly heterogeneous phenotype, so the effect of upper limb loading was studied among children with hemiplegic CP only. Applying this rehabilitation program to different forms of CP might have good outcomes.

Conclusions

This study demonstrated that both control and intervention groups (who received balance exercises, stretching exercises, strengthening exercises, partial body weight support treadmill training, and gait training exercises with and without upper limb loading) showed improvements in terms of gait speed, trunk control and balance. However, the intervention group that had upper limb loading with external weights showed significantly higher improvements in the outcome measures compared to the control group.

Conflict of Interest

The authors declare that they have no competing interests.

Funding

None.

Acknowledgments

The authors extend their appreciation to the children and parents who participated in the study.

Authors' Contributions

Conceptualization: Alya Alkhajeh, Ashokan Arumugam, Fatma Hegazy. Data curation: Alya Alkhajeh, Ehab Abd El Kafy Formal analysis: Alya Alkhajeh, Ashokan Arumugam, Ehab Abdelkafy. Investigation: Alya Alkhajeh, Fatma Hegazy. Methodology: Alya Alkhajeh, Ashokan Arumugam, Ehab Abd El Kafy, Fatma Hegazy. Project administration: Fatma Hegazy Resources: Alya Alkhajeh, Fatma Hegazy. Supervision: Ashokan Arumugam, Fatma Hegazy. Software: Alya Alkhajeh, Ashokan Arumugam. Validation: Alya Alkhajeh, Ehab Abd El Kafy. Visualization: Ashokan Arumugam, Fatma Hegazy. Writing – original draft: Alya Alkhajeh. Writing – review and editing: Ashokan Arumugam, Fatma Hegazy.

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Data Availability

All data are available within the submitted manuscript.

Trial Registration Number

NCT05444387.

Ethics Approval

Procedures of the current study were approved by the Research Ethics Committee Boards of the College of Health Sciences at the University of Sharjah (number: REC-21-06-09-01-S) and the Ministry of Health and Prevention in the UAE (MOHAP/DXB-REC/ONN/No. 105/2021).

Informed Consent

All parents were given a summary of the evaluation and treatment methods, after which they signed an informed consent form authorizing the child's participation stating, "I hereby consent to permit my child to take part in this study and I agree that the information collected about my child from this study may be used for future studies. Participation of my child is voluntary, and I may withdraw him/her from the study at any time without any consequences. I know who to contact if I have any questions about the study in general".

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