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Pamukkale J Sport Sci, 16(1), 133-153, 2025 **Research Article**

Enhancing Balance, Strength, Flexibility and Spatiotemporal Gait Parameters in Pediatric Cerebral Palsy: Treadmill Training at Variable Inclinations

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ABSTRACT

This study aimed to evaluate the effect of treadmill training at different inclinations on balance, strength, flexibility, and gait parameters in children with cerebral palsy in addition to traditional physiotherapy applications. Forty-two participants with cerebral palsy aged 7–18 years and at Gross Motor Function Classification System level II were randomized into three groups: downhill walking, uphill walking, and walking with no incline. Balance, isometric strength, flexibility, and gait parameters were assessed at baseline (2nd week) and at 11th week. The groups were provided with treadmill training and conventional treatment. All groups showed improvement in balance. Isometric strength values showed improvement in knee flexion on the affected side for both downhill walking and uphill walking groups, as well as in knee extension force for the uphill walking and walking with no incline groups. In flexibility, hip flexion, hip extension, and ankle dorsiflexion improved in all groups, while knee flexion and ankle plantar flexion improved only in downhill walking and walking with no incline. The duration of the modified timed up-and-go test showed significant improvements in both the downhill walking and uphill walking groups. Treadmill training performed at different inclinations improved balance, isometric strength, flexibility, and gait parameters on both the affected and less affected sides.

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INTRODUCTION

Cerebral Palsy (CP) is a common cause of motor disability among children (Cortés-Pérez et al., 2022). Individuals with CP have problems with daily activities such as walking and climbing stairs due to neuromuscular disorders including spasticity, muscle weakness, decreased joint flexibility, and poor coordination (Valadão et al., 2021). Improvement of the motor function of children with CP, particularly their ability to walk independently, is crucial for clinicians (Cherng et al., 2007).

Walking is an essential and important activity for daily living and social participation. Because of the complexity of gait, particularly pathological gait, it is often difficult to identify, quantify, understand the deficits of a particular patient, detect gait disorders, and make clinical decisions. Clinical gait analysis is used to facilitate this process and make the right decisions (Armand et al., 2016). Clinical gait analysis in individuals with CP has shown that these individuals have short step lengths and step widths, reduced cadence of gait, and poor dynamic gait stability (Dimakopoulos et al., 2022).

Treadmill training (TT) is a therapeutic technique in the rehabilitation of children with CP. Positive effects of different TT protocols have been observed in patients with CP; however, no study has examined the effects of forward-downhill TT. Therefore, this study aimed to investigate the effect of TT with forward downhill walking (DW), forward uphill walking (UW), and forward walking with no incline (WWI) on balance, strength, flexibility, and gait parameters in 7–18-year-old children with hemiparetic and diparetic CP in addition to traditional physiotherapy applications.

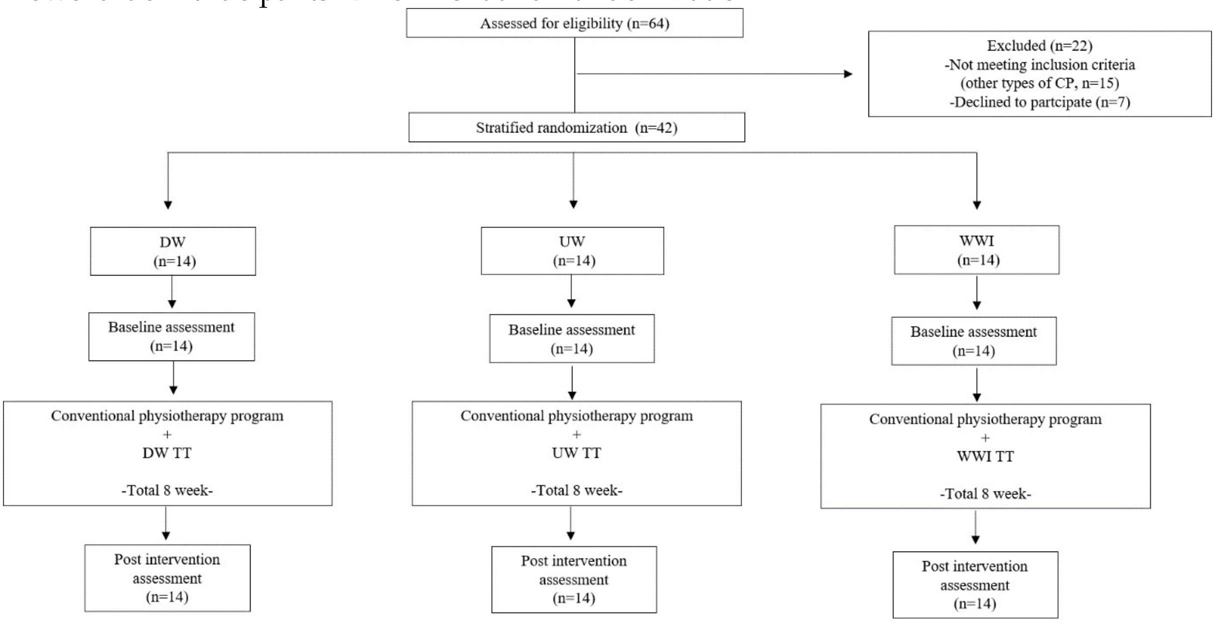
METHODS

Participants

Forty-two participants (18 females, 24 males) with hemiparetic and diparetic CP completed the study (Figure 1). The inclusion criteria for the study were (a) age between 7–18 years old, (b) being at Gross Motor Functional Classification System (GMFCS) level II, (c) no cooperation problems that would interfere with communication, (d) no surgical treatment or neuromuscular injection in the last six months (e) no uncontrolled epileptic seizures, (f) asymmetric lower extremity shortness >4 cm and (g) no any health problems except CP. Exclusion criteria from the study included trauma during the study period, not participating in the exercise program by more than 20%, and being willing to quit voluntarily. The study was approved by the Pamukkale University Clinical Research Ethics Committee (Number: 60116787-020-35801 and year: March 24, 2021).

Figure 1

Flowchart of Participants' Enrollment and Randomization



Note. DW: downhill walking, UW: forward uphill walking, WWI: forward walking with no incline, TT: Treadmill Training

Procedures

To ensure that the gender and age distributions in the groups were similar, a randomization table was prepared using a stratified randomization method prior to the study. The study lasted a total of 11 weeks. In the first week, for familiarization, both the measurements to be applied and walking trials on the treadmill were performed. Measurements were performed on two days in the second and the 11th weeks. While demographic information of the participants was obtained only at the beginning of the measurements, balance and strength measurements were taken on day one, flexibility and gait parameters measurements were taken on day two. The affected side (AS) / less affected side (LAS) of the participants were determined according to the first step they took after standing up in the Modified Up and Go Test. The first step was considered the LAS.

After the initial measurements, all participants received a conventional physiotherapy program, two days a week, and 40 minutes a day. In addition to this program, the first group performed DW TT, the second group performed UW TT, and the third group performed WWI TT walking exercise on the treadmill for two days a week, 30 minutes a day, on different days for 8 weeks. A conventional physiotherapy program, walking exercises, and measurements were conducted by the same physiotherapist.

Measurements

Balancing ability was evaluated using the functional reach test (FRT), which is a reliable and valid assessment tool for assessing balance among children with CP (Niznik et al., 1996). Participants were instructed to stand upright next to the wall and extend their arms straight ahead with their hands in fists. Then, they were instructed to reach as far forward as they could without falling, without their heels lifting off the floor and touching the wall. The distance between the first and last projections of the 3rd metacarpal joint was recorded in centimeters. Three repetitions were made, the average of the last two was taken (Duncan et al., 1990).

The isometric muscle strength is a reliable assessment tool for assessing isometric strength among children with CP (Willemse et al., 2013). Knee flexion force (KFF) and knee extension force (KEF) measurements were taken using a hand-held dynamometer (JTECH Medical PowerTrack II Commander, Salt Lake City, UT, USA) while the participants were sitting on a chair. The hands were crossed on the chest, and the legs were fixed with a belt. The force was applied from the front and back of the tibia, 5 cm above the malleolus. A performance test was conducted in which the researcher stabilized the dynamometer, and the participant pushed the dynamometer hard for 3 s, during which the peak force was assessed. The mean scores of the three tests were used for the analysis (Scholtes et al., 2008).

For flexibility measurements, the joint range of motion (ROM) was assessed manually using a goniometer. Hip flexion (HF), hip extension (HE), knee flexion (KF), ankle dorsiflexion (AD), and ankle plantar flexion (APF) were measured twice with the participant's active participation. In the active ROM measurement, the researcher moved the limb with the active arm of the goniometer to the end during the movement (Otman & Köse, 2014).

Participants' gait performance was assessed with the LEGSystm spatiotemporal gait analyzer (LegSys/BioSenics, Watertown, USA) (Aminian et al., 2002). Two sensors (left and right) were placed at the midpoint of the participant's tibia. The data was sent via Bluetooth™ to a computer using the device's own software. The modified timed up-and-go (MTUG) test, which is also available on the device interface, was used for evaluation. The participant was seated on a chair. On the command "go," the participant stood up from the chair, walked 3 m, turned around, walked back to the chair, and sat down again. The time elapsed between the moment of standing up from the chair and the moment of sitting down again was recorded in seconds (Dhote et al., 2012). Participants completed the test barefoot, without any auxiliary aids, and physical assistance. Participants were given two trials, and the average time of the two trials was recorded as MTUG total time (MTUGTT) for data analysis (Tekin & Kavlak, 2021). Stride length (SL), stride times (ST), stride velocity (SV), average velocity (AV), cadence (CD), swing phase (SWP), stance phase (STP), and double support phase (DSP) parameters were also recorded (LEGSysTM, 2015).

Conventional physiotherapy intervention

The conventional physiotherapy program consisted of various active and passive motion exercises, as well as stretching and strengthening exercises. The program also included postural control exercises, joint mobilization for joint alignment, spasticity inhibition, approximation exercises, muscle facilitation, functional exercises, balance exercises, gait exercises, and sensory exercises, and was tailored to each case (Berker & Yalçın, 2010).

Treadmill Training Intervention

Participants engaged in familiarization trials in the first week. For the next eight weeks, the first group walked downhill on a treadmill with a 9% inclination (Figure 2A), the second group walked uphill with a 9% inclination (figure 2B), and the third group walked parallel to the ground with a 0% inclination (Figure 2C). The literature emphasizes that as the incline increases, it becomes more challenging for children with CP to walk without assistance or support (Willerslev-Olsen et al., 2015). In this study, it was also observed that during familiarization, walking without assistance or support was not possible at inclines greater than 9%, and walking patterns were disrupted. Therefore, a 9% incline was chosen. During the 30-min walking period, the speed of the treadmill was set at 1.5 km/h, the speed at which all participants were able to complete the walk. Five minutes of warm-up and five minutes of active stretching exercise before walking, and five minutes of cool down and five minutes of passive stretching exercises were performed after walking.

Figure 2
Treadmill Traning Intervention

Note. Treadmill Walking for A) -9% Downhill Incline, B) +9% Uphill Incline, C) with No Incline

Data Analysis

All statistical analyses were performed using IBM SPSS Statistics software (version 25.0; IBM Corp., Armonk, NY). Continuous variables were expressed as mean ± standard deviation, median (interquartile range), and categorical variables as number and percentage. The Shapiro–Wilk test was used to test for normality. For data satisfying parametric test conditions, a one-way analysis of variance with Tukey's post-hoc test was used for comparisons among groups. For data not satisfying parametric test conditions, Kruskal–Wallis variance analysis (post hoc: Mann–Whitney *U* test with Bonferroni correction) was used for comparisons among groups. For pairwise comparisons, the paired samples t-test was used when parametric test conditions were satisfied, and the Wilcoxon signed-rank test was used when parametric test conditions were not satisfied. The chi-square test was used to compare the categorical variables. A p-value of less than 0.05 was considered statistically significant. Pre-intervention values were subtracted from post-intervention values during the calculation of difference or delta values.

RESULTS

Table 1 presents the demographic characteristics of all participants for each group, including their classifications and the homogeneity between groups (p>0.05).

Table 1
Demographic Characteristics and Classifications of All the Participants

Variables		DW (n=14)		UW (n=14)		WWI (n=14)		p (F/ χ^2)
		Mean ± S.D.	Med (IQR)	Mean ± S.D.	Med (IQR)	Mean ± S.D.	Med (IQR)	
Age (yr)		13.64±2.27	13.00 (11.75-16.00)	12.64±2.68	12.00 (10.75-14.25)	13.07±2.64	12.5 (11.00-14.75)	p = 0.583 (F=0.547)
Height (cm)		152.07±11.84	151.00 (142.75-163.50)	145.00±15.09	140.5 (135.00-161.25)	148.14±15.06	148 (138.00-163.50)	p = 0.42 (F=0.887)
Weight (kg)		53.00±7.10	54.50 (47.25-59.25)	47.14±8.33	47.00 (40.75-54.5)	51.21±10.75	51.50 (42.00-60.75)	p= 0.213 (F=1.607)
BMI (kg/m²)		22.87±1.17	23.00 (21.7-23.85)	22.35±1.44	22.05 (21.52-23.65)	23.09±1.45	23.15 (22.15-23.92)	p= 0.342 (F=1.103)
Gender (n/%)	Female	6	43	6	43	6	43	p=1.00
	Male	8	57	8	57	8	57	(χ^2=0.000)
Affected side (n/%)	Right	8	57	7	50	9	64	p=0.747
	Left	6	43	7	50	5	36	(χ^2=0.583)
MAS (n/%)	1	10	71	11	79	8	57	p=0.46
	1+	4	29	3	21	6	43	(χ^2=1.551)
Diagnose (n/%)	Hemiparetic	10	71	5	36	9	64	p=0.13
	Diaparetic	4	29	9	64	5	36	(χ^2=4.083)

Note. BMI: Body mass index, S.D.: Standard Deviation, Med (IQR): Median (25th – 75th percentiles), *p <0,05 statistically significant, F: One Way Anova; χ^2: Chi Square Test

Balance

The FRT results in Table 2 showed a significant increase in all groups after the intervention compared with the results before the intervention (p<0.05). In the intergroup analysis, the differences in values obtained from the pre- and post-intervention values were statistically significant (p = 0.001). The change in the UW group was significantly lower than that in the DW and WWI groups.

Table 2
Results of the Balance

Tests	DW (n=14)		UW (n=14)		WWI (n=14)		Inter Group p (F/kw)
	Mean ± S.D.	Med (IQR)	Mean ± S.D.	Med (IQR)	Mean ± S.D.	Med (IQR)	
FRT Pre-Test (cm)	24.70±6.90	26.4 (17.75-30.17)	20.79±6.60	22.15 (16.30-24.87)	20.22±6.22	21.20 (14.88-25.25)	p=0.159 (F=1.93)
FRT Post-Test (cm)	30.31±7.36	31.7 (25.38-34.70)	24.45±8.56	25 (18.44-30.72)	25.17±7.07	26.40 (18.83-30.38)	p=0.102 (F=2.418)
Intra Group p	**p = 0.0001 *** (t=-13.678; d=-3.654)		**p= 0.001 *** (z=-3.296; d=-0.881)		**p= 0.0001 *** (t= -9.885; d=-2.642)		
Difference	5.61±1.53		3.67±5.52		4.95±1.87		**p=0.001* (kw=14.116)ac**

Note. S.D: Standard Deviation, Med (IQR): Median (25th – 75th percentiles), *p <0,05 statistically significant, F: One Way Anova, kw: Kruskal Wallis Variance Analysis, t: Paired Samples t test, z: Wilcoxon signed rank test, a: Statistically significant difference between DW and UW groups, b: Statistically significant difference between DW and WWI groups, c: Significant difference between UW and WWI groups; d = Cohen d effect size for paired samples

Strength

Table 3 presents the isometric muscle strength test results. Analysis of the AS KFF results revealed a statistically significant increase in the DW and UW groups after the intervention compared to before the intervention (p<0.05). Examination of the differences between the groups showed that the differences in values obtained from the pre-and post-intervention values were statistically significant (p = 0.022). The change in the DW and UW groups was significantly higher than that in the WWI group. Analysis of the LAS KFF results showed a statistically significant increase in all groups after the intervention compared to the pre-intervention (p<0.05). Examination of the differences between the groups showed that the differences in values obtained from the pre-and post-intervention values were statistically significant (p = 0.004). The change in the UW group was significantly higher than that in the WWI group.

Analysis of the AS KEF results showed a statistically significant increase in the UW and WWI groups after the intervention compared with that before the intervention (p<0.05). Analysis of LAS KEF results within groups revealed a statistically significant increase only in the WWI group after the intervention, compared with the results before the intervention (p<0.05). Examination of the differences between the groups showed that the difference in values obtained from the pre- and post-intervention values were statistically significant (p = 0.012). While the KEF value decreased in the DW group, it increased in the WWI group.

Table 3
Results of the Lower Extremity Isometric Strength

Tests	DW (n=14)		UW (n=14)		WWI (n=14)		Inter Group P (F)
	Mean ± S.D.	Med (IQR)	Mean ± S.D.	Med (IQR)	Mean ± S.D.	Med (IQR)	
AS KFF Pre-test (N)	97.47 ± 23.46	98 (76.65 - 116)	101.23 ± 37.16	98 (73.75 - 127.5)	94.79 ± 49.18	110 (52.75 - 131.05)	p=0.904 (F=0.101)
AS KFF Post-test (N)	108.41 ± 27.38	117 (83.03 - 132)	111.58 ± 37.23	111.67 (85.5 - 135.5)	97.62 ± 49.57	106.92 (64.9 - 133.83)	p=0.616 (F=0.49)
Intra Group p	**p=0.001*** (z=-3.296; d=-0.881)		**p=0.001*** (z=-3.298; d=-0.88)		p=0.1 (t=-1.771; d=-0.47)		
Difference	10.95 ± 10.11		10.36 ± 10.47		2.83 ± 5.98		**p=0.022*** (kw=7.648)bc
LAS KFF Pre-test (N)	118.66 ± 29.01	123 (92 - 146.25)	118.56 ± 35.58	116.5 (91 - 142.75)	110.81 ± 51.28	120.5 (75.9 - 147.25)	p=0.836 (F=0.179)
LAS KFF Post-test (N)	123.71 ± 28.39	131.5 (95.5 - 149.5)	128.8 ± 37.45	119.5 (106.25 - 161.75)	112.76 ± 51.59	122.5 (77.1 - 151.25)	p=0.565 (F=0.58)
Intra Group p	**p=0.001*** (t=-4.54; d=-1.21)		**p=0.001*** (z=-3.175; d=-0.85)		**p=0.033*** (t=-2.391; d=-0.64)		
Difference	5.06 ± 4.17		10.24 ± 12.73		1.94 ± 3.04		**p=0.004*** (kw=10.972)c
AS KEF Pre-test (N)	149.5 ± 32.16	158 (132.5 - 170.75)	141.09 ± 54.77	135.5 (109 - 189)	138.7 ± 44.94	147 (91.85 - 170.25)	p=0.801 (F=0.223)
AS KEF Post-test (N)	153.75 ± 32.57	160.5 (141 - 175)	148.96 ± 61.28	139 (114.75 - 195)	148.94 ± 45.75	159 (96.95 - 177)	p=0.955 (F=0.047)
Intra Group p	p=0.122 (t=-1.655; d=-0.44)		**p=0.003*** (z=-2.998; d=-0.8)		**p=0.016*** (z=-2.42; d=-0.65)		
Difference	4.25 ± 9.61		7.88 ± 11.31		10.24 ± 5.16		p=0.055 (kw=5.801)
LAS KEF Pre-test (N)	165.71 ± 35.47	171.5 (150.75 - 186)	157.91 ± 51.91	152.5 (118.25 - 202)	152.94 ± 49.15	165 (125.25 - 184.75)	p=0.762 (F=0.273)
LAS KEF Post-test (N)	163.07 ± 35.06	172 (145.75 - 182)	158.72 ± 49.69	158.5 (122 - 205.25)	158.75 ± 46.17	167.5 (127.25 - 189)	p=0.956 (F=0.045)
Intra Group p	p=0.182 (z=-1.334; d=-0.36)		p=0.115 (z=-1.576; d=-0.42)		**p=0.0001*** (t=-7.43; d=-1.99)		
Difference	-2.64 ± 6.5		0.81 ± 6.25		5.81 ± 8.85		**p=0.012*** (kw=8.906)b

Note. S.D: Standard Deviation, Med (IQR): Median (25th – 75th percentiles), *p <0,05 statistically significant, F: One Way Anova, kw: Kruskal Wallis Variance Analysis, t: Paired Samples t test, z: Wilcoxon signed rank test, a: Statistically significant difference between DW and UW; b: Statistically significant difference between DW and WWI, c: Statistically significant difference between UW ve WWI; d= Cohen d effect size for paired samples.

Flexibility

Table 4 presents the active ROM results for participants in each group of this study. Analysis of the AS HF results showed a statistically significant increase in all groups after the intervention than that after the pre-intervention ($p<0.05$). LAS HF results within groups showed a statistically significant increase in the DW and UW groups after the intervention compared with that before the intervention ($p<0.05$).

Analysis of the AS HE results revealed a statistically significant increase in all groups after the intervention compared to before the intervention ($p<0.05$). AS KF results within groups showed a statistically significant increase in the DW and WWI groups after the intervention compared with that before the intervention ($p<0.05$). Examination of the differences between the groups showed that the differences in values obtained from the pre- and post-intervention values were statistically significant ($p=0.006$). The change in the UW group was significantly lower than that in the WWI group.

An analysis of the AS-AD results showed a statistically significant increase in all groups after the intervention compared with that of the pre-intervention ($p<0.05$). The LAS AD results showed a statistically significant increase in the UW and WWI groups after the intervention compared with the results before the intervention ($p<0.05$).

Analysis of the AS APF within groups showed a statistically significant increase in the DW and WWI groups after the intervention compared with that before the intervention ($p<0.05$).

Table 4
Results of the Flexibility

Tests	DW (n=14)		UW (n=14)		WWI (n=14)		Inter Group P (F/kw)
	Mean ± S.D.	Med (IQR)	Mean ± S.D.	Med (IQR)	Mean ± S.D.	Med (IQR)	
AS HF Pre-test (O)	107.50±21.19	110.00 (93.75-123.75)	95.00±29.55	97.50 (82.50-112.50)	96.79±23.99	95.00 (90.00-116.25)	p=0.373 (F=1.012)
AS HF Post-test (O)	111.43±21.52	112.50 (90.00-135.00)	102.86±23.67	110.00 (85.00-116.25)	106.43±14.86	110.00 (93.75-120.00)	p=0.54 (F=0.626)
Intra Group p	**p= 0.031*** (z= -2.156; d=-0.58)		**p= 0.018*** (z= -2.375; d=-0.63)		**p= 0.018*** (z= -2.371; d=-0.63)		
Difference	3.93 ± 5.94		7.86 ± 9.75		9.64 ± 12.63		p=0.479 (kw=1.472)
LAS HF Pre-test (O)	113.21 ± 16.71	115 (107.5 - 122.5)	101.07 ± 28.97	110 (77.5 - 120)	105.36 ± 20.42	110 (95 - 120)	0.476 (kw=1.485)
LAS HF Post-test (O)	116.43 ± 17.7	117.5 (108.75 - 131.25)	105 ± 23.37	112.5 (86.25 - 120)	106.79 ± 16.36	110 (98.75 - 120)	0.257 (F=1.409)
Intra Group p	**p=0.024*** (z=-2.264; d=-0.61)		**p=0.041*** (z=-2.041; d=-0.55)		p=0.414 (z=-0.816; d=-0.22)		
Difference	3.21 ± 4.64		3.93 ± 7.12		1.43 ± 5.69		0.205 (kw=3.174)
AS HE Pre-test (O)	6.07±5.94	10.00 (3.75-10.00)	0.00±10.00	2.50 (-2.5-6.25)	3.93±5.94	5.00 (0.00-10.00)	p=0.126 (kw=4.145)
AS HE Post-test (O)	8.93±5.61	10.00 (7.50 – 10.00)	5.71±8.52	10.00 (0.00-10.00)	9.29±3.31	10.00 (10.00-10.00)	p=0.397 (kw=1.85)
Intra Group p	**p= 0.023*** (z=-2.271; d=-0.61)		**p= 0.004*** (z= -2.889; d=-0.77)		**p= 0.004*** (z= -2.879; d=-0.77)		
Difference	2.86 ± 3.78		5.71 ± 4.32		5.36 ± 4.14		p=0.144 (kw=3.871)

Table 4 (Continued)

Tests	DW (n=14)		UW (n=14)		WWI (n=14)		Inter Group P (F/kw)
	Mean ± S.D.	Med (IQR)	Mean ± S.D.	Med (IQR)	Mean ± S.D.	Med (IQR)	
LAS HE Pre-test (°)	8.21 ± 5.41	10 (5 - 10)	6.79 ± 6.08	5 (0 - 10)	8.57 ± 6.02	10 (5 - 10)	0.654 (kw=0.851)
LAS HE Post-test (°)	8.57 ± 5.69	10 (5 - 11.25)	8.21 ± 5.41	10 (5 - 10)	9.64 ± 5.71	10 (5 - 11.25)	0.783 (F=0.246)
Intra Group p	p= 0.317 (z=-1; d=-0.27)		p= 0.102 (z=-1.633; d=-0.44)		p= 0.083 (z=-1.732; d=-0.46)		
Difference	0.36 ± 1.34		1.43 ± 3.06		1.07 ± 2.13		0.499 (kw=1.388)
AS KF Pre-test (°)	113.57±17.03	120.00 (97.50-123.75)	107.86±17.94	105.00 (93.75-122.50)	102.14±14.77	102.50 (90.00-108.75)	p=0.205 (F=1.652)
AS KF Post-test (°)	115.00±16.98	120.00 (101.25-127.50)	106.79±19.08	105.00 (90.00-122.50)	106.07±13.04	107.50 (95.00-112.50)	p=0.296 (F=1.257)
Intra Group p	**p= 0.046*** (z= -2.000; d=-0.53)		p= 0.276 (z= -1.089; d=-0.29)		**p= 0.008*** (z= -2.636; d=-0.7)		
Difference	1.43 ± 2.34		-1.07 ± 4.01		3.93 ± 4.46		p=**0.006*** (kw=10.142)c
LAS KF Pre-test (°)	118.93 ± 17.45	125 (100 - 135)	111.43 ± 16.34	110 (97.5 - 126.25)	110 ± 17.21	110 (97.5 - 126.25)	0.322 (kw=2.269)
LAS KF Post-test (°)	119.64 ± 16.81	125 (107.5 - 135)	111.07 ± 15.95	110 (97.5 - 126.25)	112.5 ± 14.64	110 (100 - 126.25)	0.294 (kw=2.446)
Intra Group p	p=0.317 (z=-1; d=-0.27)		p=0.564 (z=-0.577; d=-0.15)		p=0.197 (z=-1.289; d=-0.34)		
Difference	0.71 ± 2.67		-0.36 ± 2.37		2.5 ± 7.27		0.392 (kw=1.875)
AS AD Pre-test (°)	3.21±8.68	2.50 (-1.25-10.00)	2.86±10.32	0.00 (-2.5-11.25)	3.21±6.96	0.00 (0.00-6.25)	p=0.995 (kw=0.011)
AS AD Post-test (°)	7.14±5.79	5.00 (3.75-10.00)	7.86±7.52	10.00 (0.00-11.25)	7.14±5.79	7.50 (5.00-10.00)	p=0.944 (F=0.058)
Intra Group p	**p= 0.009*** (z= -2.598; d=-0.69)		**p= 0.006*** (z= -2.739; d=-0.73)		**p= 0.015*** (z= -2.428; d=-0.65)		
Difference	3.93 ± 4.01		5 ± 4.39		3.93 ± 4.46		p=0.742 (kw=0.595)
LAS AD Pre-test (°)	11.43 ± 6.91	10 (8.75 - 20)	8.57 ± 9.89	7.5 (0 - 20)	12.86 ± 8.48	15 (8.75 - 20)	0.42 (kw=1.733)
LAS AD Post-test (°)	11.79 ± 6.68	10 (10 - 20)	11.07 ± 8.59	12.5 (0 - 20)	15.71 ± 6.75	20 (10 - 20)	0.212 (kw=3.106)
Intra Group p	p=0.317 (z=-1; d=-0.27)		**p=0.034*** (z=-2.121; d=-0.57)		**p=0.039*** (z=-2.06; d=-0.55)		
Difference	0.36 ± 1.34		2.5 ± 4.27		2.86 ± 4.69		0.136 (kw=3.989)
AS APF Pre-test (°)	33.93±12.43	35.00 (20.00-46.25)	39.29±19.89	45.00 (32.50-50.00)	28.57±15.98	30.00 (18.75-41.25)	p=0.237 (F=1.496)
AS APF Post-test (°)	37.14±11.22	35.00 (28.75-50.00)	42.14±15.65	45 (32.5 - 50)	33.57±11.34	32.50 (23.75-45.00)	p=0.223 (F=1.559)
Intra Group p	**p= 0.014*** (z= -2.460; d=-0.66)		p= 0.102 (z= -1.633; d=-0.44)		**p= 0.017*** (z= -2.388; d=-0.64)		
Difference	3.21 ± 3.72		2.86 ± 6.11		5 ± 6.5		p=0.39 (kw=1.882)
LAS APF Pre-test (°)	43.57 ± 7.19	45 (38.75 - 50)	40.71 ± 19.1	47.5 (31.25 - 50)	36.79 ± 14.09	45 (23.75 - 45)	0.39 (kw=1.881)
LAS APF Post-test (°)	43.93 ± 6.56	45 (38.75 - 50)	41.79 ± 18.36	47.5 (37.5 - 50)	37.5 ± 14.64	45 (28.75 - 46.25)	0.471 (kw=1.505)
Intra Group p	p= 0.317 (z=-1; d=-0.27)		p= 0.18 (z=-1.342; d=-0.36)		p= 0.317 (z=-1; d=-0.27)		
Difference	0.36 ± 1.34		1.07 ± 2.89		0.71 ± 2.67		0.826 (kw=0.382)

Note. S.D: Standard Deviation, Med (IQR): Median (25th – 75th percentiles), *p <0,05 statistically significant, F: One Way Anova, kw: Kruskal Wallis Variance Analysis, t: Paired Samples t test, z: Wilcoxon signed rank test, a: Statistically significant difference between DW and UW, b: Statistically significant difference between DW and WWI, c: Statistically significant difference between UW and WWI; d = Cohen d effect size for paired samples

Spatiotemporal Gait Parameters

Basic Gait Parameters Results

Table 5 shows the results of the basic gait parameters of the participants in each group in this study. Analysis of the ST results within groups showed a statistically significant decrease only in the DW group after the intervention compared with that before the intervention (p<0.05). CD results within groups showed a statistically significant increase only in the DW group after the intervention, compared with the results before the intervention (p<0.05). MTUGTT results within groups showed a statistically significant decrease only in the DW and UW groups after the intervention compared with that before the intervention (p<0.05). A comparison of the results after the intervention showed a significant difference (p = 0.0001). The values of the UW group were significantly lower than those of the DW and WWI groups. Examination of the differences between the groups showed that the differences in values obtained from the pre-and post-intervention values were statistically significant (p = 0.0001). The values of the UW group were significantly lower than those of the DW and WWI groups, and the values of the DW group were significantly lower than those of the WWI group.

Table 5

Results of the Basic Gait Parameters

Tests	DW (n=14) Mean ± S.D.	DW (n=14) Med (IQR)	UW (n=14) Mean ± S.D.	UW (n=14) Med (IQR)	WWI (n=14) Mean ± S.D.	WWI (n=14) Med (IQR)	Inter Group p (F/kw)
SL Pre-test (m)	0.79± 0.06	0.79 (0.74-0.82)	0.78±0.10	0.76 (0.71-0.85)	0.76±0.15	0.72 (0.69-0.88)	p=0.863 (F=0.147)
SL Post-test (m)	0.78± 0.09	0.80 (0.76-0.83)	0.79±0.09	0.80 (0.71-0.84)	0.77±0.14	0.74 (0.69-0.90)	p=0.612 (kw=0.982)
Intra Group p	p=0.552 (z=-0.595; d=-0.16)		p= 0.078 (t= -1.914; d=-0.51)		p= 0.945 (t= -0.070; d=-0.02)		
Difference	-0.01 ± 0.06		0.01 ± 0.03		0 ± 0.04		p=0.56 (kw=1.159)
ST Pre-test (s)	1.17± 0.10	1.18 (1.09-1.23)	1.21±0.14	1.19 (1.09-1.28)	1.21±0.08	1.21 (1.17-1.26)	p=0.649 (F=0.438)
ST Post-test (s)	1.14± 0.09	1.1 (1.05-1.21)	1.18±0.09	1.20 (1.10-1.24)	1.21±0.07	1.20 (1.15-1.25)	p=0.09 (kw=4.82)
Intra Group p	**p= 0.007*** (t= 3.229; d=0.86)		p= 0.575 (z= -0.561; d=-0.15)		p= 1.000 (t= 0.000; d=0)		
Difference	-0.04 ± 0.04		-0.03 ± 0.1		0 ± 0.05		p=0.158 (kw=3.686)
SV Pre-test (m/s)	0.68± 0.08	0.68 (0.61-0.74)	0.65±0.12	0.68 (0.57-0.72)	0.63±0.10	0.60 (0.57-0.71)	p=0.48 (F=0.748)
SV Post-test (m/s)	0.69± 0.10	0.72 (0.65-0.75)	0.67±0.09	0.68 (0.61-0.72)	0.63±0.10	0.62 (0.57-0.72)	p=0.199 (kw=3.231)

Table 5 (Continued)

Tests	DW (n=14)		UW (n=14)		WWI (n=14)		Inter Group p (F/kw)
	Mean ± S.D.	Med (IQR)	Mean ± S.D.	Med (IQR)	Mean ± S.D.	Med (IQR)	
Intra Group p	p= 0.096 (z=-1.664; d=-0.44)		p= 0.220 (t= -1.289; d=-0.34)		p= 0.693 (t= -0.403; d=-0.11)		
Difference	0.01 ± 0.06		0.02 ± 0.05		0 ± 0.04		p=0.429 (kw=1.693)
AV Pre-test (m/s)	0.67 ± 0.07	0.67 (0.61 - 0.71)	0.65 ± 0.12	0.68 (0.57 - 0.71)	0.63 ± 0.1	0.6 (0.57 - 0.71)	p=0.564 (F=0.582)
AV Post-test (m/s)	0.69 ± 0.1	0.71 (0.64 - 0.74)	0.68 ± 0.09	0.68 (0.61 - 0.73)	0.64 ± 0.11	0.63 (0.58 - 0.71)	p=0.432 (F=0.858)
Intra Group p	p=0.115 (z=-1.575; d=-0.42)		p=0.247 (z=-1.158; d=-0.31)		p=0.343 (t=-0.984; d=-0.26)		
Difference	0.02 ± 0.06		0.02 ± 0.06		0.01 ± 0.04		p=0.699 (kw=0.717)
CD Pre-test (step/dk)	104.49±8.70	104.74 (97.76-113.03)	101.29±9.97	101.27 (94.74-110.88)	99.82±7.29	99.65 (94.82-103.67)	p=0.359 (F=1.051)
CD Post-test (step/dk)	106.95±7.77	109.09 (100.02-114.29)	101.9±8.28	101.74 (95.08-109.29)	101.75±6.39	102.09 (97.65-106.89)	p=0.128 (F=2.17)
Intra Group p	**p= 0.008*** (t= -3.114; d=-0.83)		p= 0.726 (t= -0.358; d=-0.1)		p= 0.064 (z= -1.852; d=-0.49)		
Difference	2.46 ± 2.96		0.61 ± 6.37		1.93 ± 4.07		p=0.41 (kw=1.784)
MTUGTT Pre-test (s)	13.53 ±1.14	13.82 (12.61-14.43)	14.31±1.82	14.44 (13.61-15.42)	14.13±1.35	14.3 (13.49-14.99)	p=0.345 (F=1.094)
MTUGTT Post-test (s)	11.71 ±1.39	11.34 (10.55-12.91)	10.87±0.94	10.98 (10.39-11.60)	14.02±1.71	13.93 (13.08-15.02)	p=**0.0001*** (F=19.445)bc
Intra Group p	**p=0.0001*** (t=5.453; d=1.46)		**p= 0.0001*** (t= 8.118; d=2.17)		p= 0.690 (t= 0.408; d=0.11)		
Difference	-1.81 ± 1.24		-3.44 ± 1.59		-0.11 ± 1.04		p=**0.0001*** (F=22.654)abc

Note. S.D: Standard Deviation, Med (IQR): Median (25th – 75th percentiles), *p <0,05 statistically significant, F: One Way Anova, kw: Kruskal Wallis Variance Analysis, t: Paired Samples t test, z: Wilcoxon signed rank test, a: Statistically significant difference between DW and UW, b: Statistically significant difference between DW and WWI, c: Statistically significant difference between UW ve WWI; d= Cohen d effect size for paired samples

Table 6 presents the percentages of SWP, STP, and DSP for participants in each group in this study. Analysis of the AS SWP results within groups revealed a statistically significant decrease only in the DW group after the intervention, compared with the results before the intervention (p<0.05). The comparison of the results between the groups after the intervention showed a significant difference (p = 0.0001). The values of the DW group were significantly lower than those of the UW and WWI groups. LAS SWP results within groups showed a statistically significant increase only in the WWI group after the intervention, compared with the results before the intervention (p<0.05). Comparison of the results between the groups after the intervention showed a significant difference (p = 0.03). The values of the UW group were significantly higher than those of the WWI group. There was no statistically significant difference between the DW, UW, and WWI groups. Examination of the differences between the groups revealed significant differences between the pre-and post-intervention values (p = 0.004). The values of the WWI group were significantly higher than the increase in the DW and UW groups.

Examination of the AS STP results between the groups revealed a statistically significant difference when the results after the intervention were compared (p = 0.0001). The values of the DW group were significantly higher than those of the UW and WWI groups. LAS STP results within groups showed a statistically significant decrease only in the WWI group after the intervention compared with that before the intervention (p<0.05). A comparison of the results after the intervention between the groups showed a significant difference (p = 0.031). The values of the UW group were significantly lower than those of the WWI group. Examination of the differences between the groups revealed significant differences between the pre- and post-intervention values (p = 0.004). The values of the UW group were significantly lower than those of the DW and WWI groups.

Analysis of the AS DSP results within groups revealed a statistically significant increase only in the DW group after the intervention, compared with the results before the intervention (p<0.05). Examination of the differences between the groups revealed significant differences between the pre- and post-intervention values (p = 0.022). The change in the WWI group was in the direction of decrease, whereas the change in the DW and UW groups was in the direction of increase. LAS DSP results within groups showed a statistically significant increase only in the DW group after the intervention compared with the pre-intervention period, while there was a significant decrease in the WWI group (p<0.05). Examination of the differences between the groups revealed significant differences between the pre- and post-intervention values (p = 0.002). The change in the DW group was in the direction of increase, whereas the change in the WWI group was in the direction of decrease.

Table 6

Results of the Swing Phase, Stance Phase, and Double Support Phase

Tests	DW (n=14)		UW (n=14)		WWI (n=14)		Inter Group P (F/kw)
	Mean ± S.D.	Med (IQR)	Mean ± S.D.	Med (IQR)	Mean ± S.D.	Med (IQR)	
AS SWP Pre-test (%)	42.06±2.27	41.80 (41.24-43.91)	42.27±2.02	42.06 (41.31-44.01)	42.98±2.57	43.69 (41.88-44.66)	p=0.382 (kw=1.926)
AS SWP post-test (%)	40.76±0.84	41.08 (40.09-41.27)	42.72±1.79	42.63 (41.27-43.82)	43.24±1.87	43.37 (42.63-44.76)	p=**0.0001*** (kw=17.309)ab
Intra Group p	**p= 0.013*** (t= 2.859; d=0.76)		p= 0.513 (t= -0.673; d=-0.18)		p= 0.508 (t= -0.680; d=-0.18)		
Difference	-1.3 ± 1.7		0.45 ± 2.49		0.26 ± 1.43		p=0.083 (kw=4.968)

Tablo 6 (Continued)

Tests	DW (n=14)		UW (n=14)		WWI (n=14)		Inter Group P (F/kw)
	Med (IQR)	Mean ± S.D.	Med (IQR)	Med (IQR)	Mean ± S.D.	Med (IQR)	
LAS SWP Pre-test (%)	40.59±2.10	40.55 (39.15-41.72)	41.07±1.61	41.31 (40.61-42.28)	38.96±3.06	37.66 (36.74-42.12)	p=0.071 (kw=5.291)
LAS SWP post-test (%)	40.17±1.36	40.22 (39.35-41.30)	41.43±1.56	41.27 (40.82-41.70)	40.34±2.68	39.38 (38.71-41.57)	p=**0.03*** (kw=7.008)c
Intra Group p	p= 0.219 (t= 1.293; d=0.35)		p= 0.975 (z= -0.031; d=-0.01)		**p= 0.0001*** (t= -4.835; d=-1.29)		
Difference	-0.42 ± 1.23		0.36 ± 1.82		1.39 ± 1.07		p=**0.004*** (kw=11.142)bc
AS STP Pre-test (%)	58.39±2.71	58.23 (56.09-60.14)	57.73±2.02	57.95 (55.99-58.69)	57.02±2.57	56.32 (55.35-58.13)	p=0.283 (kw=2.524)
AS STP post-test (%)	59.24±0.84	58.92 (58.74-59.91)	57.4±2.18	57.37 (56.18-58.73)	56.76±1.87	56.63 (55.24-57.37)	p=**0.0001*** (kw=17.367)ab
Intra Group p	p= 0.211 (t= -1.317; d=-0.35)		p= 0.661 (t= 0.448; d=0.12)		p= 0.508 (t= 0.680; d=0.18)		
Difference	0.85 ± 2.41		-0.33 ± 2.78		-0.26 ± 1.43		p=0.317 (F=1.183)
LAS STP Pre-test (%)	59.41±2.10	59.45 (58.29-60.85)	58.93±1.61	58.69 (57.73-59.4)	61.04±3.06	62.35 (57.88-63.26)	p=0.071 (kw=5.291)
LAS STP post-test (%)	59.83±1.36	59.78 (58.70-60.65)	58.57±1.56	58.74 (58.31-59.19)	59.66±2.68	60.62 (58.44-61.29)	p=**0.031*** (kw=6.948)c
Intra Group p	p= 0.228 (t= -1.266; d=-0.34)		p= 0.975 (z= -0.031; d=-0.01)		**p= 0.0001*** (t= 4.837; d=1.29)		
Difference	0.42 ± 1.23		-0.36 ± 1.82		-1.39 ± 1.07		p=**0.004*** (kw=11.142)bc
AS DSP Pre-test (%)	6.69 ± 1.54	6.63 (5.5 - 8.06)	6.24 ± 1.54	6.43 (5.2 - 7.49)	7.26 ± 2.18	7.01 (5.51 - 8.63)	p=0.332 (F=1.134)
AS DSP post-test (%)	7.99 ± 1.72	7.7 (6.92 - 9.27)	6.88 ± 0.83	6.74 (6.28 - 7.5)	7.07 ± 2.22	6.44 (5.69 - 7.69)	p=0.086 (kw=4.918)
Intra Group p	**p=0.002*** (t=-3.776; d=-1.01)		p=0.086 (t=-1.858; d=-0.5)		p=0.656 (t=0.457; d=0.12)		
Difference	1.3 ± 1.29		0.64 ± 1.28		-0.18 ± 1.49		**p=0.022*** (F=4.207)b
LAS DSP Pre-test (%)	11.3 ± 2.04	11.46 (9.73 - 13.48)	11.88 ± 3.24	11.46 (9.52 - 12.95)	11.74 ± 2.96	12.47 (11.74 - 13.7)	p=0.376 (kw=1.955)
LAS DSP post-test (%)	12.85 ± 2.08	12.38 (11.96 - 14.45)	11.34 ± 4.24	12.54 (9.24 - 14.31)	10.82 ± 3.01	11.27 (10.05 - 12.54)	p=0.237 (F=1.493)
Intra Group p	**p=0.0001*** (t=-6.363; d=-1.7)		p=0.778 (z=-0.282; d=-0.08)		**p=0.037*** (t=2.317; d=0.62)		
Difference	1.55 ± 0.91		-0.54 ± 3.83		-0.92 ± 1.49		**p=0.002*** (kw=12.82)b

Note. S.D: Standard Deviation, Med (IQR): Median (25th – 75th percentiles), *p <0,05 statistically significant, F: One Way Anova, kw: Kruskal Wallis Variance Analysis, t: Paired Samples t test, z: Wilcoxon signed rank test, a: Statistically significant difference between DW and UW, b: Statistically significant difference between DW and WWI, c: Statistically significant difference between UW ve WWI; d = Cohen d effect size for paired samples

DISCUSSION

Children with CP have difficulty maintaining balance when walking, running, or standing. Several investigations have also demonstrated that various TT protocols can enhance balance in children with CP (Grecco et al., 2013; Kurz et al., 2011). This study demonstrated that TT performed in addition to the conventional physiotherapy program is an important tool in the development of dynamic balance in children with hemiparetic and diparetic CP with GMFCS level II. However, unlike other studies, this study compared different slopes of TT. Analysis of the FRT results showed that the improvement in the DW and WWI groups is significantly higher than that in the UW group. The two groups have no advantage over each other. The results of the study suggest that the increases in isometric muscle strength and ROM, particularly the increase in HF ROM on the LAS only in DW and WWI, may have affected the balance results.

In individuals with CP, reduced muscle size, abnormal muscle structure, and altered neural control lead to less muscle strength development and muscle weakness compared with individuals with normal development (Verschuren et al., 2018). In the present study, AS KFF increased significantly in both the DW and UW groups, whereas it increased significantly in the UW and WWI groups. LAS KFF was significantly increased in all groups. LAS KEF increased significantly in the WWI group, whereas it decreased in the DW group, although not statistically significant. In physics, force is analyzed under two classes: contact and field forces. Contact forces are the forces that arise as a result of physical contact between two objects (Serway & Beichner, 2000), and various training methods (fitness, partner training, own body weight, etc.) to increase muscle strength fall into this category. The increase in the KFF on the AS and LAS in the DW and UW groups compared with that of the WWI group may be due to the fact that the lower extremities have to exert more force in the STP of the gait. Similarly, the increase in KEF on both sides in the WWI group may be due to the lower extremities trying to maintain balance and stabilization in the STP of gait. Our study results support the outcomes of prior investigations, which have observed that TT improves the strength of the lower extremity (Kurz et al., 2011; Serway & Beichner, 2000). However, the improvements reported in the aforementioned studies are for different TT protocols (type, duration, frequency, and severity). Strength score measurement differences and participant group differences in the studies (different CP subtypes and GMFCS levels) also make comparison difficult.

With decreased ROM, there is an increase in energy expenditure during walking and other functional activities, making it difficult to perform movements (Ballaz et al., 2010). Hösl et al. (2018), compared the effectiveness level of passive stretching applied to the plantar flexor muscles with backward DW in ten children with CP. In a 9-week study conducted for three days/a week, no increase in passive dorsiflexion angle was observed in ROM, whereas dorsiflexion angle in the mid-STP of walking increased, and KF in swing decreased. There was also an increase in forward walking speed, attributed to enhanced neuromuscular control. In the aforementioned study, walking exercise on a treadmill was not superior to passive stretching; however, a significant increase in AD was observed. In another study, 16 children with CP aged 5–14 years performed walking exercises on a treadmill for 30 minutes per day for 4 weeks. The results showed that voluntary AD and heel weight increased significantly in the early mid STP (Millichap, 2015). In the present study, HF/HE and AD increased similarly in all groups in ROM. In contrast, AS KF decreased in the UW group, although the change was not statistically significant, and increased significantly in the DW and WWI groups. These two groups had no advantage over each other. The increase in APF was higher in the DW and WWI groups; however, neither group had an advantage over the other.

CP is highly likely to lead to gait disorders, which limit the child's participation in activities of daily living such as self-care, education, and recreation (Hoffman et al., 2018; Qian et al., 2023). Previous studies have shown that the use of different types of TT interventions may improve walking performance (Cherng et al., 2007; Ameer et al., 2019; Grecco et al., 2013; Kurz et al., 2011; Hoffman et al., 2018; Hösl et al., 2018; Millichap, 2015). These studies were conducted in different CP subtypes with groups of participants at varying GMFCS levels, and gait performance was evaluated using various gait parameters. Two important parameters determine SV: SL and CD. Based on the findings of this study, although there was an increase in CD in the DW group, there was no increase in SL and AV. This may be explained by the fact that although there was no statistical difference in the DW group, there was a decrease in SL. Children with CP tend to carry their body weight preferentially on the LAS side because of the loss of strength and poor balance on the AS, which leads to impaired gait symmetry. In particular, there is a decrease in the percentage of STP and an increase in the SWP of the lower limb on the AS, which typically has a ratio of 60% STP and 40% SWP. The DSP is also reduced for the same reason. In normal walking, this rate is around 11% (Niznik et al., 1996). In the present study, a decrease in the percentage of SWP and an increase in the percentage of STP of the AS was observed in the DW group. Examination of the rates of increase and decrease showed that it approaches the normal gait symmetry values (swing 40% and stance 60%). This may be because children with CP have to take more controlled and slower steps with eccentric contraction in DW. In the WWI group, an increase in percentage SWP and a decrease in percentage STP was observed on the intact side. The lack of slope may have contributed to a rhythmic and easy walking pattern. In their study, Grecco et al. (2013) reported that walking exercise on a treadmill had positive effects on mediolateral oscillation. In the present study, the favorable improvement in percentage SWP and percentage STP coincides with the mediolateral release. No statistically significant change was observed only in UW. This may be because children who have difficulty with dorsiflexion may have to break their gait to walk fluently when going uphill. In the study by Grecco et al. (2013), the slope was increased weekly, whereas in this study, the slope remained the same throughout the process. There was a significant increase in the percentage of DSP in AS and LAS in the DW group. When this data was evaluated in conjunction with the improvements in AS KFF, AS HF, and HE, as well as AS KF, AS AD, and APF in the DW group, the contact with the ground increased, balance improved, and asymmetry in gait decreased in the DW group. In the present study, a significant improvement in MTUGTT results was observed in both the DW and UW groups, whereas no statistically significant improvement was observed in the WWI group. Although not statistically significant, AV increased, and MTUGTT decreased in all three groups. The increase in AS and LAS KFF in the DW and UW groups, the increase in AS KEF in the UW and WWI groups, and the increase in LAS KEF in the WWI group contributed to the decrease in MTUGTT in the rising from the chair and sitting sections. Therefore, statistically significant improvements were observed in balance, strength, and gait parameters in the DW group. Although there were significant improvements in the UW group in some data and in the WWI group in some data, the highest improvement was in the DW group. In CP, dead nerve cells cannot be replaced, but function can be improved by increasing the connections between existing cells. This increase in connectivity, called neuroplasticity, is achieved by optimally surprising the brain, gaining new experiences, and frequent repetition. The improvements seen in children who have never experienced DW on a treadmill can be attributed to this reason. Walking exercises performed on a flat surface are not rhythmic in children with CP, as they occur at a self-selected pace and remain at the cerebral cortex level. However, in daily life, walking is not controlled at the cerebral cortex level but rather at lower levels such as the cerebellum, meaning the movement becomes automatic. From this perspective, shifting walking to a subconscious level is important for transferring it to daily life (Hikosaka et al., 2002).

The present study has some strengths that can support therapists and researchers in future studies. They include the high number of individuals who participated and completed the assessment, the homogeneity of the groups, the use of three different slopes simultaneously in a single study, and the evaluation of multiple variables. However, there are also some limitations. In children with CP, the training program should be specific and functional to the individual. The results of this study are specific to the sample group in question.

CONCLUSION

The main findings were that gait exercises performed at different inclinations in children with CP were related to AS balance, strength, ROM, and gait parameters. Balance improved significantly in all groups. DW and WWI groups showed the highest improvement in balance. Evaluation of isometric KFF in lower extremity strength showed an increase in DW and UW groups in AS and in all groups in LAS. Evaluation of isometric KEF showed an increase in AS UW and WWI groups. Evaluation of ROM in all groups showed a significant increase in HF, HE, and AD angle in AS. There was an increase in KF and APF in the DW and WWI groups, with the highest increase in the DW group.

Downhill and no incline TT resulted in a significant improvement in the acquisition of gait symmetry. In gait parameters, improvement was observed in ST and CD only in the DW group. Evaluation of SWP showed improvement in the DW group in AS and the WWI group in LAS. Evaluation of STP showed that LAS improved only in the WWI group. Evaluation of DSP showed that both AS and LAS increased in the DW group, whereas only LAS decreased in the WWI group. In DSP, the highest increase in AS was observed in the DW group.

In children with CP, the stance phase percentage on the affected side decreases, and there is a tendency to shift more weight to the less affected side (Acavedo, 1999). Since downhill walking requires greater attention to maintain balance during movement, it may promote increased weight shifting toward the affected side. Evaluation of MTUGTT revealed a decrease in duration in both the DW and UW groups, with the greatest decrease observed in the UW group.

PRACTICAL IMPLICATIONS

Downhill and uphill gait training is an effective method for improving walking parameters in children with CP. Treadmill training, particularly at different inclinations, can be used in the clinic. Treadmill exercises with different inclinations can be used to adapt to daily living activities. If the clinician's goal is to improve lower extremity strength, an inclined surface is recommended for knee flexion strength, while a flat surface is suggested for knee extension strength. If the goal is to increase flexibility in the lower extremity (especially on the affected side) and/or improve balance, treadmill exercises with varying inclinations can be recommended. If the goal is to increase walking speed, inclined treadmill exercises are preferred. Conversely, if the aim is to make walking more fluid and symmetrical (especially on the affected side), downhill treadmill exercises are recommended.

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Authors' Contributions

The first, second and third authors were responsible for the research design, data collection, data analysis and interpretation and writing the manuscript. Fourth and fifth authors were responsible for data analysis and interpretation, writing the manuscript. All authors read and approved the final version of the manuscript.

Declaration of Conflict Interest

The authors have no conflicts of interest to report.

Ethics Statement

The study was approved by the Pamukkale University Clinical Research Ethics Committee (Number: 60116787-020-35801 and year: March 24, 2021).

REFERENCES

Acavedo, S. J. (1999). Physical Therapy for the Child with Cerebral Palsy. In: Tecklin, J. S. (Ed). Pediatric Physical Therapy. 3. ed. Philadelphia: Saunders WB. p.: 107-162.

Ameer, M. A., Fayez, E.S., & Elkholy, H.H. (2019). Improving spatiotemporal gait parameters in spastic diplegic children using treadmill gait training. *Journal of Bodywork and Movement Therapies.* 23(4):937-942. https://doi.org/10.1016/j.jbmt.2019.02.003

Aminian, K., Najafi, B., Büla, C., Leyvraz, P. F., & Robert, P. (2002). Spatio-temporal parameters of gait measured by an ambulatory system using miniature gyroscopes. *Journal of Biomechanics.* 35(5):689-699. https://doi.org/10.1016/S0021-9290(02)00008-8

Armand, S., Decoulon, G., & Bonnefoy-Mazure, A. (2016). Gait analysis in children with cerebral palsy. *EFORT open reviews.* 1(12):448-460. https://doi.org/10.1302/2058-5241.1.000052

Ballaz, L., Plamondon, S., & Lemay, M. (2010). Ankle range of motion is key to gait efficiency in adolescents with cerebral palsy. *Clinical Biomechanics.* 25(9):944-948. https://doi.org/10.1016/j.clinbiomech.2010.06.011

Berker, N., & Yalçın, S. (2010). The Help Guide to Cerebral Palsy. Merrill Corporation Washington.

Cherng, R.J., Liu, C.F., Lau, T.W., & Hong, R.B. (2007). Effect of treadmill training with body weight support on gait and gross motor function in children with spastic cerebral palsy. *American Journal of Physical Medicine & Rehabilitation.* 86(7):548-555. https://doi.org/10.1097/PHM.0b013e31806dc302

Cortés-Pérez, I., González-González, N., Peinado-Rubia, A.B., Nieto-Escamez, F.A., Obrero-Gaitán, E., & García-López, H. (2022). Efficacy of robot-assisted gait therapy compared to conventional therapy or treadmill training in children with cerebral palsy: A systematic review with meta-analysis. *Sensors.* 22(24):9910. https://doi.org/10.3390/s22249910

Dhote, S.N., Khatri, P.A., & Ganvir, S.S. (2012). Reliability of "modified timed up and go" test in children with cerebral palsy. *Journal of Pediatric Neurosciences.* 7(2):96. https://doi.org/10.4103%2F1817-1745.102564

Dimakopoulos, R., Syrogiannopoulos, G., Grivea, I., Dailiana, Z., Youroukos, S., & Spinou, A. (2022). Kinematic and temporospatial changes in children with cerebral palsy during the initial stages of gait development. *Developmental Neurorehabilitation.* 25(1):10-18. https://doi.org/10.1080/17518423.2021.1914763

Duncan, P. W., Weiner, D. K., Chandler, J., & Studenski, S. (1990). Functional reach: a new clinical measure of balance. *Journal of Gerontology.* 45(6):M192-M197. https://doi.org/10.1093/geronj/45.6.M192

Grecco, L. A., Tomita, S. M., Christovão, T. C., Pasini, H., Sampaio, L. M., & Oliveira, C. S. (2013). Effect of treadmill gait training on static and functional balance in children with cerebral palsy: a randomized controlled trial. *Brazilian Journal of Physical Therapy*. 17:17-23. http://dx.doi.org/10.1590/S1413-35552012005000066

Hikosaka, O., Nakamura, K., Sakai, K., & Nakahara, H. (2002). Central mechanisms of motor skill learning. *Current opinion in neurobiology.* 12(2),217–222. https://doi.org/10.1016/s0959-4388(02)00307-0

Hoffman, R. M., Corr, B. B., Stuberg, W. A., Arpin, D. J., & Kurz, M. J. (2018). Changes in lower extremity strength may be related to the walking speed improvements in children with cerebral palsy after gait training. *Research in Developmental Disabilities.* 73:14-20. https://doi.org/10.1016/j.ridd.2017.12.005

Hösl, M., Böhm, H., Eck, J., Döderlein, L., & Arampatzis, A. (2018). Effects of backward-downhill treadmill training versus manual static plantarflexor stretching on muscle-joint pathology and function in children with spastic Cerebral Palsy. *Gait & Posture.* 65:121-128. https://doi.org/10.1016/j.gaitpost.2018.07.171

Kurz, M. J., Corr, B., Stuberg, W., Volkman, K. G., & Smith, N. (2011). Evaluation of lower body positive pressure supported treadmill training for children with cerebral palsy. *Pediatric Physical Therapy.* 23(3):232-239. https://doi.org/10.1097/PEP.0b013e318227b737

LEGSysTM User's Guide. Version 2.3: BioSensics LLC; 2015.

Millichap, J. G. (2015). Gait training and ankle dorsiflexors in cerebral palsy. *Pediatric Neurology Briefs*. 22-22. https://doi.org/10.15844/pedneurbriefs-29-3-5

Niznik, T. M., Turner, D., & Worrell, T. W. (1996). Functional reach as a measurement of balance for children with lower extremity spasticity. *Physical & Occupational Therapy in Pediatrics*. 15(3):1-16. https://doi.org/10.1080/J006v15n03_01

Otman, A. S., & Köse, N. (2014). Tedavi Hareketlerinde Temel Değerlendirme Prensipleri. Hipokrat Kitabevi.

Qian, G., Cai, X., Xu, K., Tian, H., Meng, Q., Ossowski, Z., & Liang, J. (2023). Which gait training intervention can most effectively improve gait ability in patients with cerebral palsy? A systematic review and network meta-analysis. *Frontiers in Neurology*. 13:1005485. https://doi.org/10.37766/inplasy2022.10.0108

Scholtes, V. A., Dallmeijer, A.J., Rameckers, E.A., Verschuren, O., Tempelaars, E., Hensen, M., & Becher, J.G. (2008). Lower limb strength training in children with cerebral palsy–a randomized controlled trial protocol for functional strength training based on progressive resistance exercise principles. *BMC Pediatrics*. 8(1):1-11. https://doi.org/10.1186/1471-2431-8-41

Serway, R. A., & Beichner, R. J. (2000). Physics for Scientists and Engineers with Modern Physics. 5th Edition: Saunders College Publishing.

Tekin, F., & Kavlak, E. (2021). Short and long-term effects of whole-body vibration on spasticity and motor performance in children with Hemiparetic cerebral palsy. *Perceptual and Motor Skills*. 128(3):1107-1129. https://doi.org/10.1177/0031512521991095

Verschuren, O., Smorenburg, A. R., Luiking, Y., Bell, K., Barber, L., & Peterson, M. D. (2018). Determinants of muscle preservation in individuals with cerebral palsy across the lifespan: a narrative review of the literature. *Journal of Cachexia, Sarcopenia and Muscle*. 9(3):453-464. https://doi.org/10.1002/jcsm.12287

Valadão, P., Piitulainen, H., Haapala, E. A., Parviainen, T., Avela, J., & Finni, T. (2021). Exercise intervention protocol in children and young adults with cerebral palsy: the effects of strength, flexibility and gait training on physical performance, neuromuscular mechanisms and cardiometabolic risk factors (EXECP). *BMC Sports Science, Medicine and Rehabilitation*. 13(1):1-19. https://doi.org/10.1186/s13102-021-00242-y

Willemse, L., Brehm, M. A., Scholtes, V. A., Jansen, L., Woudenberg-Vos, H., & Dallmeijer, A. J. (2013). Reliability of isometric lower-extremity muscle strength measurements in children with cerebral palsy: implications for measurement design. *Physical Therapy*. 93(7):935-941. https://doi.org/10.2522/ptj.20120079

Willerslev-Olsen, M., Petersen, T. H., Farmer, S. F., & Nielsen, J. B. (2015). Gait training facilitates central drive to ankle dorsiflexors in children with cerebral palsy. *Brain : a journal of neurology*. 138(Pt 3), 589–603. https://doi.org/10.1093/brain/awu399