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RESEARCH ARTICLE

PLANTAR PRESSURE, BALANCE, AND SENSORY DEFICITS IN RIGHT HEMIPLEGIC CEREBRAL PALSY: A COMPARATIVE PEDIATRIC STUDY

Nezehat Özgül Ünlüer[1], Oğuzhan Akbaşlı[2], Banu Ünver[3]

[1] University of Health Sciences, Faculty of Gülhane Physiotherapy and Rehabilitation, Ankara, Türkiye
[2] Antalya Bilim University, Faculty of Health Sciences, Department of Physiotherapy and Rehabilitation, Antalya, Türkiye
[3] Lokman Hekim University, Faculty of Health Sciences, Department of Physiotherapy and Rehabilitation, Ankara, Türkiye

ORCID: N.Ö.Ü. 0000-0003-2314-0738; O.A. 0000-0002-0097-7829; B.Ü. 0000-0001-9758-6607

Corresponding author: Nezehat Ozgul Unluer, **E-mail:** nunluer80@yahoo.com
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ABSTRACT

Purpose: The study aimed to compare plantar pressure distribution, balance, and plantar sensation between children with right hemiplegic cerebral palsy (rHCP) and typical developing children (TDC).
Material and Methods: The study included 19 children with rHCP (Gross Motor Function Classification System Level I) and 24 TDC aged 4-15 years. Plantar pressure distribution and balance were assessed using the Analysis System Foot Scanner, and plantar sensation was evaluated with the Semmes-Weinstein Monofilament Test.
Results: It was observed that the load exerted on the left feet of the rHCP was significantly higher compared to TDC (p=0.002). Conversely, the load on their right feet was significantly lower compared to TDC (p=0.002). The Center of Pressure (CoP) sway area was found to be significantly higher in the rHCP (p=0.007). The plantar sensation of the rHCP was notably lower (p<0.05).
Conclusion: We observed notable differences between rHCP and TDC regarding static balance and the load applied to the right and left feet in plantar pressure distribution. Importantly, the detection of sensory deficits in the clinically “less-involved” foot of children with rHCP represents a novel finding, challenging the conventional assumption that the contralateral limb is functionally intact. In addition to plantar pressure assessments, incorporating sensory evaluations is valuable for designing effective rehabilitation programs for children with rHCP.

Keywords: Cerebral palsy, balance, plantar pressure, plantar sensation, pedobarography

INTRODUCTION

Cerebral palsy (CP) is a group of permanent, non-progressive disorders affecting the development of movement and posture, leading to activity limitations. In addition to motor impairments, CP is frequently accompanied by disturbances in sensation, perception, cognition, and musculoskeletal function. Approximately 70–80% of CP cases are classified as spastic CP, including increased deep tendon reflexes, tremors, decreased selective motor control, abnormal muscle tone due to imbalance between agonist and antagonist muscles, sensory impairments, and muscle weakness in the affected limbs. Hemiplegia is among the most frequently observed clinical presentations in spastic CP, highlighting the common lateralized involvement in this population (1).

Sensory and motor impairments alter the way children with CP interact with the ground during standing and walking. Therefore, assessment of plantar loading provides important insight into their

postural function (2, 3). The examination of plantar pressure distributions has been demonstrated to be an effective method for assessing the impact of foot deformities on the functional abilities of children with CP. It provides valuable information regarding the prognosis of their walking abilities, offers insights into their balance, and facilitates correction of deformities in their gait cycles (4, 5). Altered plantar loading not only reflects foot deformities and motor impairments but may also influence postural control by modifying the sensory information and mechanical support available during standing.

The primary functions of balance system are to maintain specific postural positions, such as sitting or standing, to facilitate voluntary movements between postures, and to restore balance following disturbances occurring in posture, such as slipping or pushing (6). Neuro-muscular abnormalities in children with CP, such as abnormal muscle tone, reduced and slowed primary reflexes, and postural reactions, lead to postural stability issues, and inadequate motor development is associated with balance-related problems (7). Static and dynamic balance in children with CP is affected, making it more challenging to maintain postural stability during standing compared to a typically developing child (1), (8). Effective postural control, however, depends not only on motor function but also on accurate sensory feedback from the plantar surface of the feet, which provides essential information for balance regulation (6, 9).

Since plantar cutaneous receptors provide critical afferent input for postural orientation and weight distribution, sensory impairments may contribute to abnormal plantar loading and impaired balance in children with HCP. Nevertheless, although numerous studies have demonstrated a relationship between balance performance and somatosensory information (8), lower extremity sensory function remains insufficiently investigated (9).

Given the close interaction between sensory feedback, plantar loading, and postural control during standing, these factors should ideally be evaluated within the same framework rather than in isolation. Previous studies have investigated balance, plantar pressure distribution, and motor function separately in children with CP. For example, research has explored trunk control and balance, single-leg standing performance, changes in plantar pressure during stepping, and reactive balance responses (10–13). However, despite the interdependence of plantar sensation, plantar pressure distribution, and balance control, few studies have examined these components simultaneously. Consequently, it remains unclear how sensory deficits may influence plantar loading patterns and whether these alterations are associated with balance performance, particularly in children with unilateral involvement such as rHCP.

Therefore, the aim of this study was to compare children with rHCP and TDC in terms of plantar pressure distribution, balance, and plantar sensation, and to investigate the relationship between plantar pressure and balance in children with rHCP. It was hypothesized that significant differences would exist between groups and that plantar pressure characteristics would be associated with balance performance.

MATERIAL AND METHODS

Sample Size

Sample size estimation was performed using G*Power software (version 3.1) based on an independent-samples t-test (two-tailed), with mean plantar pressure as the primary outcome measure. The expected effect size was estimated using previously published plantar pressure data reported by Galli et al. (14). Specifically, the mean and standard deviation values for midfoot plantar pressure in children with cerebral palsy (14.89 ± 8.35 kPa) and typically developing controls (8.84 ± 3.20 kPa) were used to calculate the standardized effect size (Cohen's d). With a significance level of $\alpha = 0.05$, a statistical power of 80% ($1-\beta = 0.80$), and an allocation ratio of 1:1, the analysis indicated that a minimum of 21 participants per group (total n = 42) was required. To account for an anticipated dropout rate of approximately 20%, the target sample size was increased to 50 participants. Ultimately, 43 participants completed the study, including 19 children with rHCP and 24 typically developing children (TDC).

Participants

This study was conducted at Naz Special Education and Rehabilitation Center. The inclusion criteria of HCP group were as follows: (1) being rHCP (2) being in an age range between 4 and 15 years, (3) being at Gross Motor Function Classification System (GMFCS) level I, and (4) being able to understand and follow verbal instructions. The control group consisted of TDC aged between the ages of 4 and 15

years. TDC were recruited from the local community through advertisements and personal contact. Parents completed a health questionnaire to confirm the absence of neurological, orthopedic, or developmental conditions that could affect balance or gait.

The age range of 4–15 years was selected to ensure that participants had sufficient cognitive and motor abilities to follow instructions and to provide reliable and consistent performance during balance and plantar pressure assessments. The sample was restricted to children with rHCP to ensure group homogeneity.

The study excluded children with neurological disorders other than CP, those who received Botulinum toxin injections or underwent surgical interventions within the past year, individuals using medications affecting muscle tone, those with secondary conditions hindering ambulation, and those with uncontrolled epileptic seizures. The families of children were informed about the study objectives and provided consent for their children to participate. Ethical approval was obtained from the Ankara Yıldırım Beyazıt University Health Sciences Ethics Committee (Date: 03.01.2023, Number: 23-1360).

Measurements

Demographic and Disease Information: The age, height, and weight of children participating in this study were obtained from their caregiver. Body Mass Index was calculated. All assessments were conducted by the same physiotherapist (O.A.). Measurements were taken in a quiet room without any distracting materials.

Static plantar pressure measurements: The plantar pressure measurements of the participants were obtained using AS Foot Scanner (Analysis Systems Medical Technology Import Export Industry Inc., 2019-Istanbul, Türkiye), a pedobarography device that utilizes System Analysis software. The system comprises a color printer, a monitor, a pressure-sensing platform, a power unit, and cables for connections. The pressure measurement platform of the device is 40x40 cm in size, containing a total of 2288 sensors arranged in a 52*44 matrix. There are 1.4 sensors per cm^2 of the sensing area. The device exhibits a data quality of 12 bits, a data rate of 200-400 Hz, a pressure range of 0.5-100 pound per square inch (PSI), a delay of less than 3%, a temperature range for measurements between 15 and 36 degrees Celsius, and a power connection of 220/110 volts. The validity and reliability of the AS Foot Scanner were established by Soylu et al. (ICC=0.80–0.99) (10). Plantar pressure measurement is a reliable method for assessing balance control in children with CP (ICC=0.86) (8).

Before performing the measurements, procedure was demonstrated to the child's caregiver. The children were allowed to rest for a period of 5 minutes, and the pedobarographic device was calibrated before each session. During the static plantar pressure distribution measurement, the children stood with their feet shoulder-width apart, evenly distributing their weight on both barefeet in static position. A single static trial was recorded for each participant during quiet standing on the platform. Load pressure, mean pressure (kg/cm^2), forefoot mean pressure(kPA), rearfoot (hind foot) mean pressure of both feet in were recorded (Figure 1) (11).

Balance: Dynamic and static aspects of balance were measured separately. Balance assessment was conducted using the AS Foot Scanner (Analysis Systems Medical Technology Import Export Industry Inc., 2019-Istanbul, Turkiye), device. Initially, the children were positioned on the platform with their arms at their sides, eyes open, bare feet and feet shoulder-width apart for static balance assessment. They were instructed to maintain a stationary posture, and data were recorded for 30 seconds (Figure 2) (12). The following Center of Pressure (CoP) parameters were included in the analysis: sway area (mm^2), major axis length (mm), minor axis length (mm), and CoP path length (mm). For, dynamic balance assessment the children were positioned on the platform with their arms at their sides, eyes open, bare feet, and their feet shoulder-width apart. They were instructed to reach forward as far as they could without lifting their heels from the platform, and data were recorded for 30 seconds (13) using a forward reaching task based on the Pediatric Functional Reach Test (20).

Plantar sensation assessment: Semmes Weinstein monofilaments were used to assess plantar light touch sensation. During the study, with the children's eyes closed, monofilaments were applied for 3 seconds to the 1st and 5th metatarsophalangeal joints and the midpoint of the heel. They were then asked to accurately identify the location where the

monofilaments were applied (14). The initial monofilament used was Baseline® Tactile™ Monofilament (2018-Germany) with a value of 2.83. If the child did not feel 2.83 filament after 3 attempts, the next higher-value filament was tested until the patient's sensory threshold was determined. The value of the filament felt by the child and trial number were recorded. The test-retest reliability for recording and unilateral spatial touch perception tests in children with CP was high intraclass correlation coefficient (ICC=0.79–0.96) (15).

Statistical Analysis

Statistical analysis was performed using the Statistical Package for Social Science (SPSS), version 27 (SPSS Inc., Chicago, IL, USA). The significance level was set at $p<0.05$.

The normality of the data was assessed using visual methods (histograms and probability plots) and Shapiro–Wilk test. Since the continuous variables were not normally distributed, Mann-Whitney U test was used to compare demographic, static plantar pressure, and balance variables between the two groups. The Chi-square test was used to compare the sex and plantar sensation threshold ratios. Spearman's test was conducted to determine the correlation coefficients and their significance while investigating the associations between plantar pressure and balance variables. Correlation analysis results were classified as follows: 0.00–0.20 (poor correlation); 0.21–0.40 (fair correlation); 0.41–0.60 (moderate correlation); 0.61–0.80 (good correlation); and 0.81–1.00 (very good correlation (23).

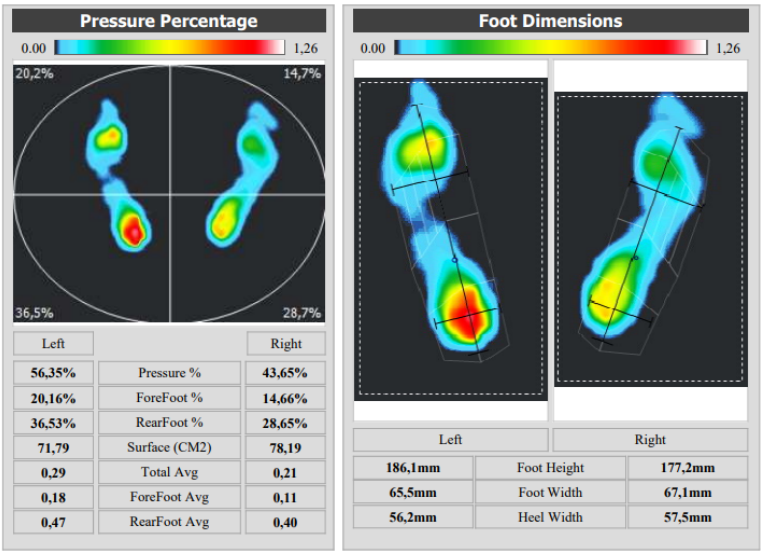


Figure 1. Measurement of static plantar pressure distribution

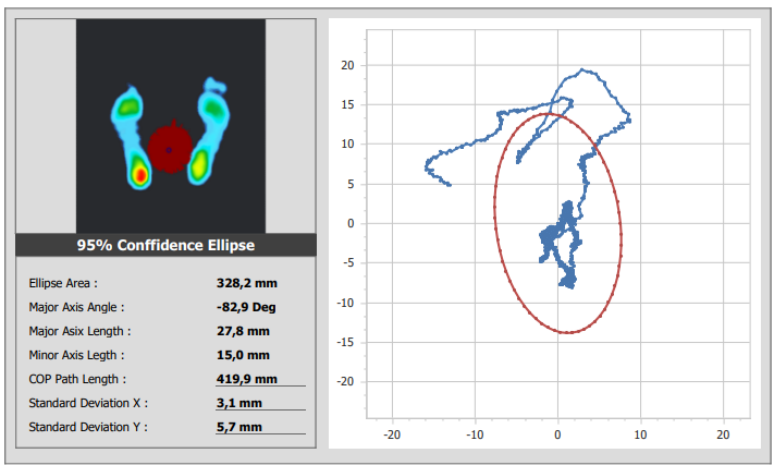


Figure 2. Dynamic balance analysis

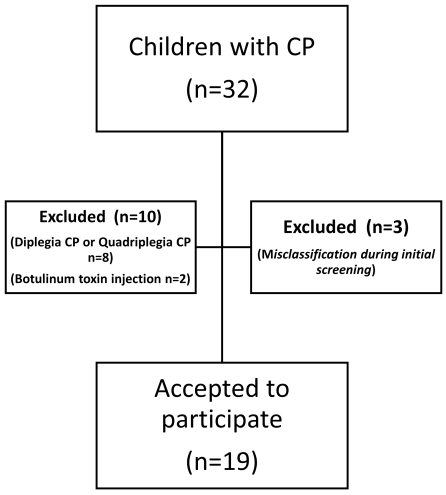


Figure 3. Consort follow diagram illustrating children

RESULTS

A total of 62 children were initially screened for participation. Ten children with CP (diplegic, quadriplegic, or with a history of botulinum toxin injection) and three rHCP who discontinued the treatment and six TDC who refused participation were excluded based on the inclusion criteria (Figure 3). The demographic characteristics of both groups are presented in Table 1.

The mean pressure values and forefoot mean pressure values obtained from the measurements of static plantar pressure distribution in groups did not show a statistically significant difference (p>0.05). However, a comparison of the load distribution between the right and left feet revealed that the percentage of load applied to the left foot was significantly higher in the rHCP group than in the TDC (p = 0.002). In contrast, load applied to their r foot was significantly lower than that applied to right foot of the TDC (p=0.002). Besides, hindfoot pressure of the left foot was higher in the rHCP group compared to the TDC (p=0.023). The static plantar pressure distribution measurements of the groups are presented in Table 2.

The static balance analysis measurements of the groups revealed that CoP sway area, which assesses the change in pressure centers, was significantly higher in rHCP group (p=0.007). Similarly, in the same measurement, the major (p=0.005) and minor axis length (p=0.013) of the groups were also significantly higher in the rHCP group. There was no statistically significant difference observed in the dynamic balance analysis values during functional reaching between the groups (p>0.05). The static and dynamic balance analysis measurements during functional reaching of the groups are presented in Table 2.

The results of the monofilament test revealed that the sensory scores of the rHCP group were significantly lower in all areas where application was made on both the right and left feet, including midpoint of heel, first metatarsophalangeal joint, and the fifth metatarsophalangeal joint (p<0.05). The monofilament test results of the groups are presented in Table 3.

The correlations between plantar pressure distribution and balance parameters in the rHCP group are presented in Table 4.

Table 1. Demographic features of the groups

	Right Hemiplegic CP [n=19]	**Typical Developing Children [n=24]**	**p**	**Effect Size (r-rb)**
Age [years]				
Mean ± SD	10.21 ± 4.66	8.65 ± 2.90	0.299	-0,192
Median (Interquartile range)	10.00 (5.00- 15.00)	8.00 (7.00- 10.00)		
Body weight [kg]				
Mean ± SD	33.07 ± 14.88	32.91 ± 16.38	0.665	-0,050
Median (Interquartile range)	29.00 (19.20- 46.60)	27.80 (22.12- 32.90)		
Height [cm]				
Mean ± SD	133.42 ± 29.64	131.17 ± 15.55	0.966	-0,118
Median (Interquartile range)	130.00 (112.00- 162.00)	126.00 (120.00- 139.75)		
BMI [kg/m²]				
Mean ± SD	17.88 ± 3.83	17.94 ± 4.39	0.613	-0,138
Median (Interquartile range)	16.91 (15.21- 19.71)	16.01 (15.10- 18.93)		
Sex [Female/Male]	4/15	8/16	0.373	φ=0.136

CP= cerebral palsy, BMI=body mass index. *p<0.05 statistically significant. r-rb = Rank-biserial correlation. Φ = phi coefficient

Table 2. Balance assessment outcomes of the groups and static plantar pressure outcomes of the groups

	Right Hemiplegic CP [n=19]	Typical Developing Children [n=24]	p	Effect Size (r-rb)
Balance assessment				
Static Postural sway				
CoP sway area [mm²]				
Mean ± SD	1049.51 ± 1449.53	301.36 ± 299.51	**0.007***	**-0,478**
Median (Interquartile range)	492.20 (234.30- 1108.80)	206.00 (64.97- 411.87)		
Major axis length [mm]				
Mean ± SD	42.93 ± 28.19	25.16 ± 13.79	**0.005***	**-0,526**
Median (Interquartile range)	35.80 (22.50- 52.30)	23.85 (13.55- 30.90)		
Minor axis length [mm]				
Mean ± SD	22.64 ± 15.33	12.42 ± 7.51	**0.013***	**-0,423**
Median (Interquartile range)	18.20 (11.10- 29.70)	12.20 (5.97- 16.57)		
CoP path length [mm]				
Mean ± SD	629.87 ± 303.66	505.45 ± 212.14	0.242	-0,114
Median (Interquartile range)	540.90 (419.90- 951.80)	531.30 (365.62- 662.32)		
Dynamic Postural sway during functional reach				
CoP sway area [mm²]				
Mean ± SD	2381.09 ± 2083.04	1803.82 ± 1681.06	0.307	-0,184
Median (Interquartile range)	1895.50 (843.60- 3786.40)	1396.85 (772.05- 1918.00)		
Major axis length [mm]				
Mean ± SD	72.56 ± 35.13	66.78 ± 41.59	0.337	-0,162
Median (Interquartile range)	67.50 (47.30- 92.50)	56.35 (42.45- 82.17)		
Minor axis length [mm]				
Mean ± SD	51.95 ± 72.06	30.77 ± 13.05	0.302	-0,199
Median (Interquartile range)	33.00 (22.80- 54.60)	28.95 (21.07- 37.55)		
CoP path length [mm]				
Mean ± SD	727.45 ± 300.17	715.23 ± 298.71	0.941	0.043
Median (Interquartile range)	577.70 (525.90- 853.00)	723.00 (500.95- 885.35)		
Static plantar pressure				
Load per. [%]				
Right				
Mean ± SD	42.71 ± 8.20	49.75 ± 6.27	**0.002***	**0.530**
Median (Interquartile range)	46.88 (36.01- 50.00)	50.00 (46.65- 51.46)		
Left				
Mean ± SD	57.28 ± 8.20	50.24 ± 6.27	**0.002***	**-0,530**
Median (Interquartile range)	53.12 (50.00- 63.99)	50.00 (48.53- 53.35)		
Mean pressure [kg/cm^2]				
Right				
Mean ± SD	0.22 ± 0.11	0.21 ± 0.09	0.907	-0,032
Median (Interquartile range)	0.21 (0.12- 0.33)	0.19 (0.14- 0.23)		
Left				
Mean ± SD	0.27 ± 0.10	0.21 ± 0.09	0.055	-0,396
Median (Interquartile range)	0.25 (0.21- 0.35)	0.17 (0.14- 0.25)		
Forefoot mean pressure[kPA]				
Right				
Mean ± SD	0.16 ± 0.08	0.15 ± 0.08	0.891	-0,083
Median (Interquartile range)	0.14 (0.09- 0.21)	0.12 (0.08- 0.19)		
Left				
Mean ± SD	0.16 ± 0.08	0.15 ± 0.09	0.506	-0,201
Median (Interquartile range)	0.16 (0.09- 0.21)	0.12 (0.09- 0.17)		
Hindfoot mean pressure [kPA]				
Right				
Mean ± SD	0.35 ± 0.20	0.33 ± 0.16	0.908	-0,030
Median (Interquartile range)	0.27 (0.17- 0.55)	0.29 (0.19- 0.40)		
Left				
Mean ± SD	0.47 ± 0.20	0.33 ± 0.15	**0.023***	**-0,418**
Median (Interquartile range)	0.47 (0.30- 0.61)	0.30 (0.18- 0.44)		

CP= cerebral palsy, CoP= Center of Pressure, mm=millimeter, mm2. millimetres squared, kg=kilogram, kPA=kilopascal, *p<0.05. r-rb = Rank-biserial correlation. Φ = phi coefficient

Table 3. Plantar light touch sensation outcomes of the groups

Plantar Light Touch Sensation	Monofilament Size [Gram Force]	Rhcp Affected (Right) n [%]	TDC Right n [%]	P	Rhcp Less-Involved (Left) n [%]	TDC Left n [%]	P
Heel	2.83 [0.07]	0	0	**0.016***	0	0	**0.016***
	3.61 [0.4]	13 [68.4]	23 [95.8]		13 [68.4]	23 [95.8]	
	4.31 [2.0]	6 [31.6]	1 [4.2]		6 [31.6]	1 [4.2]	
	4.56 [4.0]	0	0		0	0	
	5.07 [10.0]	0	0		0	0	
First MTP	2.83 [0.07]	0	0	**0.006***	0	0	**0.037***
	3.61 [0.4]	12 [63.2]	23 [95.8]		14 [73.7]	23 [95.8]	
	4.31 [2.0]	7 [36.8]	1 [4.2]		5 [26.3]	1 [4.2]	
	4.56 [4.0]	0	0		0	0	
	5.07 [10.0]	0	0		0	0	
Fifth MTP	2.83 [0.07]	0	0	**0.037***	0	0	**0.016***
	3.61 [0.4]	14 [73.7]	23 [95.8]		13 [68.4]	23 [95.8]	
	4.31 [2.0]	5 [26.3]	1 [4.2]		6 [31.6]	1 [4.2]	
	4.56 [4.0]	0	0		0	0	
	5.07 [10.0]	0	0		0	0	

rHCP=right hemiplegic cerebral palsy, TDC=Typically Developing children MTP= metatarsophalangeal joint, * p<0.05

Table 4. Correlation between plantar pressure distribution and balance parameters in the rHCP group

	Mean Pressure		**Forefoot Mean Pressure**		**Hindfoot Mean Pressure**	
	Right (r)	Left (r)	Right (r)	Left (r)	Right (r)	Left (r)
Statik Postural Sway						
CoP sway area	-0.221	-0.155	-0.247	-0.017	-0.178	-0.266
Major axis length	-0.149	-0.103	-0.166	0.004	-0.125	-0.190
Minor axis length	-0.314	-0.210	-0.299	-0.070	-0.286	-0.311
CoP sway length	-0.819**	-0.624*	-0.594*	-0.413	-0.778**	-0.659*
Postural Sway During Functional Reach						
CoP sway area	0.079	0.029	-0.088	0.076	0.050	-0.106
Major axis length	0.149	0.139	-0.004	0.177	0.008	-0.004
Minor axis length	0.123	0.007	-0.044	0.062	0.127	-0.138
CoP path length	-0.748**	-0.606*	-0.740**	-0.476*	-0.621*	-0.617*

*p<0.05 **p<0.001 Spearman's correlation coefficients (r). rHCP: right hemiplegic cerebral palsy. CoP= Center of Pressure

In the static postural sway assessment, CoP sway length was significantly negatively correlated with mean plantar pressure at the right forefoot (r = −0.819, $p < 0.001$), left forefoot (r = −0.624, $p < 0.05$), right hindfoot (r = −0.594, $p < 0.05$), right total foot (r = −0.778, $p < 0.001$), and left total foot (r = −0.659, $p < 0.05$). No significant correlations were observed between plantar pressure variables and CoP sway area, major axis length, or minor axis length.

Similarly, during the functional reach task, CoP path length was significantly negatively correlated with mean plantar pressure at the right forefoot (r = −0.748, $p < 0.001$), left forefoot (r = −0.606, $p < 0.05$), right hindfoot (r = −0.740, $p < 0.001$), left hindfoot (r = −0.476, $p < 0.05$), right total foot (r = −0.621, $p < 0.05$), and left total foot (r = −0.617, $p < 0.05$).

No significant associations were found between plantar pressure measures and CoP sway area, major axis length, or minor axis length during the functional reach task.

DISCUSSION

The study was conducted to compare rHCP and TDC in terms of the plantar pressure distribution, balance, and plantar sensation. Additionally, we investigated the relationship between plantar pressure distribution

and balance in the rHCP group. Consistent with our hypothesis, we found that static balance levels and plantar sensation were lower in the rHCP group, with a higher load ratio on the left foot and a lower load ratio on the right foot. Furthermore, we observed a significant correlation between plantar pressures and CoP path length in rHCP.

In literature, children with HCP have extensively examined somatosensory sensations, such as vibration, tactile sensation, 2-point discrimination, and proprioception. However, the relationship between plantar pressure distribution and somatosensory sensations, which are crucial for walking and balance, has not been adequately addressed (16).

Leunkeu et al. (2) reported increased plantar pressure at the medial heel and decreased pressure at the hallux and lateral heel during walking in the HCP group, leading to altered foot load during both walking and standing and affecting postural control, particularly due to foot deformities in children with CP. Galli et al. (14), in their study comparing plantar pressure distributions in children aged 5-13 years with HCP, diplegic CP, and healthy children in static positions, found that plantar pressure distributions in children with CP differ from those in healthy children. They noted an increase in pressure on the forefoot and midfoot and a decrease in pressure on the hindfoot in children with rHCP compared to their healthy peers. In contrast to some existing studies, this study assessed foot pressure distributions of children with rHCP in static positions, as opposed to during ambulation. A comparison of plantar pressures between children with rHCP and TDC in our study revealed no significant differences in mean plantar pressure values for the entire foot and the forefoot. However, we determined that the mean pressures on the left hindfoot were higher in rHCP. Furthermore, our results revealed a moderate to high negative correlation between mean plantar pressures and balance during static and functional reach. Specifically, as mean pressures decreased overall and, in the forefoot, and hindfoot regions, path length traced by the CoP during weight-bearing static positions increased, indicating a longer sway. This suggests a potential relationship between sway length and sway speed, as opposed to sway area and major and minor axis length, which are not linked to plantar pressures. Although we have insufficient data on sway speed, decrease in mean pressures on the right foot in rHCP may be associated with an increase in sway speed. Consequently, high-level negative correlation between weight-bearing on the right foot and sway length, as observed during static balance analysis, may reflect this pattern. However, given the cross-sectional design and the large number of correlation analyses performed without correction for multiple comparisons, these findings should be interpreted with caution, and no causal or directional relationships can be inferred. Although these findings may indicate that lower plantar pressures tend to co-occur with greater CoP path length, they should be interpreted as exploratory observations rather than evidence of a robust physiological relationship. Because multiple correlation analyses were performed without adjustment for multiple comparisons, some statistically significant associations may represent chance findings (Type I error). Therefore, no mechanistic, causal, or directional inferences can be drawn from these results, which should be regarded as hypothesis-generating and require confirmation in larger studies using appropriate statistical correction. In conclusion, children with rHCP may show a tendency to shift weight to the stronger side to maintain static balance. Evaluating balance in children with CP is vital for effective treatment planning. Studies in the literature have assessed static balance in children with CP, both in isolation and with dual tasks (17), (18). Another study found differences in antero-posterior balance reactions during stepping responses in children with CP compared to healthy controls (19). Reaching forward is essential for children to explore their environment and is involved in many daily activities, requiring balance maintenance (20). Cunha et al. (28) found that children with spastic CP exhibited reduced forward displacement, impaired movement control, and difficulties in bending the trunk forward and extending shoulders compared to healthy children. In our study, consistent with the literature, we observed poorer static balance in rHCP compared to TDC. However, no significant difference was observed in forward reaching between groups. Importantly, this lack of difference is unlikely to indicate that the task is inherently challenging for TDC. Instead, it may reflect a ceiling effect, particularly in children with higher functional levels (e.g., GMFCS Level I), for whom reach-based tasks may not be sufficiently sensitive to detect subtle impairments in dynamic balance. From a biomechanical standpoint, forward reaching primarily assesses the ability to control CoM displacement

through well-coordinated anticipatory and compensatory postural strategies. These mechanisms are typically well developed in both TDC and high-functioning children with CP, potentially resulting in comparable performance outcomes.

The large standard deviations observed in dynamic balance parameters indicate considerable variability within the rHCP group, likely attributable, at least in part, to the broad age range (4–15 years). Since postural control and dynamic balance continue to mature throughout childhood, developmental differences may have influenced performance independently of neurological impairment. Because no age-adjusted, stratified, or covariate-based analyses were undertaken, the potential confounding effect of age cannot be excluded. Therefore, the lack of significant between-group differences in forward reaching should be interpreted cautiously, as developmental heterogeneity may have obscured subtle deficits. Although the observed effect sizes were small, suggesting minimal between-group differences, future studies should recruit more age-homogeneous samples or incorporate age as a covariate to better isolate the effects of unilateral cerebral palsy on balance performance. Also, the developmental trajectory of postural control is not linear across this age span; therefore, age-related maturation may have influenced balance performance to a greater extent than disease-related factors in some participants.

Furthermore, it should be noted that forward reaching in this study was assessed by quantifying CoP excursion using a pressure platform rather than by applying the standardized Pediatric Functional Reach Test protocol. Consequently, the construct evaluated in this study may not be directly equivalent to that measured by the conventional clinical Functional Reach Test. Therefore, comparisons with previous studies employing standardized Functional Reach Test protocols should be made cautiously, as differences in assessment methodology may influence both construct validity and the interpretation of findings. Accordingly, our findings should be interpreted as reflecting CoP-based postural control during a forward-reaching task rather than performance on the standardized Pediatric Functional Reach Test.

Postural control and motor planning require integration of visual, vestibular, and somatosensory inputs (21). Impairment in any of these senses can lead to balance deficits in children with CP. Studies have evaluated light touch sensation in children with CP using monofilament or cotton alone (22), (23). Zarkou et al. (31) found reduced plantar light touch sensation assessed with monofilament in diplegic CP children compared to healthy children. In contrast, McLaughlin et al. (30) found no difference in plantar light touch sensation between children with CP and healthy children when evaluated with cotton. In our study, we assessed sensation using monofilament and compared plantar light touch sensation in children with rHCP to that of TDC on both feet. Interestingly, sensory differences were observed in both feet only in children with rHCP compared to TDC. This finding may reflect altered central sensory processing beyond the clinically defined “affected” side. Although the general anatomical organization of the somatosensory system is preserved in children with CP, cortical reorganization and atypical sensory integration have been reported in CP, which may lead to bilateral sensory involvement. In addition, somatosensory inputs are represented bilaterally at cortical and subcortical levels through interhemispheric connections and partially overlapping representations within the primary and secondary somatosensory cortices. These neurophysiological characteristics may contribute to sensory deficits observed in both limbs, including the clinically classified “less-involved limb” side. Therefore, these findings challenge the traditional dichotomous classification of “affected” versus ‘’ less-involved” limbs in hemiplegic cerebral palsy and suggest that sensory impairment may reflect a more distributed neural involvement rather than a strictly lateralized lesion effect.

Our study extends the current literature by highlighting the relationship between plantar sensory deficits and functional balance during forward reaching, as well as their potential influence on plantar pressure distribution. However, several limitations should be acknowledged. Although all children were able to understand and complete the testing procedures following standardized and age-appropriate instructions, the reliability of monofilament testing in younger participants may still be influenced by developmental factors such as attention span and variability in cooperation, particularly given that our sample included children as young as four years of age.

Limitations

The final sample size was slightly lower than the minimum sample size estimated using the revised sample size calculation based on published data. Consequently, the statistical power may have been reduced, particularly for detecting small between-group differences. Also the findings are limited to children with rHCP, which may restrict generalizability. Sensory assessment was confined to light touch, and plantar pressure analysis was based on a two-region (anterior–posterior) model, limiting more detailed regional interpretation. Finally, the absence of assessor blinding may have introduced potential bias. Future studies including broader CP subtypes, more comprehensive sensory evaluations, detailed plantar analyses, and blinded assessment protocols are warranted to strengthen the evidence base.

CONCLUSION

In conclusion, the present study demonstrated differences between children with rHCP and TDC in static balance, plantar light-touch sensation, and weight-bearing distribution between the right and left feet. These findings suggest that sensory and postural impairments may coexist in children with rHCP and support the inclusion of both motor and sensory assessments during clinical evaluation.

The observation of reduced plantar sensation in both the clinically affected and less-involved feet is noteworthy. However, the mechanisms underlying this bilateral sensory involvement cannot be determined from the present study and should be regarded as hypotheses requiring confirmation through future neurophysiological and neuroimaging research.

Although this study demonstrated significant associations between plantar pressure distribution and balance, as well as reduced plantar sensation in children with rHCP, it did not directly examine the relationship between plantar sensation and the other outcome measures. Therefore, the potential contribution of sensory impairment to altered plantar loading or balance should be considered hypothetical and warrants further investigation.

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