ORIGINAL ARTICLE

Foot pressure profile for the paretic and non-paretic lower extremities in children with spastic hemiplegic cerebral palsy and the relationship with postural stability. Cross-sectional study

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Abstract. *Background:* Cerebral palsy is a nonprogressive neurodevelopmental disorder that causes motor impairments and limb asymmetries in children with hemiplegic CP, leading to altered plantar pressure, reduced postural stability, and functional gait limitations. *Aim:* This study compared foot pressure profiles between paretic and non-paretic limbs in children with hemiplegic cerebral palsy and controls and examined their relationship with postural stability. *Methods*: In this cross-sectional study, 20 children with HCP (mean age: 8.1±1.65 years) and 31 TD (mean age: 8.06±1.15 years) underwent spasticity assessment using the Modified Ashworth Scale. Static plantar pressures were measured with the DIERS Pedoscan system, while dynamic PS indices were recorded using the TecnoBody device under eyes-open and closed conditions. *Results:* Within the HCP group, affected feet demonstrated significantly lower maximum and average pressures, pressure distribution, surface area, and hindfoot pressure compared to non-affected feet (all $p \leq 0.019$). Compared to controls, children with HCP showed significantly greater limb length discrepancies ($p<0.001$) and poorer Overall Stability Index (OSI) scores at level 10 under both eyes-open ($p=0.015$) and eyes-closed ($p=0.005$) conditions. Correlation analyses revealed that higher body weight ($r=0.559$; $p=0.014$) and BMI ($r=0.548$; $p<0.015$) were positively associated with increased symmetry of the foot axis angle. In contrast, greater foot length differences ($r=-0.528$; $p<0.017$) were associated with reduced symmetry in maximum hindfoot pressure. Regression analysis identified leg length difference ($B=0.50$, $p=0.04$) and OSI at stability level 10 with eyes closed ($B=0.17$, $p=0.47$) as significant predictors of the symmetry index for anteroposterior and mediolateral foot movements in HCP children. *Conclusion:* Children with HCP show notable foot pressure asymmetries, reduced hindfoot support, and poorer postural stability, influenced by limb length differences, body weight, and BMI. Leg length discrepancy and eyes-closed stability strongly predict foot movement symmetry, emphasizing the need for targeted rehabilitation to improve gait and mobility.

Key words: cerebral palsy, hemiplegia, foot pressure profile, postural stability, plantar pressure, weight-bearing asymmetry

Introduction

Spastic hemiplegic cerebral palsy (HCP) is a neurodevelopmental condition characterized by motor impairments, including deficits in motor coordination and muscle weakness (1). While most children with HCP are capable of independent ambulation, they often exhibit gait abnormalities associated with increased muscle tightness, limited joint range of motion, foot deformities, and impaired motor control (2). A common feature of HCP is lower limb asymmetry, with the hemiplegic side typically shorter and smaller (3). Due to this asymmetrical alignment, children with HCP tend to shift weight-bearing predominantly to the unaffected limb. Combined with underlying spasticity, this compensatory pattern can lead to muscle weakness and atrophy on the affected side, impaired postural stability, delayed growth, and progressive foot deformities (1). Foot deformities are frequently observed in children with CP and contribute to abnormal foot contact, uneven plantar pressure distribution, and altered posture and gait (4,5). Plantar pressure analysis is widely recognized as a reliable tool for assessing plantar load distribution, identifying abnormal gait patterns, evaluating lower limb alignment, determining the severity of pediatric impairments, monitoring rehabilitation progress, and validating movement strategies (5). Previous research has examined plantar load distribution in children with hemiplegia, comparing affected and non-affected feet (4,6,7). Findings suggest that the location of plantar loading on the paretic limb varies depending on the task and severity level. In static assessments, studies have reported increased pressure on the forefoot and midfoot regions (8,9), while dynamic assessments have shown elevated pressures in the hallux, midfoot, and forefoot (10), consistent with static results. Additionally, (6) found that severe cases had greater forefoot and hallux pressure, whereas mild cases exhibited higher heel loading, similar to results reported by (7) during gait and stance analysis. Postural control and balance are fundamental for maintaining equilibrium and upright posture, allowing proper head and trunk alignment against gravity (11). Impairments in postural control reduce functional balance and significantly impact movement in children with CP (1). Individuals with HCP often experience difficulties in tasks requiring postural stability (12,13). While (14) reported that children with HCP demonstrated similar static postural sway to typically developing peers, (13) identified postural abnormalities in the same population due to unequal weight-bearing between limbs. Expanding on this, (15) noted that altered loading strategies on the paretic limb contributed to gait abnormalities and balance deficits. Moreover, even when static balance appeared normal, (16) found that children with spastic CP exhibited increased sway shifts and reduced frequency, indicating mild postural control impairments. Despite growing research interest, plantar pressure distribution in children with hemiplegia remains underexplored, particularly under static conditions (8,9). Most studies have focused on dynamic assessments (6,7,10), and existing findings are inconsistent, potentially due to variations in participant age, sample size, spasticity severity, foot deformities, and measurement tools used. Static plantar pressure research is especially limited in Saudi pediatric populations (17), particularly concerning how lower limb loading during standing affects postural stability. To address this research gap, the present study aims to (1) assess and compare foot pressure profiles of paretic and non-paretic limbs in children with spastic HCP and a control group, and (2) determine the association between foot pressure profiles and postural stability in children with HCP compared to typically developing peers.

Materials and Methods

Study design and participants

A cross-sectional study with an analytic descriptive structure included 51 children aged 5-10 years: 20 children with HCP (mean age 8.1±1.65 years) and 31 typically developing (TD) (8.06±1.15 years). HCP children were recruited from Al-Dammam and Al-Khobar general hospitals, while TD Children recruited from Al Fursan International schools. Ethical approval was granted by the Institutional Review Board of Imam Abdulrahman bin Faisal University (IRB-PGS-2024-03-321). Informed consent was obtained from all legal guardians.

Inclusion and exclusion criteria

Children were eligible for inclusion if they were aged 5–10 years and able to follow instructions. For the HCP group, participants required a confirmed diagnosis of spastic hemiplegia, the ability to stand independently without assistance, full plantar contact while standing, GMFCS levels I or II, spasticity grades 1, 1+, or 2, with no BMI restrictions. Exclusion criteria included the use of assistive devices, history of orthopedic surgery or botulinum toxin injections within the past six months, and fixed lower limb deformities. The control group consisted of healthy children with no history of lower extremity surgeries, including trauma-related procedures, fractures, osteotomies, or other corrective musculoskeletal interventions.

Sample size

The study's sample size was determined using G*POWER software based on data from (5), which reported arch index values of 0.26 ± 0.03 for children with CP and 0.22 ± 0.04 for typically developing peers. With an alpha of 0.05 and a power of 0.95, the required sample size was 36 participants (18 per group), with an additional 4 children (2 per group) included to account for potential dropouts.

Degree of spasticity

Spasticity was assessed using the Modified Ashworth Scale (MAS), a reliable and valid clinical tool that scores muscle resistance from 0 (no resistance) to 4 (rigidity), with an added 1+ category for improved sensitivity(18). Evaluations were conducted in a supine position, assessing resistance during passive movements of hip flexors, adductors, internal rotators, hamstrings, and plantar flexors on the affected side. Each muscle group was tested in a calm environment while the child remained relaxed, with three repeated measures taken to ensure reliability.

Lower limb discrepancies

Lower limb length was evaluated using tape measurements, a widely accepted, noninvasive, and cost-effective clinical method with proven validity and reliability (19). Measurements were taken with participants in a supine position: thigh length was measured from the greater trochanter to the medial knee joint line, leg length from the medial knee joint line to the medial malleolus, and foot length from the center of the heel to the tip of the second toe (20). Differences between the right and left limbs were then calculated to determine discrepancies.

Foot pressure profile and weight-bearing symmetry

Plantar pressure distribution was evaluated using the DIERS Pedoscan system (RS scan 1.0m, DIERS International GmbH, Germany), a validated device equipped with 4,096 sensors and operating at a 300 Hz sampling rate (21,22). For static measurements, participants stood upright and barefoot on the platform. The system recorded pressure data across four regions (forefoot and rearfoot of both feet) and generated outputs including (21,23):

- Maximum pressure: Highest pressure value detected.
- Average pressure: Mean value across all sensors.
- Pressure distribution: Percentage of total pressure between left and right feet.
- Surface area: Sensor area engaged by each foot.
- Foot axis angle: Angle from heel midpoint to forefoot midpoint relative to sensor alignment.
- Centre of gravity rotation: Angle between the centers of gravity of both feet and sensor direction, quantifying balance in anterior-posterior and mediolateral directions.

Symmetry indices were subsequently computed by dividing the pressure values of the affected side by those of the non-affected side in the HCP group and, for the control group, by dividing left-side values by right-side values. These measurements provided both visual and numerical representations of plantar load symmetry.

Postural stability

Postural stability was assessed using the ProKin 212 N system (TecnoBody S.r.l., Italy), a validated multidirectional tilting platform designed to measure dynamic balance (24). Stability indices, including anterior-posterior, medial-lateral, and overall scores, were recorded at instability levels 10 and 30 under both eyes-open and eyes-closed conditions (25). Each level consisted of two 30-second trials with rest intervals in between. Higher stability scores reflected greater postural instability.

Statistical analysis

Statistical analyses were performed using SPSS version 27.0 (SPSS Inc., Chicago). Normality of continuous variables was assessed using the Shapiro–Wilk test and visual inspection of histograms and Q-Q plots. Data were summarized as means ± standard deviations or medians and percentages. Wilcoxon signed-rank and Mann–Whitney tests were used for within- and between-group comparisons, respectively. Bivariate Spearman correlations and linear regression analyses were conducted to examine associations between foot pressure symmetry indices and clinical characteristics.

Results

The results indicated that the distribution of foot pressure and postural stability parameters was non-normal, therefore non-parametric statistical methods were employed.

Demographic, anthropometric, and clinical characteristics

Table 1 presents descriptive statistics for both the control group (n=31) and the cerebral palsy group (n=20). No significant differences were observed between groups in terms of age, gender, weight, height, BMI, or hand dominance. However, children with CP exhibited significantly greater asymmetries in thigh, leg, and foot lengths (p<0.001), highlighting underlying structural discrepancies associated with hemiplegia. All CP participants were classified under GMFCS Level I, with varying degrees of spasticity (55% scoring 1 and 45% scoring 1+ on the MAS).

Table 1. Demographic, anthropometric, and clinical characteristics of all study children

		Normal Children	CP Children	Sig.
Number		31	20	-
Age (Years) (Mean/SD)		8.06 (1.15)	8.10 (1.65)	0.812
Gender (N/%)	Boys	16 (51.6)	14 (70.0)	0.197
	Girls	15 (48.4)	6 (30.0)	
Weight (Kg) (Mean/SD)		27.95 (8.06)	31.89 (14.65)	0.839
Height (Cm) (Mean/SD)		124.84 (6.78)	128.80 (16.99)	0.569
BMI (Mean/SD)		17.67 (3.27)	18.35 (5.15)	0.885
Thigh Length Difference (Cm) (Mean/SD)		0.00 (0.00)	1.10 (1.45)	<0.001*
Leg Length Difference (Cm) (Mean/SD)		0.00 (0.00)	1.02 (1.22)	<0.001*
Foot Length Difference (Cm) (Mean/SD)		0.00 (0.00)	0.15 (0.33)	0.010*
Hand dominance (N/%)	Right-Handed	31 (100)	20 (100)	1.000
	Left-Handed	0 (0)	0 (0)	
Affected Side (N/%)	Right	-	15 (75.0)	-
	Left	-	5 (25.0)	
Gross Motor Function Classification System (N/%)	I	-	20 (100)	-
	II	-	0 (0)	
Modified Ashworth Scale (N/%)	0	-	0 (0)	-
	1	-	11 (55.0)	
	1+	-	9 (45.0)	
	2	-	0 (0)	

Postural stability:

Table 2 shows intra-group comparisons of anteroposterior and mediolateral stability indices across two levels (10 and 30). Among normal children, APSI was significantly poorer than MLSI at level 10 with eyes closed (p=0.037), suggesting increased instability in the anteroposterior direction under visually deprived conditions. Dynamic postural stability parameters, including OSI, MLSI, and APSI, were compared between groups using the Mann–Whitney test (Table 3). Notably, children with CP showed significantly higher OSI values at level 10 with both eyes open (p=0.015) and closed (p=0.005), indicating reduced balance control under dynamic conditions. No significant differences were found in other stability parameters, especially at level 30, suggesting selective impairments in CP under more unstable conditions.

Foot pressure profile

Table 4 highlights foot pressure characteristics in both groups. In CP children, the nonaffected foot showed significantly higher maximum pressure (8.19±3.31) than the affected foot (5.38±2.19, p<0.001), with similar disparities seen in average pressure and pressure distribution. In contrast, normal children displayed minor asymmetries, with only average pressure and pressure distribution reaching significant levels (p>0.001 and 0.047 respectively). Surface area was significantly larger in the nonaffected foot of CP children (p=0.019), reinforcing the presence of compensatory loading and altered biomechanical strategies. The hindfoot maximum pressure also increased significantly on the nonaffected foot compared to the affected one in CP children (p<0.001), whereas forefoot pressure, axis angle, and movement parameters showed no substantial intra-group variation. Table 5 compares symmetry indices (SI) for both groups. CP children demonstrated significantly lower symmetry indices in maximum pressure (p<0.001), average pressure (p=0.021), pressure distribution (p=0.001), surface area (p=0.003), and hindfoot pressure (p=0.001), underscoring impaired load distribution and asymmetry. Interestingly, no significant differences were detected in forefoot pressure, axis angle, or movement symmetry (anteroposterior/mediolateral), nor in center of gravity rotation.

Associations of foot pressure symmetry indices

Spearman correlation analysis (Table 6) revealed significant positive associations between foot axis angle SI and both weight (r=0.559, p=0.014) and BMI (r=0.548, p=0.015), and negative correlations between hindfoot pressure SI and foot length difference (r=−0.528, p=0.017). Mediolateral movement SI correlated negatively with APSI (r=−0.478, p=0.033), while combined movement SI correlated positively with leg length difference (r=0.47, p=0.036) and OSI (r=0.45, p=0.049). Multiple

Table 2. Comparing the anteroposterior and mediolateral different stability indices in all study children (Within group analysis) (Wilcoxon Signed Ranks Test)

Parameters		Normal Children				CP Children			
		Mean	SD	Z Score	Sig.	Mean	SD	Z Score	Sig.
Level of stability 10_ Eyes open	Anteroposterior	0.78	0.46	-0.34	0.73	0.87	0.91	-0.48	0.63
	Mediolateral	0.77	0.34			0.80	0.49		
Level of stability 10_ Eyes closed	Anteroposterior	2.04	1.48	-2.09	0.037*	1.40	1.30	-0.64	0.53
	Mediolateral	1.58	1.03			1.41	1.09		
Level of stability 30_ Eyes open	Anteroposterior	0.51	0.28	-0.22	0.83	0.38	0.18	-0.82	0.41
	Mediolateral	0.47	0.29			0.44	0.23		
Level of stability 30_ Eyes closed	Anteroposterior	0.75	0.41	-1.2	0.23	0.60	0.55	-1.44	0.15
	Mediolateral	0.82	0.55			0.76	0.60		

Table 3. Comparing the dynamic postural stability parameters (Between groups analysis) (Mann Whitney test).

Parameters		Mean	SD	Mean Rank	Sig.
Level of stability 10_ OSI_ Eyes open	Normal	1.13	0.49	21.94	0.015*
	CP	2.02	1.19	32.30	
Level of stability 10_ MLSI_ Eyes open	Normal	0.77	0.34	26.10	0.95
	CP	0.80	0.49	25.85	
Level of stability 10_ APSI_ Eyes open	Normal	0.78	0.46	27.39	0.41
	CP	0.87	0.91	23.85	
Level of stability 10_ OSI_ Eyes close	Normal	2.11	0.96	21.31	0.005*
	CP	3.05	1.11	33.28	
Level of stability 10_ MLSI_ Eyes close	Normal	1.58	1.03	27.24	0.46
	CP	1.41	1.09	24.08	
Level of stability 10_ APSI_ Eyes close	Normal	2.04	1.48	28.94	0.08
	CP	1.40	1.30	21.45	
Level of stability 30_ OSI_ Eyes open	Normal	0.73	0.31	28.06	0.22
	CP	0.61	0.23	22.80	
Level of stability 30_ MLSI_ Eyes open	Normal	0.47	0.29	25.98	0.99
	CP	0.44	0.23	26.03	
Level of stability 30_ APSI_ Eyes open	Normal	0.51	0.28	28.31	0.17
	CP	0.38	0.18	22.43	
Level of stability 30_ OSI_ Eyes close	Normal	1.22	0.64	28.32	0.17
	CP	1.04	0.87	22.40	
Level of stability 30_ MLSI_ Eyes close	Normal	0.82	0.55	26.85	0.61
	CP	0.76	.60	24.68	
Level of stability 30_ APSI_ Eyes close	Normal	0.75	0.41	29.02	0.07
	CP	0.60	0.55	21.33	

Abbreviations: MLSI: Medial-lateral Stability Index; APSI: Anterior-posterior Stability Index; OSI: Overall Stability Index.

regression showed that only leg length difference significantly predicted combined movement SI (B=0.50, p=0.04), explaining 35% of variance.

Discussion

Demographic characteristics

This study identified notable lower limb asymmetries in children with spastic hemiplegic cerebral palsy, with mean side-to-side differences of 1.08±1.2 cm in leg length, 1.13±1.43 cm in thigh length, and 0.18±0.34 cm in foot length. Similar discrepancies reported by (3,26,27) have been linked to unilateral spasticity, corticospinal tract injury, and chronic muscle tone imbalance, which hinder longitudinal bone growth. Consistent with (27), these asymmetries are strongly associated with altered gait, reduced social engagement, and impaired functional mobility. Such findings highlight the influence of spasticity severity and motor impairment distribution on skeletal growth and alignment. Clinically, early detection and ongoing monitoring of anthropometric asymmetries are crucial for mitigating abnormal gait mechanics, postural instability, and uneven plantar pressures. Further research is needed to clarify their role in plantar load distribution and guide orthotic intervention strategies.

Table 4. Comparing both sides foot pressure parameters in all study children (Within group analysis) (Wilcoxon Signed Ranks Test)

Parameters		Normal Children					CP Children			
		Mean	SD	Z Score	Sig.	Parameters	Mean	SD	Z Score	Sig.
Maximum Pressure	Left	7.67	2.38	-1.69	0.09	Affected	5.38	2.19	-3.92	<0.001*
	Right	8.44	2.73			Nonaffected	8.19	3.31		
Average Pressure	Left	2.36	0.45	-3.53	<0.001*	Affected	2.15	0.49	-3.78	<0.001*
	Right	2.62	0.35			Nonaffected	2.7	0.63		
Pressure Distribution	Left	47.99	4.86	-1.99	0.047*	Affected	40.11	8.15	-3.58	<0.001*
	Right	52.01	4.86			Nonaffected	59.89	8.15		
Surface Area	Left	68.98	17.78	-1.38	0.17	Affected	67.09	23.17	-2.35	0.019*
	Right	66.69	15.61			Nonaffected	79.05	24.30		
Foot Axis Angle	Left	9.39	8.46	-1.55	0.12	Affected	6.69	10.96	-1.61	0.11
	Right	7.09	6.86			Nonaffected	2.56	10.96		
Maximum Pressure (Forefoot)	Left	2.75	0.76	-1.37	0.17	Affected	3.73	2.21	-0.62	0.54
	Right	2.97	0.90			Nonaffected	3.99	3.16		
Maximum Pressure (Hindfoot)	Left	7.93	3.08	-0.91	0.36	Affected	4.64	2.26	-3.58	<0.001*
	Right	8.07	2.16			Nonaffected	7.32	3.0		
Anteroposterior Movement	Left	1.41	2.60	-1.45	0.15	Affected	4.82	7.01	-1.18	0.24
	Right	1.22	2.59			Nonaffected	2.31	5.85		
Mediolateral Movement	Left	4.51	3.55	-0.61	0.54	Affected	6.1	4.24	-1.04	0.30
	Right	4.43	3.27			Nonaffected	5.5	4.42		
Movement (Both Feet)	Anteroposterior	3.57	3.07	-1.80	0.07	Anteroposterior	5.86	5.25	-1.01	0.31
	Mediolateral	3.99	3.15			Mediolateral	4.59	2.28		

Postural stability parameters

In the control group, anteroposterior stability (APSI) with eyes closed was significantly poorer than mediolateral stability (MLSI) (p=0.037), indicating that healthy children rely heavily on visual input for maintaining anteroposterior stability. Removing visual feedback increases sway velocity and impairs postural control, consistent with (14,16). Children with spastic hemiplegic cerebral palsy (CP) exhibited significantly poorer overall stability (OSI) than controls with both eyes open (p=0.015) and closed (p=0.005) at level 10, reflecting greater sway and instability. This aligns with findings from (11,12,14), who linked impaired balance in CP to deficient trunk control and neuromotor dysfunction. Unlike typically developing children, those with CP benefit less from visual input due to sensory integration deficits (16). While visual cues are critical for postural stability, evidence suggests proprioceptive input can sometimes compensate for visual loss (12,26,28), highlighting the complex multisensory nature of balance. These findings emphasize the need for individualized rehabilitation focusing on proprioceptive training and trunk stabilization to enhance postural control in children with CP.

Foot pressure profile

This study compared foot pressure parameters in typically developing children and those with spastic hemiplegic cerebral palsy (CP), focusing on side-to-side differences (right vs. left in controls; nonaffected vs. affected in CP). Among healthy children, no significant asymmetry was found in maximum pressure,

Table 5. Comparing the foot pressure parameters (Between groups analysis) (Mann Whitney test)

Parameters		Mean	SD	Mean Rank	Sig.
Maximum Pressure SI	Normal	0.95	0.27	32.11	<0.001*
	CP	0.67	0.17	16.52	
Average Pressure SI	Normal	0.90	0.12	29.87	0.021*
	CP	0.81	0.13	20.00	
Pressure Distribution SI	Normal	0.94	0.18	31.76	0.001*
	CP	0.70	0.24	17.08	
Surface Area SI	Normal	1.04	0.15	30.97	0.003*
	CP	0.87	0.27	18.30	
Foot Axis Angle SI	Normal	1.48	1.84	25.21	0.19
	CP	0.15	3.14	19.97	
Center of Gravity Rotation	Normal	3.16	2.91	23.44	0.13
	CP	5.24	4.58	29.98	
Maximum Pressure (Forefoot) SI	Normal	0.97	0.25	26.35	0.83
	CP	1.06	0.59	25.45	
Maximum Pressure (Hindfoot) SI	Normal	1.00	0.32	31.77	<0.001*
	CP	0.68	0.33	17.05	
Anteroposterior Movement SI	Normal	1.32	.85	24.52	0.38
	CP	2.97	3.69	28.30	
Mediolateral Movement SI	Normal	1.17	0.75	25.03	0.56
	CP	1.59	1.47	27.50	
Movement (Both Feet) SI	Normal	0.96	0.41	23.81	0.190
	CP	1.19	0.64	29.40	

Abbreviation: SI: Symmetry Index.

though slightly higher values were recorded on the right foot (8.44±2.73 vs. 7.67±2.38; p=0.09), consistent with minor physiological variations linked to limb dominance (29,30). In children with CP, marked asymmetry was observed, with significantly higher maximum pressure in the nonaffected foot (8.19±3.31 vs. 5.38±2.19; p<0.001), reflecting compensatory weight-shifting due to weakness, spasticity, and foot deformities (4,6). Average pressure and pressure distribution showed similar trends (p<0.001), with the nonaffected foot bearing 60% of total load. Surface area was also larger (79.05±24.30 vs. 67.09±23.17; p=0.019), indicating a broader base of support for stability (6). Asymmetry was most pronounced in the hindfoot (p<0.001), while forefoot pressures and dynamic sway measures showed no significant differences. Symmetry indices for maximum pressure, average pressure, pressure distribution, surface area, and hindfoot pressure were significantly lower in CP than controls (p≤0.003), indicating substantial imbalance in weight-bearing and postural control (16). Conversely, indices for forefoot pressure, foot axis angle, and center of gravity rotation were preserved, suggesting partial maintenance of directional control (9). Overall, unilateral motor impairment in CP profoundly disrupts plantar pressure distribution and postural mechanics, contrasting with the minor asymmetries seen in healthy peers. Rehabilitation should target improved weight-bearing symmetry through proprioceptive training, strengthening of the affected limb, and orthotic support (8,26,28). Further research should examine the dynamic implications

Table 6. Correlations between foot pressure parameters and demographic, anthropometric, clinical, and dynamic postural stability parameters in children with cerebral palsy

Spearman Correlations					
		Foot Axis Angle SI	**(Maximum Pressure Hindfoot) SI**	**Mediolateral Movement SI**	**Movement (Both Feet) SI**
Weight	r	0.559*	-0.06	-0.23	-0.07
	P	0.01	0.80	0.34	0.78
Height	r	0.29	0.15	-0.02	-0.13
	P	0.23	0.52	0.93	0.60
BMI	r	0.548*	-0.15	-0.31	0.04
	P	0.015	0.54	0.19	0.89
Thigh Length Difference	r	-0.11	-0.01	0.41	0.11
	P	0.65	0.98	0.07	0.63
Leg Length Difference	r	0.45	-0.22	-0.01	0.47*
	P	0.06	0.35	0.98	0.036
Foot Length Difference	r	0.08	-0.528*	0.19	0.15
	P	0.74	0.017	0.41	0.53
Level of stability 10_ OSI_ Eyes open	r	-0.07	0.43	-0.06	0.02
	P	0.76	0.06	0.79	0.95
Level of stability 10_ MLSI_ Eyes open	r	-0.24	-0.11	-0.19	-0.17
	P	0.33	0.65	0.43	0.48
Level of stability 10_ APSI_ Eyes open	r	-0.28	0.08	-0.478*	0.17
	P	0.25	0.74	0.03	0.47
Level of stability 10_ OSI_ Eyes close	r	0.05	-0.30	0.08	0.45*
	P	0.86	0.20	0.72	0.049
Level of stability 10_ MLSI_ Eyes close	r	-0.02	0.09	-0.02	-0.35
	P	0.94	0.72	0.95	0.13
Level of stability 10_ APSI_ Eyes close	r	0.19	-0.07	0.00	-0.20
	P	0.44	0.78	0.99	0.38
Level of stability 30_ OSI_ Eyes open	r	0.23	-0.15	-0.10	-0.33
	P	0.36	0.54	0.68	0.15
Level of stability 30_ MLSI_ Eyes open	r	0.12	-0.24	0.07	-0.14
	P	0.62	0.30	0.78	0.55
Level of stability 30_ APSI_ Eyes open	r	0.14	0.16	-0.30	-0.40
	P	0.58	0.49	0.20	0.08
Level of stability 30_ OSI_ Eyes close	r	-0.07	-0.14	0.29	-0.01
	P	0.77	0.54	0.21	0.98
Level of stability 30_ MLSI_ Eyes close	r	-0.11	-0.10	0.43	-0.11
	P	0.66	0.67	0.06	0.65
Level of stability 30_ APSI_ Eyes close	r	0.05	-0.06	0.16	0.02
	P	0.83	0.80	0.51	0.92
**. Correlation is significant at the 0.01 level (2-tailed).					
*. Correlation is significant at the 0.05 level (2-tailed).					
Group = Cerebral Palsy					

Abbreviations: SI: Symmetry Index; MLSI: Medial-lateral Stability Index; APSI: Anterior-posterior Stability Index; OSI: Overall Stability Index.

Table 7. Prediction of foot pressure parameters in children with cerebral palsy

Linear Regression Analysis				
Foot Pressure Indices	**Predictors**	**B**	**Sig**	**Model Summary R Square (Sig)**
Maximum Pressure (Hindfoot) SI	Foot Length Difference	-0.39	0.09	0.15 (0.09)
Mediolateral Movement SI	Level of stability 10_ APSI_ Eyes open	-0.31	0.19	0.09 (0.19)
Foot Axis Angle SI	Weight	0.27	0.53	0.17 (0.23)
	BMI	0.16	0.71	
Movement (Both Feet) SI	Leg Length Difference	0.50	0.04	0.35 (0.02)*
	Level of stability 10_ OSI_ Eyes close	0.17	0.47	

Abbreviations: B: Standardized Coefficients Beta; SI: Symmetry Index; APSI: Anterior-posterior Stability Index; OSI: Overall Stability Index.

of these static asymmetries, their effects on gait and mobility, and the efficacy of symmetry-focused interventions.

Relationship between foot pressure parameters and other outcomes

This study examined associations between foot pressure symmetry indices and demographic, anthropometric, clinical, and postural stability measures in children with cerebral palsy (CP), providing insights into factors influencing plantar pressure asymmetries and postural control. Body weight and BMI were positively correlated with the foot axis angle symmetry index, suggesting that higher body mass may reduce foot axis asymmetry through increased plantar contact and compensatory postural strategies (8,31). Conversely, hindfoot pressure symmetry was negatively correlated with foot length difference, indicating that structural asymmetries impair weight-bearing on the affected side and lead to contralateral hindfoot overloading (6,10). Dynamic stability analysis revealed that poorer anteroposterior (AP) stability was associated with greater mediolateral movement asymmetry, consistent with sensory integration challenges in CP(16). Interestingly, the symmetry index for AP vs. mediolateral movement was positively correlated with both leg length difference and overall stability index (OSI) under eyes-closed conditions. This may represent a compensatory adaptation to limb-length discrepancy and generalized postural instability, leading to a more balanced sway pattern (7,9). The first simple linear regression showed a negative but non-significant relationship between foot length difference and hindfoot maximum pressure symmetry index (B=–0.39, R^2=0.15, p=0.09), consistent with prior findings linking structural asymmetries to uneven weight distribution (6,10). Similarly, the association between anteroposterior stability index (APSI) and mediolateral movement SI was negative but non-significant (B=–0.31, R^2=0.09, p=0.19), reflecting known sensory integration challenges in CP (7,16). The multiple regression model assessing weight and BMI as predictors of foot axis angle SI explained 17% of the variance (R^2=0.17, p=0.23), but neither was significant, suggesting neuromotor deficits and structural factors play a larger role than body composition (8,31). Importantly, leg length difference and overall stability index (OSI) at level 10 with eyes closed significantly predicted anteroposterior/mediolateral movement SI (R^2=0.35, p=0.02), with leg length difference as an independent predictor (B=0.50, p=0.04). This supports the impact of limb-length discrepancies and sensory integration deficits on postural symmetry in hemiplegic CP (9,26,28). In summary, despite some non-significant predictors likely due to sample size, leg length discrepancy and OSI are key factors influencing movement symmetry, emphasizing the need to address structural and sensory-motor impairments in rehabilitation. Future studies should explore these relationships in larger cohorts and during dynamic activities like gait. These findings highlight that structural factors (e.g., limb-length discrepancies) and impaired sensory integration significantly influence weight distribution and sway symmetry in CP. Clinically, interventions should prioritize correcting structural inequalities and enhancing sensory-motor control through targeted rehabilitation strategies (3,26,28).

Limitations

The current study has certain limitations that should be acknowledged. The relatively small sample size may limit the generalizability of the findings. Furthermore, the cross-sectional design offers only a static view, and longitudinal research is needed to capture the progression of postural and pressure imbalances over time. Finally, the exclusive inclusion of participants with GMFCS Level I narrows the scope of the study and may overlook variability across different functional levels.

Conclusion

This study identified significant structural and functional asymmetries in children with spastic hemiplegic cerebral palsy, including altered lower limb measurements, plantar pressure distribution, and postural stability. Limb length discrepancy was strongly linked to asymmetric hindfoot loading and impaired directional control. Children with CP showed greater postural instability under eyes open and closed conditions, reflecting deficits in neuromuscular coordination and sensory integration. Regression analysis revealed leg length discrepancy and overall postural instability (OSI) as key predictors of anteroposterior and mediolateral asymmetry, with body weight and BMI showing non-significant trends. These findings highlight the need for individualized rehabilitation addressing both structural and sensory-motor deficits. Further research should explore gait-related postural control and assess proprioceptive, stabilization, and orthotic interventions to improve functional outcomes.

List of Abbreviations

CP: Cerebral Palsy
TD: Typically Developing
PS: postural stability
HCP: Hemiplegic Cerebral Palsy
WB: Weight Bearing
APSI: Anterior-Posterior Stability Index
MLSI: Medial-Lateral Stability Index
OSI: Overall Stability Index
BMI: Body Mass Index

Ethic Approval: The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of Imam Abdulrahman bin Faisal University (IRB-PGS-2024-03-321).

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References

1. Malick WH, Butt R, Awan WA, Ashfaq M, Mahmood Q. Effects of augmented reality interventions on the function of upper extremity and balance in children with spastic hemiplegic cerebral palsy: a randomized clinical trial. Front Neurol. 2022;13:936838. doi:10.3389/fneur.2022.895055
2. Huang HP, Kuo CC, Lu TW, Wu KW, Kuo KN, Wang TM. Bilateral symmetry in leg and joint stiffness in children with spastic hemiplegic cerebral palsy during gait. J Orthop Res. 2020;38(9):2006–14. doi:10.1002/jor.24635

3. Riad J, Finnbogason T, Broström E. Leg length discrepancy in spastic hemiplegic cerebral palsy: a magnetic resonance imaging study. J Pediatr Orthop. 2010;30(8):846–50. doi:10.1097/BPO.0b013e3181fc35dd
4. Trevisan CM, Oliveira GC, Souza JA, Silva EC. Distribution of plantar pressure and body posture in spastic cerebral palsy. Man Ther Posturology Rehabil J. 2016;14:347. doi:10.17784/mtprehabjournal.2016.14.316
5. Chow TH. Traceable features of static plantar pressure characteristics and foot postures in college students with hemiplegic cerebral palsy. J Pers Med. 2022;12(3):392. doi:10.3390/jpm12030394
6. Femery V, Moretto P, Renaut H, Thévenon A, Lensel G. Measurement of plantar pressure distribution in hemiplegic children: changes to adaptive gait patterns in accordance with deficiency. Clin Biomech. 2002;17(5):406–13. doi:10.1016/S0021-9290(02)00063-5
7. Leunkeu AN, Lelard T, Shephard RJ, Doutrellot PL, Ahmaidi S. Gait cycle and plantar pressure distribution in children with cerebral palsy: clinically useful outcome measures for management and rehabilitation. NeuroRehabilitation. 2014;35(4):657–63. doi:10.3233/NRE-141163
8. Galli M, Cimolin V, Pau M, Leban B, Brunner R, Albertini G. Foot pressure distribution in children with cerebral palsy while standing. Res Dev Disabil. 2015;41–42:52–7. doi:10.1016/j.ridd.2015.05.006
9. Righi NC, Martins FK, Souza JA, Trevisan CM. Distribuição da pressão plantar e morfologia do pé de crianças com paralisia cerebral e crianças com desenvolvimento típico. Fisioter Pesqui. 2017;24(3):321–6. doi:10.1590/1809-2950/17454624032017
10. Park ES, Kim HW, Park CI, Rha DW, Park CW. Dynamic foot pressure measurements for assessing foot deformity in persons with spastic cerebral palsy. Arch Phys Med Rehabil. 2006;87(5):703–9. doi:10.1016/j.apmr.2005.12.038
11. Panibatla S, Kumar V, Narayan A. Relationship between trunk control and balance in children with spastic cerebral palsy: a cross-sectional study. J Clin Diagn Res. 2017;11(9):YC05–YC08. doi:10.7860/JCDR/2017/28388.10649
12. Kenis-Coskun O, Giray E, Eren B, Ozkok O, Karadağ-Saygı E. Evaluation of postural stability in children with hemiplegic cerebral palsy. J Phys Ther Sci. 2016;28(5):1398–402. doi:10.1589/jpts.28.1398
13. Szopa A, Domagalska-Szopa M. Postural stability in children with hemiplegia estimated for three postural conditions: standing, sitting and kneeling. Res Dev Disabil. 2015;39:67–75. doi:10.1016/j.ridd.2015.01.001
14. Saxena S, Rao BK, Kumaran S. Analysis of postural stability in children with cerebral palsy and children with typical development: an observational study. Pediatr Phys Ther. 2014;26(3):325–30. doi:10.1097/PEP.0000000000000060
15. Domagalska-Szopa M, Szopa A, Czamara A. Dependence of gait deviation on weight-bearing asymmetry and postural instability in children with unilateral cerebral palsy. PLoS One. 2016;11(10):e0164760. doi:10.1371/journal.pone.0165583
16. Rose J, Wolff DR, Jones VK, Bloch DA, Oehlert JW, Gamble JG. Postural balance in children with cerebral palsy. Dev Med Child Neurol. 2002;44(1):58–63. doi:10.1017/s0012162201001669
17. Elshazly FA. Therapeutic functional electrical stimulation in hemiplegic cerebral palsy. Neurosciences (Riyadh). 2001;6(3):162–5. PMID:24185362
18. Bohannon RW, Smith MB. Interrater reliability of a modified Ashworth scale of muscle spasticity. Phys Ther. 1987;67(2):206–7. doi:10.1093/ptj/67.2.206
19. Farahmand B, Takamjani EE, Yazdi HR, Saeedi H, Kamali M, Cham MB. A systematic review on the validity and reliability of tape measurement method in leg length discrepancy. Med J Islam Repub Iran. 2019;33(1):17. doi:10.34171/mjiri.33.46
20. Lampe HIH, Swierstra BA, Diepstraten AFM. Measurement of limb length inequality: comparison of clinical methods with orthoradiography in 190 children. Acta Orthop Scand. 1996;67(3):242–4. doi:10.3109/17453679608994680
21. Draus C, Moravec D, Kopiec A, Knott P. Comparison of barefoot vs shod gait on spinal dynamics using DIERS Formetric 4D and DIERS Pedoscan systems. Open J Ther Rehabil. 2015;3(3):70–6. doi:10.4236/ojtr.2015.33010
22. Yang DJ, Park SK, Kim JH, Heo JW, Lee YS, Uhm YH. Effect of changes in postural alignment on foot pressure and walking ability of stroke patients. J Phys Ther Sci. 2015;27(9):2943–5. doi:10.1589/jpts.27.2943
23. Abdel-Aziem AA, Ameer MA, Al Abbad AM, Mahdi MA. Relationship between plantar pressure distribution and sagittal spinal curvatures among handball players: a cross-sectional study. Hong Kong Physiother J. 2024;44(1):1–7. doi:10.1142/S1013702525500040
24. Zawadzki J, Bober T, Siemienski A. Validity analysis of the Biodex System 3 dynamometer under static and isokinetic conditions. Acta Bioeng Biomech. 2010;12(4):25–32. PMID:21361253
25. Ibrahim AI, Muaidi QI, Abdelsalam MS, Hawamdeh ZM, Alhusaini AA. Association of postural balance and isometric muscle strength in early- and middle-school-age boys. J Manip Physiol Ther. 2013;36(9):633–43. doi:10.1016/j.jmpt.2013.08.009
26. Kim HS, Son SM. Limb length discrepancy and corticospinal tract disruption in hemiplegic cerebral palsy. Children (Basel). 2022;9(8):1187. doi:10.3390/children9081198
27. Zonta MB, Ramalho-Júnior A, Puppi M, et al. Side-to-side growth discrepancies in children with hemiplegic cerebral palsy: association with function, activity and social participation. Arq Neuropsiquiatr. 2014;72(5):360–7. doi:10.1590/0004-282x20140020
28. Hussein ZA, Salem IA, Ali MS. Effect of simultaneous proprioceptive-visual feedback on gait of children with spastic diplegic cerebral palsy. J Musculoskelet Neuronal Interact. 2019;19(4):500–6. PMID:31789301
29. Pi CM, Arrese AL, Aparicio AV, Masià JR. Distribution of plantar pressures during gait in different zones of the foot in

healthy children: the effects of laterality. Percept Mot Skills. 2015;120(1):159–76. doi:10.2466/26.10.PMS.120v15x8

30. Liu W, Xu L, Wu H, et al. Bilateral asymmetries of plantar pressure and foot balance during walking, running, and turning gait in typically developing children. Bioengineering (Basel). 2025;12(2):151. doi:10.3390/bioengineering12020151
31. Burtner PA, Qualls C, Woollacott MH. Muscle activation characteristics of stance balance control in children with spastic cerebral palsy. Gait Posture. 1998;8(3):163–74. doi:10.1016/s0966-6362(98)00032-0

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