

Article

Association Between Plantar Pressure Distribution and Postural Stability in Patients with Diabetic Foot: A Cross-Sectional Study

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Abstract

Plantar load distribution and postural stability are key functional domains in diabetic foot assessment, yet their association in early-stage disease remains poorly characterized. This study aimed to investigate the association between static plantar load distribution and postural stability parameters in 31 patients with early-stage diabetic foot (Meggitt-Wagner grade 0–1). A cross-sectional study was conducted with 31 participants (mean age 58.48 ± 9.53 years; 51.6% with loss of protective sensation). Static plantar load distribution was assessed using the Tekscan Pressure Measurement System (Presto-Scan DB software) and postural stability was assessed using the Nintendo Wii Balance Board[®] under bipedal eyes-open, bipedal eyes-closed, and single-leg stance conditions. Spearman correlation analyses with Benjamini–Hochberg false discovery rate (FDR) correction were performed. A rearfoot-dominant loading pattern was observed bilaterally (right: $61.5 \pm 8.2\%$; left: $61.8 \pm 7.9\%$). Mean CoP sway velocity was 4.78 ± 1.98 mm/s (eyes open) and 5.76 ± 1.88 mm/s (eyes closed) in bipedal stance. No statistically significant associations between plantar load distribution and CoP parameters were found after FDR correction (all $q > 0.05$). Adults with early-stage diabetic foot exhibit a rearfoot-dominant loading pattern and sensory-dependent postural control behavior. The absence of significant cross-domain associations suggests that static plantar load distribution and postural stability represent complementary assessment targets. Future controlled studies with matched healthy comparators are needed to determine clinical significance.



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Keywords: diabetic foot; plantar pressure distribution; postural stability; pedobarography

1. Introduction

Diabetes mellitus is a major global health problem associated with a wide range of chronic complications, among which diabetic foot remains one of the most challenging conditions in clinical management due to its links with neuropathy, vascular compromise, impaired tissue tolerance, and functional decline [1]. Diabetic foot is commonly associated with peripheral neuropathy, microvascular changes, and lower-limb biomechanical changes, which collectively affect the foot–ankle complex and may influence functional capacity even before overt deformity or ulceration becomes clinically apparent [2–4]. This pre-ulcerative period is particularly important for orthotic and rehabilitation practice, because timely

identification of functional and functional characteristics can support early preventive interventions and individualized care planning [4–6].

Plantar pressure assessment is widely used to quantify foot loading characteristics in people with diabetes and to identify mechanical patterns that may contribute to localized tissue stress. Abnormal plantar loading patterns are clinically relevant because they can guide preventive strategies such as offloading footwear modifications, custom insoles, and orthotic interventions aimed at redistributing stress and improving load tolerance [7,8]. However, plantar pressure measures—particularly when interpreted alone—do not fully capture the functional components of stability and balance that may influence how patients load the foot in static stance and during daily activities.

Postural stability represents another key domain of functional assessment in individuals with diabetes. Both static and dynamic balance difficulties have been reported in association with peripheral neuropathy and sensory deficits, potentially influencing stance control, movement confidence, and overall lower-limb function [8–10]. Importantly, postural control characteristics may interact with plantar loading behavior by promoting compensatory weight-shifting strategies or asymmetrical reliance on one limb, which may have implications for orthotic prescription and fall-risk-informed rehabilitation planning [11].

In patients with diabetic foot, functional characteristics related to plantar loading patterns and postural stability may be observable early, even before the appearance of overt deformity or ulceration. Although plantar pressure and static load distribution analyses are commonly used to identify regions exposed to increased mechanical loading, these metrics capture distinct biomechanical phenomena, and their relationship with postural stability parameters in early-stage diabetic foot has not been sufficiently characterized. This gap limits their integration into routine orthotic and rehabilitation decision-making. Therefore, the aim of the present study was to investigate the association between plantar pressure distribution and postural stability parameters in patients with early-stage diabetic foot (Meggitt–Wagner grades 0–1) and to discuss its potential implications of these associations for early functional foot assessment and preventive orthotic care in clinical settings.

2. Materials and Methods

2.1. Study Design and Ethical Considerations

This cross-sectional observational study was approved by the Non-Interventional Clinical Research Ethics Committee of Istanbul Medipol University (Approval No: 671 approval number code E-10840098-202.3.02-4025; 26 June 2025). All participants received verbal and written information regarding study procedures and provided written informed consent prior to participation. The study was conducted in accordance with the Declaration of Helsinki and was prospectively registered at ClinicalTrials.gov (NCT07084922; 2 July 2025). The study was reported in accordance with the STROBE reporting guidelines (File S1) for observational cross-sectional research.

2.2. Participants and Setting

An a priori sample size calculation was performed using G*Power (version 3.1.9.7) for correlation analyses between continuous variables. Assuming a large effect size correlation coefficient ($r = 0.60$), a power of 0.80, and a two-sided alpha level of 0.05, the minimum required sample size was calculated as 28 participants. To account for potential data loss, 31 participants were recruited. In the statistical analyses, multiple comparisons were controlled using the Benjamini–Hochberg false discovery rate procedure, with statistical significance determined accordingly.

Inclusion criteria were as follows: (1) clinical diagnosis of type 1 or type 2 diabetes mellitus; (2) early-stage diabetic foot defined as Meggitt–Wagner grade 0 or 1 (intact foot at

risk or superficial ulceration, only non-infected wounds were included); (3) ability to stand independently for at least 30 s; and (4) ability to understand and follow test instructions.

Exclusion criteria were as follows: (1) history of lower-limb amputation or reconstructive surgery; (2) active infection or severe ulceration requiring urgent care; (3) other known neurological or vestibular disorders affecting balance; (4) use of medications likely to substantially influence balance or motor control; and (5) use of assistive walking devices.

Diabetic foot clinical staging according to the Meggitt–Wagner classification was confirmed before biomechanical testing by a clinician experienced in diabetic foot assessment [12]. Peripheral sensory status was screened using Semmes–Weinstein monofilament testing (10 g) on standard plantar sites of both feet; loss of protective sensation (LOPS) was recorded when the participant failed to perceive the filament at one or more sites. For the purposes of this study, neuropathy-related sensory status was operationally categorized according to LOPS status based on Semmes–Weinstein monofilament testing at standard plantar sites. This screening-based classification should not be interpreted as a complete neurophysiological diagnosis of peripheral neuropathy.

Participants classified as grade 1 had superficial ulcers that were covered with standard wound dressings during testing. Assessments were performed without debridement and without exposing the wound surface; the dressing surface, rather than the wound bed, contacted the measurement platform.

2.3. Static Plantar Load Assessment Using Pedobarography

Static plantar load distribution was assessed using the EsCoScan[®] pressure measurement platform (EsCo Orthopädie Service GmbH, Remscheid, Germany), a digital pedobarography system incorporating 2288 pressure sensors operated using with Presto-Scan DB software (version 6.6; Tekscan Inc., South Boston, MA, USA). The system provides regional plantar load as a percentage of total body weight for predefined foot regions (forefoot, midfoot, and rearfoot). The reliability of capacitive pressure platform systems of comparable design has been documented in prior studies [13–15].

Participants stood barefoot, with wound dressings retained only when clinically required for grade 1 ulcers, in quiet bipedal stance with arms relaxed and gaze fixed on a target at eye level. Foot position was standardized at approximately 10° of external rotation using an alignment reference passing through the first–second metatarsal line and the calcaneal midline to improve between-participant consistency (Figure 1). The software segmented the plantar surface into predefined regions; for the present analysis, forefoot and rearfoot loads were extracted together with total load per foot. The system measures static plantar load as a percentage of total body weight (relative load distribution, %), reflecting postural weight-bearing strategy during quiet standing. The primary plantar loading outcomes were total load per foot (%), forefoot load (%), and rearfoot load (%).

2.4. Postural Stability Assessment

Postural stability was assessed using a validated low-cost balance platform with computerized center of pressure (CoP) analysis (Wii Balance Board[®] integrated with Becure Balance System (BeCure, Istanbul, Türkiye) blinded balance-analysis software/platform; version blinded). This platform approach has been previously reported as reliable for common CoP-based postural metrics in adults [16,17]. Lower-limb dominance was determined by self-report as the preferred leg used to kick a ball; the opposite limb was classified as non-dominant.

Each participant completed four standardized 30 s trials: (1) double-leg stance, eyes open; (2) double-leg stance, eyes closed; (3) single-leg stance on the right limb, eyes open; and (4) single-leg stance on the left limb, eyes open (Figure 2). A 30 s duration was selected

as a clinically practical and commonly used interval in stabilometric assessment and has been shown to yield reliable CoP velocity parameters in static standing conditions [18]. To minimize fatigue effects, participants were provided with seated rest between trials and testing resumed only after the participant reported readiness. Participants stood barefoot, with wound dressings retained when clinically required and were instructed to remain still, refrain from speaking, and avoid unnecessary movements. CoP signals were transmitted wirelessly and processed to derive mediolateral (X-axis) and anteroposterior (Y-axis) CoP displacement (cm), mean sway velocity (mm/s), and total CoP path length (cm). These variables were used as indicators of postural control under varying sensory and stance demands [19].

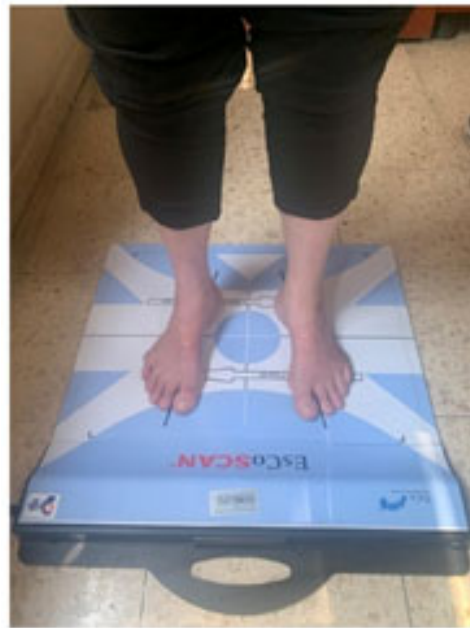


Figure 1. Static plantar load distribution assessment.

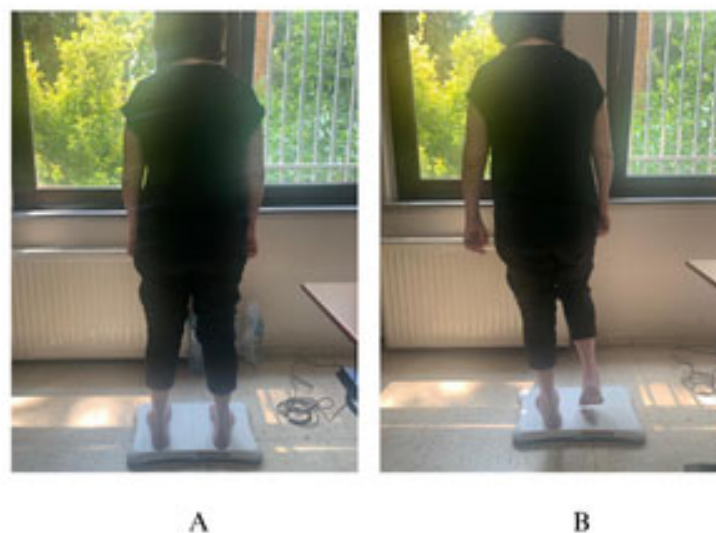


Figure 2. Postural balance assessment: (A) double-leg stance; (B) single-leg stance on the right foot.

2.5. Statistical Analysis

All analyses were performed using IBM SPSS Statistics (version 27.0; IBM Corp., Armonk, NY, USA). Spearman's rank correlation coefficient was used to examine the relationships between postural stability parameters and relative plantar load distribution

values. All tests were two-tailed, with a nominal significance level set at $p < 0.05$. To control for Type I error due to multiple correlation analyses, the Benjamini–Hochberg false discovery rate (FDR) procedure was applied. Adjusted q -values were calculated, and $q < 0.05$ was considered statistically significant. Correlation coefficients were interpreted based on both their direction and magnitude. Descriptive statistics are presented as mean $\pm$ standard deviation. All participants completed the protocol, and no missing data were recorded.

3. Results

3.1. Participant Characteristics

All 31 participants with type 1 or type 2 diabetes mellitus (14 men; 17 women), aged 35–75 years, were recruited from a tertiary hospital outpatient setting and completed the assessment protocol (Figure 3). Mean age was 58.48 ± 9.53 years, height 164.7 ± 8.7 cm, body weight 79.0 ± 14.2 kg, and BMI 29.1 ± 4.9 kg/m². Most participants had type 2 diabetes mellitus ($n = 26$, 83.9%). Loss of protective sensation based on 10 g monofilament screening was present in 16 participants (51.6%), whereas 15 participants (48.4%) had no loss of protective sensation (Table 1). The cohort was classified as early-stage diabetic foot according to the Meggitt–Wagner classification (grades 0–1).

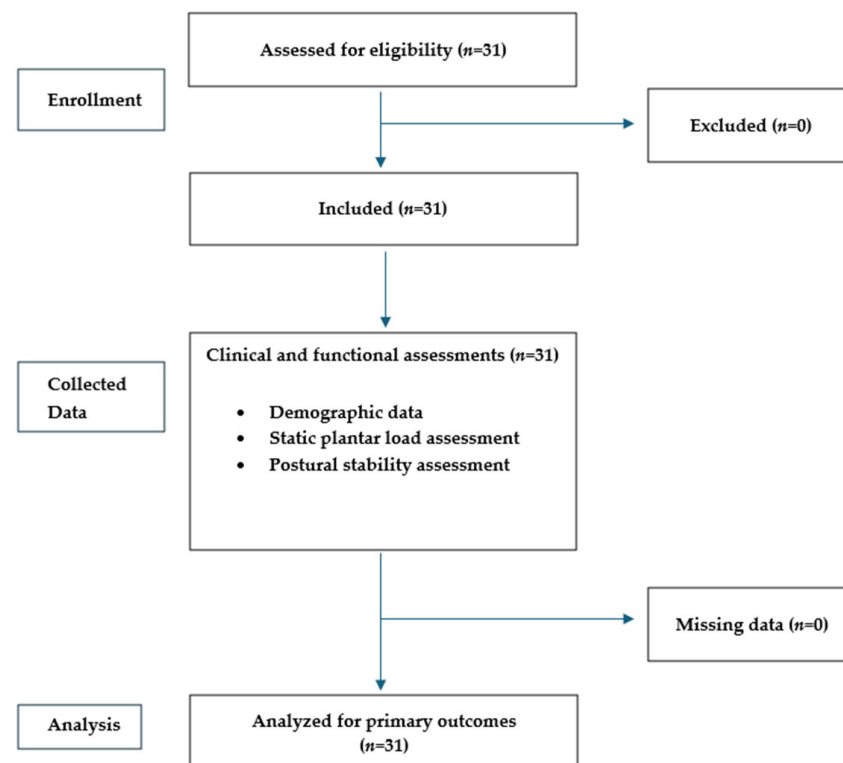


Figure 3. Flow diagram.

3.2. Association Between Plantar Loading and Postural Stability

The primary finding of this study was the absence of statistically significant associations between static plantar load distribution and CoP-based postural stability parameters after Benjamini–Hochberg FDR correction. Unadjusted moderate correlations observed in exploratory analyses (e.g., $r = -0.428$ for CoP velocity and left total load) did not survive multiple comparison correction and should be interpreted as hypothesis-generating only. In Spearman correlation analyses using unadjusted p -values, a moderate negative correlation was observed between CoP sway velocity under eyes-open conditions and total loading on the left foot ($r = -0.428$; $p = 0.016$), accompanied by a moderate positive correlation with right rearfoot loading ($r = 0.428$; $p = 0.016$). Additionally, mediolateral (X-axis) CoP

displacement during right single-leg stance was moderately negatively correlated with left forefoot loading ($r = -0.409$; $p = 0.038$) and positively correlated with left rearfoot loading ($r = 0.409$; $p = 0.038$) (Table 2). However, after applying the Benjamini–Hochberg false discovery rate (FDR) correction for multiple comparisons, none of these associations remained statistically significant ($q > 0.05$).

Table 1. Demographic and clinical characteristics of the participants ($n = 31$).

Variable	Min–Max	<i>n</i> or Mean $\pm$ SD
Age (years)	35–75	58.48 $\pm$ 9.53
Height (cm)	185–151	164.74 $\pm$ 8.70
Weight (kg)	57–110	79 $\pm$ 14.2
Gender		
Female	-	14
Male	-	17
Neuropathy		
Present	-	16
Absent	-	15
Body Mass Index (BMI) (kg/cm ²)	-	29.1 $\pm$ 4.87
Diabetes Type		
Type 1	-	5
Type 2	-	26

Table 1 presents the demographic and clinical characteristics of the study participants ($n = 31$). Continuous variables are expressed as mean $\pm$ standard deviation (SD) and range (minimum–maximum), while categorical variables are presented as counts (*n*). Min: minimum, Max: maximum, and SD: standard deviation.

Table 2. Correlation matrix between Center of Pressure (CoP) parameters and plantar load distribution variables.

Center of Pressure Parameters	Plantar Load Distribution					
	LT (<i>r, p, q</i>)	RT (<i>r, p, q</i>)	LFF (<i>r, p, q</i>)	LRF (<i>r, p, q</i>)	RFF (<i>r, p, q</i>)	RRF (<i>r, p, q</i>)
CoP Velocity: Double-leg stance with EO	−0.428 (0.016, 0.576)	0.428 (0.016, 0.576)	−0.071 (0.704, 0.985)	0.071 (0.704, 0.985)	0.084 (0.654, 0.985)	−0.084 (0.654, 0.985)
CoP Displacement: Double-leg stance with EO—X axis	−0.168 (0.367, 0.985)	0.168 (0.367, 0.985)	−0.118 (0.526, 0.985)	0.118 (0.526, 0.985)	0.124 (0.505, 0.985)	−0.124 (0.505, 0.985)
CoP Displacement: Double-leg stance with EO—Y axis	0.173 (0.353, 0.985)	−0.173 (0.353, 0.985)	−0.193 (0.299, 0.985)	0.193 (0.299, 0.985)	−0.003 (0.985, 0.985)	0.003 (0.985, 0.985)
CoP Velocity: Double-leg stance with EC	0.053 (0.777, 0.985)	−0.053 (0.777, 0.985)	0.061 (0.746, 0.985)	−0.061 (0.746, 0.985)	0.074 (0.694, 0.985)	−0.074 (0.694, 0.985)
CoP Displacement: Double-leg stance with EC—X axis	−0.208 (0.261, 0.985)	0.208 (0.261, 0.985)	0.021 (0.913, 0.985)	−0.021 (0.913, 0.985)	0.257 (0.163, 0.985)	−0.257 (0.163, 0.985)
CoP Displacement: Double-leg stance with EC—Y axis	0.046 (0.806, 0.985)	−0.046 (0.806, 0.985)	−0.214 (0.247, 0.985)	0.214 (0.247, 0.985)	−0.092 (0.623, 0.985)	0.092 (0.623, 0.985)
CoP Velocity: Single-leg stance on the right foot with EO	0.102 (0.619, 0.985)	−0.102 (0.619, 0.985)	0.223 (0.274, 0.985)	−0.223 (0.274, 0.985)	0.249 (0.220, 0.985)	−0.249 (0.220, 0.985)
CoP Displacement: Single-leg stance on the right foot with EO—X axis	0.104 (0.613, 0.985)	−0.104 (0.613, 0.985)	−0.409 (0.038, 0.684)	0.409 (0.038, 0.684)	−0.191 (0.351, 0.985)	0.191 (0.351, 0.985)

Table 2. Cont.

Center of Pressure Parameters	Plantar Load Distribution					
	LT (r, p, q)	RT (r, p, q)	LFF (r, p, q)	LRF (r, p, q)	RFF (r, p, q)	RRF (r, p, q)
CoP Displacement: Single-leg stance on the right foot with EO—Y axis	−0.095 (0.644, 0.985)	0.095 (0.644, 0.985)	0.029 (0.890, 0.985)	−0.029 (0.890, 0.985)	0.020 (0.925, 0.985)	−0.020 (0.925, 0.985)
CoP Velocity: Single-leg stance on the left foot with EO	−0.290 (0.151, 0.985)	0.290 (0.151, 0.985)	0.150 (0.463, 0.985)	−0.150 (0.463, 0.985)	0.189 (0.355, 0.985)	−0.189 (0.355, 0.985)
CoP Displacement: Single-leg stance on the left foot with EO—X axis	0.106 (0.607, 0.985)	−0.106 (0.607, 0.985)	0.021 (0.921, 0.985)	−0.021 (0.921, 0.985)	0.160 (0.436, 0.985)	−0.160 (0.436, 0.985)
CoP Displacement: Single-leg stance on the left foot with EO—Y axis	0.034 (0.870, 0.985)	−0.034 (0.870, 0.985)	−0.298 (0.139, 0.985)	0.298 (0.139, 0.985)	−0.152 (0.457, 0.985)	0.152 (0.457, 0.985)

Table 2 illustrates the correlation analysis between center of pressure (CoP) stability parameters and plantar load distribution across various stance conditions. The matrix includes Spearman rank correlation coefficients (r) along with raw p -values and Benjamini–Hochberg adjusted q values to control for the false discovery rate. The statistical analysis reveals that there are no significant correlations ($q < 0.05$) between CoP velocity or displacement and the regional plantar loading variables. CoP: center of pressure, EO: eyes open, and EC: eyes closed.

3.3. Plantar Loading Distribution

Static pedobarography showed a rearfoot-dominant load distribution. Across participants, mean rearfoot loading ranged from 61.5% to 61.8% and mean forefoot loading from 38.1% to 38.4% (Table 3). Inverse associations were observed between left and right total load percentages and between forefoot and rearfoot load percentages on each side, reflecting their mutually dependent distribution structure (Table 3). Moderate correlations were observed across contralateral plantar regions (Table 4). Left forefoot loading was positively correlated with right forefoot loading ($r = 0.612$; $p < 0.001$) and negatively correlated with right rearfoot loading ($r = -0.612$; $p < 0.001$). Similarly, left rearfoot loading showed a negative correlation with right forefoot loading ($r = -0.612$; $p < 0.001$) and a positive correlation with right rearfoot loading ($r = 0.612$; $p < 0.001$). Other pairwise correlations were not statistically significant ($p > 0.05$). As expected, perfect inverse associations were observed between forefoot and rearfoot loading within the same foot ($r = -1.000$), reflecting their mathematically complementary distribution because the two regional percentages sum to 100%. Therefore, these within-foot inverse associations should not be interpreted as independent biomechanical correlations.

Table 3. Plantar loading distribution and characteristics (%).

Variable	Min (%)	Max (%)	Mean (%)	SD
LT	37.0	64.0	49.65	6.0
RT	36.0	63.0	50.35	6.0
LFF	18.0	70.0	38.48	13.73
LRF	30.0	82.0	61.52	13.73
RFF	14.0	60.0	38.19	10.33
RRF	40.0	86.0	61.81	10.33

Table 3 summarizes the descriptive statistics of plantar loading variables for the study participants (%). Data are presented as minimum, maximum, mean, and standard deviation (SD) values for each variable, including LT: left foot total loading, RT: right foot total loading, LFF: left forefoot loading, LRF: left rearfoot loading, RFF: right forefoot loading, RRF: right rearfoot loading, Min: minimum, Max: maximum, and SD: standard deviation.

Table 4. Correlation matrix between regional and total plantar load distribution parameters.

Plantar Load Distribution Parameters		LT	RT	LFF	LRF	RFF	RRF
LT	r	1.000	−1.000 **	−0.043	0.043	0.176	−0.176
	p			0.817	0.817	0.345	0.345
LFF	r	−0.043	0.043	1.000	−1.000 **	0.612 **	−0.612 **
	p	0.817	0.817			0.000	0.000
RFF	r	0.176	−0.176	0.612 **	−0.612 **	1.000	−1.000 **
	p	0.345	0.345	0.000	0.000		

Table 4 presents the Spearman rank correlation matrix for plantar load distribution parameters among the study participants. The data include correlation coefficients (r) and significance levels (p or adjusted q) for foot loading parameters. r = Spearman rank correlation coefficient; p values are two-tailed. Benjamini–Hochberg FDR-corrected q values are reported; significance was set at $q < 0.05$. ** indicates significance at $p < 0.01$. LT: left foot total loading, RT: right foot total loading, LFF: left forefoot loading, LRF: left rearfoot loading, RFF: right forefoot loading, and RRF: right rearfoot loading.

3.4. Postural Stability Parameters

During double-leg stance with eyes open, mean CoP sway velocity was 4.78 mm/s and increased to 5.76 mm/s with eyes closed (Table 5). Mean CoP displacements were 1.48 cm (X-axis) and 2.89 cm (Y-axis) with eyes open and 1.42 cm (X-axis) and 2.70 cm (Y-axis) with eyes closed (Table 6).

Table 5. Descriptive statistics of center of pressure (CoP) velocity values across different stance conditions (mm/s).

Condition	Min	Max	Mean	SD
Double-leg stance (EO)	2.31	10.46	4.78	1.98
Double-leg stance (EC)	3.0	11.46	5.76	1.88
Single-leg stance (Right, EO)	3.27	36.61	11.01	6.73
Single-leg stance (Left, EO)	3.61	25.74	8.83	5.14

Table 5 presents the descriptive statistics for center of pressure (CoP) velocity, under four different postural conditions (mm/s). The data are summarized as minimum, maximum, mean, and standard deviation (SD) values. CoP: center of pressure, EO: eyes open, and EC: eyes closed.

Table 6. Descriptive statistics of center of pressure (CoP) displacement in medial-lateral (X) and anterior-posterior (Y) axes across different stance conditions (cm).

Condition	Axis	Min	Max	Mean	SD
Double-leg stance (EO)	X	0.02	5.26	1.48	1.27
	Y	0.08	4.68	2.89	1.18
Double-leg stance (EC)	X	0.0	5.56	1.42	1.32
	Y	0.11	4.99	2.7	1.27
Single-leg stance (Right, EO)	X	4.66	16.48	11.36	2.63
	Y	0.48	5.52	3.03	1.49
Single-leg stance (Left, EO)	X	6.0	14.37	10.36	2.14
	Y	0.02	6.29	2.54	1.8

Table 6 summarizes the descriptive statistics for center of pressure (CoP) displacement across four postural conditions (cm), categorized by medial-lateral (X) and anterior-posterior (Y) axes. The data are presented as minimum, maximum, mean, and standard deviation (SD) values. CoP: center of pressure, EO: eyes open, and EC: eyes closed.

Single-leg stance resulted in higher sway velocity than double-leg stance. Mean sway velocity was 11.01 mm/s during right single-leg stance and 8.83 mm/s during left single-leg stance. Variability in sway measures was greater during single-leg stance compared with double-leg stance (Table 5).

CoP sway velocity values obtained under eyes-open and eyes-closed double-leg stance were strongly correlated ($r = 0.534$, $p = 0.002$, and FDR $q = 0.044$). During double-leg stance with opened eyes, X-axis CoP displacement was correlated with double-leg stance with closed eyes, X-axis CoP displacement ($r = 0.856$, $p < 0.001$, and FDR $q = 0.000$). Y-axis CoP displacements values during double-leg stance with opened eyes and double-leg stance with closed eyes were correlated ($r = 0.832$, $p < 0.001$, and FDR $q = 0.000$) (Table 7).

Table 7. Correlation matrix between center of pressure (CoP) velocity and displacement parameters across different stance conditions.

Center of Pressure Parameters	Center of Pressure Parameters (r, p, q Values)											
	1	2	3	4	5	6	7	8	9	10	11	12
1. CoP Velocity: Double-leg stance with EO	1											
2. CoP Displacement: Double-leg stance with EO—X axis	0.027 0.886, 0.985	1										
3. CoP Displacement: Double-leg stance with EO—Y axis	−0.189 0.309, 0.982	0.077 0.681, 0.985	1									
4. CoP Velocity: Double-leg stance with EC	0.534 0.002, 0.044 *	−0.068 0.715, 0.985	0.080 0.669, 0.985	1								
5. CoP Displacement: Double-leg stance with EC—X axis	0.010 0.956, 0.988	0.856 < 0.001, 0.000 *	0.194 0.297, 0.982	−0.057 0.762, 0.985	1							
6. CoP Displacement: Double-leg stance with EC—Y axis	−0.094 0.615, 0.982	−0.006 0.975, 0.988	0.832 < 0.001, 0.000 *	0.084 0.652, 0.985	0.179 0.335, 0.985	1						
7. CoP Velocity: Single-leg stance on the right foot with EO	−0.023 0.910, 0.985	0.303 0.132, 0.871	−0.249 0.219, 0.982	−0.097 0.636, 0.985	0.084 0.684, 0.985	−0.384 0.053, 0.446	1					
8. CoP Displacement: Single-leg stance on the right foot with EO—X axis	−0.235 0.247, 0.982	−0.005 0.980, 0.988	0.091 0.659, 0.985	−0.218 0.284, 0.982	−0.186 0.362, 0.985	−0.121 0.556, 0.982	−0.066 0.748, 0.985	1				
9. CoP Displacement: Single-leg stance on the right foot with EO—Y axis	0.003 0.988, 0.988	0.047 0.821, 0.985	0.185 0.365, 0.985	−0.044 0.832, 0.985	−0.082 0.690, 0.985	0.144 0.483, 0.985	−0.095 0.643, 0.985	−0.383 0.054, 0.446	1			
10. CoP Velocity: Single-leg stance on the left foot with EO	0.233 0.253, 0.982	0.099 0.631, 0.985	0.102 0.619, 0.982	−0.104 0.613, 0.982	0.197 0.336, 0.985	0.050 0.809, 0.985	0.388 0.050, 0.446	0.035 0.866, 0.985	−0.262 0.197, 0.982	1		
11. CoP Displacement: Single-leg stance on the left foot with EO—X axis	0.123 0.548, 0.982	−0.027 0.897, 0.985	−0.083 0.687, 0.985	0.176 0.389, 0.985	−0.202 0.321, 0.985	−0.104 0.612, 0.982	0.070 0.735, 0.985	0.463 0.017, 0.224	−0.256 0.207, 0.982	0.117 0.568, 0.982	1	
12. CoP Displacement: Single-leg stance on the left foot with EO—Y axis	−0.057 0.782, 0.985	−0.074 0.720, 0.985	0.154 0.454, 0.985	−0.031 0.879, 0.985	−0.118 0.566, 0.982	0.288 0.154, 0.931	0.007 0.972, 0.988	−0.116 0.574, 0.982	0.564 0.003, 0.050 *	−0.331 0.098, 0.719	−0.043 0.833, 0.985	1

Table 7 presents the Spearman rank correlation coefficients (r) and adjusted significance values (q) between CoP velocity and displacement parameters. Benjamini–Hochberg FDR correction was applied to the raw p -values to account for multiple comparisons, *: with significance set at $q < 0.05$. CoP: center of pressure, EO: eyes open, and EC: eyes closed.

4. Discussion

The present study examined the association between static plantar load distribution and postural stability parameters in adults with early-stage diabetic foot (Meggitt–Wagner grade 0–1). The results indicate that measurable functional characteristics in plantar loading and postural control are detectable even at a pre-ulcerative or early ulcerative stage, when overt deformity may be absent. From an orthotic and rehabilitation perspective, these findings are clinically relevant because they suggest that objective biomechanical screening

may contribute to earlier, individualized offloading and stability-oriented interventions rather than waiting for advanced tissue breakdown or recurrent ulceration [2,6].

4.1. Absence of Significant Association Between Plantar Load Distribution and Postural Stability After FDR Correction

Although no statistically significant associations were found after Benjamini–Hochberg FDR correction (all $q > 0.05$), the descriptive co-occurrence of rearfoot-dominant loading and sensory-dependent postural control behavior in this cohort is consistent with the concept that mechanical loading and postural regulation may represent complementary domains of early functional assessment in diabetic foot rather than directly correlated outcomes in the present dataset. The strong and statistically significant correlations of CoP displacements and sway velocity across visual conditions suggest relatively consistent postural control strategies within this sample, while unadjusted moderate correlations with loading parameters (e.g., $r = -0.428$ for CoP velocity and left total load) may be considered hypothesis-generating observations warranting further investigation in larger samples [20,21].

In orthotic practice, the integration of both assessment domains may be clinically useful: pedobarography can identify loading tendencies and potential offloading targets, while balance metrics can flag stability limitations that may influence safe footwear and orthosis selection and patient education. Rather than positioning these assessments as replacements for established clinical examination, the present findings support their use as complementary tools to enrich early functional assessment and inform preventive strategies [6,22,23].

The absence of significant associations after FDR correction may reflect several methodological factors: the modest sample size may have limited statistical power to detect small-to-moderate effects; the use of static load distribution (%) as opposed to dynamic peak pressure (kPa) may have reduced the sensitivity of the plantar loading measure to postural control-related variance; and the heterogeneity of the sample with respect to age and loss of protective sensation status may have introduced noise into the correlation analyses. These findings do not preclude a clinically meaningful relationship between these domains but rather suggest that larger, more homogeneous samples and multimodal assessment approaches are needed to characterize it adequately.

4.2. Rearfoot-Dominant Loading as a Potentially Relevant Orthotic Phenotype

A key finding was a consistent rearfoot-dominant loading pattern (approximately 61.5–61.8% rearfoot vs. 38.1–38.4% forefoot). Altered plantar loading is well documented in diabetes and neuropathy, and pressure redistribution is a cornerstone of preventive foot care [24,25]. Although diabetic foot risk is often discussed in relation to forefoot peak pressures during gait, static loading patterns may still provide clinically interpretable information about postural strategy and tissue loading tendency during quiet standing and daily functional tasks.

Clinically, posteriorly oriented loading may reflect a compensatory approach to increase perceived stability in the setting of reduced plantar sensation. However, because this study did not include a healthy control group and used relative static load distribution rather than dynamic peak pressure, this interpretation should be considered exploratory. For orthotic decision-making, this loading pattern important for two reasons. First, reduced forefoot loading at rest does not exclude forefoot risk during gait; therefore, static findings should be interpreted alongside clinical signs and, where feasible, dynamic assessments [26–31]. Second, sustained rearfoot loading may increase cumulative stress under the heel, although this inference is based on relative load distribution data, not peak pressure measurements in kPa, and may influence ankle–hindfoot mechanics, potentially suggesting the need for targeted heel cushioning, heel cup contouring, or rocker-sole optimization. These orthotic considerations remain hypothetical in the absence of interven-

tional data and require empirical validation in future studies [6,32]. In this sense, rearfoot dominance can inform not only “where to offload” but also “how to offload” without compromising balance. However, it should be noted that the dominant rearfoot loading profile demonstrated in this cohort (61.5–61.8%) generally appears to overlap with static weight-bearing values reported in healthy individuals. Indeed, Ohlendorf et al. described a median loading of 66.16% for the rearfoot in healthy females between ages 31 and 40 years, whereas Ohlendorf et al. found rearfoot loading ranging between 54% and 55% among mixed-sex adults from 18 to 65 years old with values depending on age and BMI [33,34].

It must be pointed out that the parameter used in this study—the relative distribution of plantar loads (%)—is not equivalent to peak plantar pressures (kPa), the latter representing mechanical stress during dynamic weight bearing and having more direct connections with ulceration. Therefore, the results presented herein are related to the static posture-related weight bearing and cannot be interpreted as indicators of ulceration risk related to dynamic peak pressure.

Although direct comparison is limited by differences in sample selection and methods used, the posterior loading trend found in this study seems to fall into the physiological boundaries for postures during quiet standing and cannot be considered a distinctly abnormal redistribution of plantar load. Thus, an inclusion of appropriately selected age- and sex-matched healthy controls should be regarded as critical in future research.

4.3. Visual and Sensory Dependence and Postural Control: Implications for Orthotic Function and Safety

Postural stability parameters varied by visual condition, with increased sway velocity under eyes-closed stance compared to eyes-open stance suggesting greater reliance on visual input for postural regulation. In diabetes—particularly when somatosensory input is compromised—postural regulation commonly involves sensory reweighting and increased reliance on visual cues [35,36].

This finding of the present study supports the possibility of increased dependence on visual input to maintain balance in diabetic patients with weakened somatosensory feedback, especially given that loss of protective sensation was identified in 51.6% of the participants. Moreover, the strong correlation between eyes-open and eyes-closed conditions for CoP sway velocity ($r = 0.534$) suggests a relatively stable underlying balance capacity that is not entirely dependent on visual conditions. Given the potential coexistence of diabetes-related retinopathy, reduced visual compensation may plausibly increase fall risk and postural instability in some patients. Clinically, visual dependence can reduce adaptability in low-light environments or on irregular surfaces, which can be highly relevant for patient safety and community ambulation.

For orthotic and footwear interventions, this finding has practical implications: footwear modifications that change proprioceptive input (e.g., sole stiffness, rocker profiles, and cushioning density) may influence stability in visually challenging contexts. Therefore, orthotic prescriptions in early-stage diabetic foot may benefit from considering not only plantar pressure redistribution but also balance requirements, though this proposition awaits confirmation in interventional studies, particularly for patients who demonstrate sensory-dependent sway behavior [37–39]. Integrating balance screening into orthotic pathways may help clinicians anticipate which individuals require additional stability features (e.g., wider base, appropriate outsole friction, and ankle support where indicated) or balance-focused rehabilitation alongside offloading strategies.

4.4. Limb Asymmetry and Single-Leg Stance: Relevance to Insole/Footwear Personalization

Single-leg stance produced substantially higher sway velocities than double-leg stance, with greater sway on the non-dominant limb. Asymmetric postural performance has

been described in diabetes and peripheral sensory involvement and may reflect differences in neuromuscular control, strength, confidence, and sensory integration between limbs [40,41]. Importantly, unilateral differences may be missed during bilateral stance testing, yet they can meaningfully affect functional tasks such as stepping, turning, and negotiating obstacles—situations where falls and foot trauma can occur.

From a clinical standpoint, limb asymmetry supports the rationale for individualized (and potentially asymmetrical) orthotic prescriptions. For example, when instability is greater on one side, future interventional studies should evaluate whether competing priorities between offloading and stability can be reconciled through side-specific modifications such as differential posting or tailored material stiffness, whereas overly stiff designs may reduce adaptability. Consequently, the combination of plantar loading and single-leg balance findings may help guide side-specific modifications such as differential posting, tailored material stiffness, or stability features incorporated into footwear [42–44].

4.5. Comparison with Existing Literature and Added Contribution

Previous studies have documented plantar pressure pattern differences and postural control characteristics in diabetes, often emphasizing dynamic gait metrics or more advanced stages of disease [41,42]. The present study adds complementary insight by focusing on early-stage diabetic foot (grade 0–1) and by examining the association between static load distribution and postural stability across visual and stance conditions. This approach aligns with the practical needs of orthotic and rehabilitation settings, where brief, clinic-feasible screening tools may be required to support timely intervention. Importantly, the study does not claim causality; instead, it characterizes a functional profile that may be relevant to early orthotic decision-making and fall-risk-informed care planning.

Concerning the postural stability values, the average CoP sway velocity in this study population (4.78 ± 1.98 mm/s eyes open; 5.76 ± 1.88 mm/s eyes closed) may be considered in light of the results of Huang et al., who investigated static postural stability in 706 adult patients with type 2 diabetes mellitus, stratified by three age cohorts [45]. They reported age-related differences in CoP total tracking length, sway area, and velocity with age advancement, with younger patients showing lower values than older patients. Despite the lack of direct numerical comparability due to the different testing equipment used, the sway velocity values in our cohort appear broadly consistent with the range reported for middle-aged adults with type 2 diabetes in that reference study, suggesting that our sample reflects a clinically representative postural profile for this stage of disease.

4.6. Clinical Implications for Orthotics and Rehabilitation

These findings have several practical implications for orthotic and prosthetic services involved in diabetic foot care:

1. Early identification of functional phenotypes: Rearfoot-dominant loading and sensory-/stance-dependent balance behavior may help clinicians recognize early functional phenotypes that warrant preventive attention even before advanced ulceration or deformity [2,5,7].
2. Insole and footwear optimization: Static loading patterns may provide preliminary information to guide material selection hypotheses, though controlled trials are needed to confirm whether specific design choices effectively redistribute load without compromising postural safety [6,43].
3. Balance-informed offloading: Patients with greater instability—particularly under single-leg stance or sensory challenge—may require orthotic strategies that explicitly consider stability (e.g., outsole traction, base of support, and ankle support when clinically appropriate) alongside offloading [6,23].

4. Integrated care pathways: Combining plantar pressure assessment with brief balance testing is proposed as a hypothesis for future multidisciplinary pathway development; whether coordinated orthotic and balance interventions reduce ulceration and fall risk requires prospective evaluation [23,43,44].

4.7. Limitations and Future Directions

Several limitations should be considered when interpreting the findings of this study. First, the relatively wide age range of the sample, from 35 to 75 years, may have introduced variability in neuromuscular performance, vestibular function, sensory integration, and postural control that was independent of diabetic foot status. However, the mean age of the cohort, 58.48 ± 9.53 years, is consistent with the age profile commonly observed in patients presenting with early-stage diabetic foot in clinical practice. Therefore, although age-related heterogeneity may have influenced the results, it may also reflect the clinical diversity of this patient population. Future studies should consider age-stratified analyses or narrower age categories to better control for this source of variability.

Second, foot deformities were not systematically assessed. Structural abnormalities such as claw toes, hallux valgus, limited joint mobility, arch alterations, or prominent metatarsal heads may affect both plantar load distribution and postural stability. The absence of a structured foot deformity assessment may therefore have contributed to unexplained variability in the biomechanical outcomes. Future studies should incorporate standardized clinical or imaging-based evaluations of foot deformity to clarify its contribution to plantar loading and balance parameters.

Third, the plantar assessment system used in the present study provides relative plantar load distribution as a percentage of total body weight during static standing. Although this approach is clinically feasible and suitable for routine orthotic assessment, it does not capture dynamic peak plantar pressure, shear stress, or pressure–time integrals during gait. These parameters are particularly relevant for ulceration risk prediction in diabetic foot biomechanics. Therefore, the direct clinical translation of the present findings to ulcer risk assessment should be interpreted with caution. Future research should combine static pedobarographic evaluation with dynamic gait analysis and shear-related parameters to provide a more comprehensive biomechanical profile.

Fourth, the cross-sectional design precludes causal inference. The observed associations between plantar load distribution and postural stability do not establish whether loading patterns influence postural control, whether impaired postural stability modifies plantar loading behavior, or whether both are consequences of underlying neuropathic, musculoskeletal, or sensory changes. In addition, the absence of a healthy control group is an important limitation. Without normative comparisons, the plantar loading and postural stability values observed in this study cannot be definitively characterized as altered relative to healthy adults, except by reference to external benchmarks.

Fifth, the inclusion of participants with and without loss of protective sensation may have increased sample heterogeneity. Differences in sensory status may influence both plantar loading and postural control through altered sensory feedback, impaired proprioception, and delayed neuromuscular responses. Future studies should stratify participants according to neuropathy severity using standardized tools such as Semmes–Weinstein monofilament testing, vibration perception threshold assessment, and, where feasible, nerve conduction studies.

Finally, the sample size was modest. Although it was powered for correlation analyses, the generalizability of the findings may be limited. Moreover, although the use of a low-cost balance platform offers an important pragmatic advantage in routine clinical and orthotic settings, it does not provide the same level of measurement granularity as laboratory-grade

force plates. This methodological trade-off should be considered when interpreting the balance outcomes.

Future work should include longitudinal designs to determine whether combined pressure–balance profiles can predict clinically relevant outcomes such as ulcer development, ulcer recurrence, or falls. Interventional studies are also needed to evaluate whether orthotic modifications, including customized insoles and offloading footwear, when combined with balance-focused rehabilitation, can improve functional outcomes and reduce biomechanical risk in patients with early-stage diabetic foot. Expanding biomechanical assessment to include dynamic gait parameters, shear-related measures, neuropathy-stratified analyses, and appropriately matched healthy control groups would further strengthen the clinical translation of these findings.

5. Conclusions

Patients with early-stage diabetic foot (Meggitt–Wagner grade 0–1) demonstrated measurable functional characteristics in both plantar load distribution and postural stability, even when overt deformity was not clinically evident and ulceration was absent or limited to superficial lesions. In this cohort, a consistent posterior rearfoot-dominant loading pattern and stance-, visual- and sensory-dependent balance behavior were observed. However, in the absence of a healthy control group, these findings should be interpreted as cohort-specific descriptive characteristics rather than evidence of abnormality relative to healthy adults. Future studies including appropriately matched healthy controls are needed to clarify the normative relevance of these findings.

From an orthotic and rehabilitation perspective, integrating static pedobarography with a brief, clinic-feasible balance protocol may enrich early functional foot assessment by combining information on mechanical loading patterns and stability-related functional limitations. Such combined screening may potentially help clinicians tailor preventive strategies—particularly individualized insole/footwear offloading and balance-oriented rehabilitation, although this approach requires confirmation in prospective studies before routine clinical implementation. Future longitudinal and interventional studies are needed to determine whether these functional profiles predict ulceration and falls and to evaluate the impact of targeted orthotic interventions on clinical outcomes.

Clinical implication: Even though there was no statistically significant correlation between plantar load distribution and postural stability after multiple comparison correction, both factors may still represent complementary assessment domains. Static pedobarography combined with a brief balance assessment could help inform early orthotic decision-making by assessing specific functional parameters that may not be fully captured by either test alone; however, this hypothesis needs further validation.

Supplementary Materials: The following supporting information can be downloaded at <https://www.mdpi.com/article/10.3390/japma116040044/s1>: File S1: STROBE Statement—checklist of items that should be included in reports of observational studies.

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Informed Consent Statement: All participants received verbal and written information regarding study procedures and provided written informed consent prior to participation. The study was conducted in accordance with the Declaration of Helsinki and was prospectively registered at ClinicalTrials.gov (NCT07084922).

Data Availability Statement: The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Abbreviations

The following abbreviations are used in this manuscript:

DM	Diabetes Mellitus (DM)
CoP	Center of Pressure
WBB	Wii Balance Board (WBB)
SD	Standard Deviation
FDR	False Discovery Rate
LOPS	Loss of Protective Sensation

References

1. American Diabetes Association. Standards of medical care in diabetes 2017. *Diabetes Care* **2017**, *40*, 11–14. [[CrossRef](#)] [[PubMed](#)]
2. Mima, S.; Abe, Y.; Yamasaki, H.; Bando, M.; Nagasaka, S.; Yamashita, Y.; Mineda, K.; Yoshida, S.; Endo, I.; Matsuhisa, M.; et al. Plantar pressure and shear stress during gait in people with diabetic neuropathy. *Diabetol. Int.* **2025**, *16*, 285–293. [[CrossRef](#)] [[PubMed](#)]
3. Jones, A.D.; Crossland, S.R.; Nixon, J.E.; Siddle, H.J.; Russell, D.A.; Culmer, P.R. STrain Analysis and Mapping of the Plantar Surface (STAMPS): A novel technique of plantar load analysis during gait. *Proc. Inst. Mech. Eng. Part H J. Eng. Med.* **2023**, *237*, 841–854. [[CrossRef](#)] [[PubMed](#)]
4. Sartor, C.D.; Hasue, R.H.; Cacciari, L.P.; Butugan, M.K.; Watari, R.; Pássaro, A.C.; Giacomozzi, C.; Sacco, I.C. Effects of strengthening, stretching and functional training on foot function in patients with diabetic neuropathy: Results of a randomized controlled trial. *BMC Musculoskelet. Disord.* **2014**, *15*, 137. [[CrossRef](#)] [[PubMed](#)]
5. Schaper, N.C.; van Netten, J.J.; Apelqvist, J.; Bus, S.A.; Hinchliffe, R.J.; Lipsky, B.A. Practical guidelines on the prevention and management of diabetic foot disease. *Diabetes Metab. Res. Rev.* **2020**, *36*, e3266. [[CrossRef](#)] [[PubMed](#)]
6. Bus, S.A.; Valk, G.D.; van Deursen, R.W.; Armstrong, D.G.; Caravaggi, C.; Hlaváček, P.; Bakker, K.; Cavanagh, P.R. The effectiveness of footwear and offloading interventions to prevent and heal foot ulcers and reduce plantar pressure in diabetes: A systematic review. *Diabetes Metab. Res. Rev.* **2008**, *24*, S162–S180. [[CrossRef](#)] [[PubMed](#)]
7. Patry, J.; Belley, R.; Côté, M.; Chateau-Degat, M.L. Plantar pressures, plantar forces, and their influence on diabetic foot ulcers. *J. Am. Podiatr. Med. Assoc.* **2013**, *103*, 322–332. [[CrossRef](#)] [[PubMed](#)]
8. Spolaor, F.; Guiotto, A.; Ciniglio, A.; Sawacha, Z. The effect of custom insoles on muscle activity in diabetic individuals with neuropathy. *Appl. Sci.* **2023**, *13*, 2326. [[CrossRef](#)]
9. D'Silva, L.J.; Lin, J.; Staecker, H.; Whitney, S.L.; Kluding, P.M. Impact of diabetic complications on balance and falls: Contribution of the vestibular system. *Phys. Ther.* **2016**, *96*, 400–409. [[CrossRef](#)] [[PubMed](#)]
10. Lai, Y.R.; Chiu, W.C.; Ting, C.P.; Chiang, Y.F.; Lin, T.Y.; Chiang, H.C.; Huang, C.C.; Lu, C.H. Postural sway serves as a predictive biomarker in balance and gait assessments for diabetic peripheral neuropathy screening: A community-based study. *J. Neuroeng. Rehabil.* **2025**, *22*, 123. [[CrossRef](#)] [[PubMed](#)]

11. Kavounoudias, A.; Roll, R.; Roll, J.-P. The plantar sole is a “dynamometric map” for human balance control. *NeuroReport* **1998**, *9*, 3247–3252. [[CrossRef](#)] [[PubMed](#)]
12. Wagner, F.W. The dysvascular foot: A system for diagnosis and treatment. *Foot Ankle* **1981**, *2*, 64–122. [[CrossRef](#)] [[PubMed](#)]
13. Arzehgar, A.; Nia, R.G.N.N.; Hoseinkhani, M.; Masoumi, F.; Sayyed-Hosseini, S.H.; Eslami, S. An overview of plantar pressure distribution measurements and its applications in health and medicine. *Gait Posture* **2025**, *117*, 235–244. [[CrossRef](#)] [[PubMed](#)]
14. Skopljak, A.; Muftic, M.; Sukalo, A.; Masic, I.; Zunic, L. Pedobarography in diagnosis and clinical application. *Acta Inform. Med.* **2014**, *22*, 374–378. [[CrossRef](#)] [[PubMed](#)]
15. Hafer, J.F.; Lenhoff, M.W.; Song, J.; Jordan, J.M.; Hannan, M.T.; Hillstrom, H.J. Reliability of plantar pressure platforms. *Gait Posture* **2013**, *38*, 544–548. [[CrossRef](#)] [[PubMed](#)]
16. Clark, R.A.; Mentiplay, B.F.; Pua, Y.H.; Bower, K.J. Reliability and validity of the Wii Balance Board for assessment of standing balance: A systematic review. *Gait Posture* **2018**, *61*, 40–54. [[CrossRef](#)] [[PubMed](#)]
17. Álvarez-Barbosa, F.; Del Pozo-Cruz, J.; Sañudo, B.; Alfonso-Rosa, R.M. Is the Wii Balance Board a valid and reliable instrument to assess postural stability in older adults with type 2 diabetes mellitus? *Diabetes Res. Clin. Pract.* **2020**, *166*, 108313. [[CrossRef](#)] [[PubMed](#)]
18. Nagymaté, G.; Orlovits, Z.; Kiss, R.M. Reliability analysis of a sensitive and independent stabilometry parameter set. *PLoS ONE* **2018**, *13*, e0195995. [[CrossRef](#)] [[PubMed](#)]
19. Estévez-Pedraza, Á.G.; Hernandez-Laredo, E.; Millan-Guadarrama, M.E.; Martínez-Méndez, R.; Carrillo-Vega, M.F.; Parra-Rodríguez, L. Reliability and usability analysis of an embedded system capable of evaluating balance in elderly populations based on a modified Wii Balance Board. *Int. J. Environ. Res. Public Health* **2022**, *19*, 11026. [[CrossRef](#)] [[PubMed](#)]
20. Anjos, D.M.; Gomes, L.P.; Sampaio, L.M.; Correa, J.C.; Oliveira, C.S. Assessment of plantar pressure and balance in patients with diabetes. *Arch. Med. Sci.* **2010**, *6*, 43–48. [[CrossRef](#)] [[PubMed](#)]
21. Fan, Z.Q.; Liu, D.W. Impairment characteristics of static balance and plantar load distribution of patients undergoing tibial cortex transverse distraction for diabetic foot ulcers. *J. Orthop. Surg. Res.* **2022**, *17*, 171. [[CrossRef](#)] [[PubMed](#)]
22. Owings, T.M.; Woerner, J.L.; Frampton, J.D.; Cavanagh, P.R.; Botek, G. Custom therapeutic insoles based on both foot shape and plantar pressure measurement provide enhanced pressure relief. *Diabetes Care* **2008**, *31*, 839–844. [[CrossRef](#)] [[PubMed](#)]
23. Alaei, S.J.; Barati, K.; Hajiaghahi, B.; Ghomian, B.; Moradi, S.; Poorpirali, M. Immediate effect of textured insoles on the balance in patients with diabetic neuropathy. *J. Diabetes Investig.* **2023**, *14*, 435–440. [[CrossRef](#)] [[PubMed](#)]
24. Gefen, A. Plantar soft tissue loading under the medial metatarsals in the standing diabetic foot. *Med. Eng. Phys.* **2003**, *25*, 491–499. [[CrossRef](#)] [[PubMed](#)]
25. Rojas-Torres, F.; Infanzón-Talango, H.; García-Ulloa, A.C.; Hernández-Jiménez, S.; Rodríguez-Reyes, G. Exploring plantar pressure distribution in patients with newly diagnosed diabetes: Implications for foot ulcer prevention in an overweight Mexican population. *Endocrinol. Diabetes Nutr. (Engl. Ed.)* **2024**, *71*, 340–347. [[CrossRef](#)]
26. Maetzler, M.; Bochdanský, T.; Wang, W.; Abboud, R.J. Barefoot pressure distribution of diabetic patients and non-diabetic volunteer subjects after sensorimotor training with an unstable shoe construction. *Foot* **2024**, *60*, 102102. [[CrossRef](#)] [[PubMed](#)]
27. Perry, S.D.; McIlroy, W.E.; Maki, B.E. The role of plantar cutaneous mechanoreceptors in the control of compensatory stepping reactions evoked by unpredictable, multi-directional perturbation. *Brain Res.* **2000**, *877*, 401–406. [[CrossRef](#)] [[PubMed](#)]
28. Mueller, M.J.; Hastings, M.; Commean, P.K.; Smith, K.E.; Pilgram, T.K.; Robertson, D.; Johnson, J. Forefoot structural predictors of plantar pressures during walking in people with diabetes and peripheral neuropathy. *J. Biomech.* **2003**, *36*, 1009–1017. [[CrossRef](#)] [[PubMed](#)]
29. Cavanagh, P.R.; Bus, S.A. Off-loading the diabetic foot for ulcer prevention and healing. *J. Vasc. Surg.* **2010**, *52*, 37S–43S. [[CrossRef](#)] [[PubMed](#)]
30. Horak, F.B. Postural orientation and equilibrium: What do we need to know about neural control of balance to prevent falls? *Age Ageing* **2006**, *35*, ii7–ii11. [[CrossRef](#)] [[PubMed](#)]
31. Fernando, M.E.; Crowther, R.G.; Pappas, E.; Lazzarini, P.A.; Cunningham, M.; Sangla, K.S.; Buttner, P.; Golledge, J. Plantar pressure in diabetic peripheral neuropathy patients with active foot ulceration, previous ulceration and no history of ulceration: A meta-analysis of observational studies. *PLoS ONE* **2014**, *9*, e0099050. [[CrossRef](#)] [[PubMed](#)]
32. Janisse, D.J.; Janisse, E. Shoe modification and the use of orthoses in the treatment of foot and ankle pathology. *J. Am. Acad. Orthop. Surg.* **2008**, *16*, 152–158. [[CrossRef](#)] [[PubMed](#)]
33. Ohlendorf, D.; Pflaum, J.; Wischniewski, C.; Schamberger, S.; Erbe, C.; Wanke, E.M.; Holzgreve, F.; Groneberg, D.A. Standard reference values of the postural control in healthy female adults aged between 31 and 40 years in Germany: An observational study. *J. Physiol. Anthropol.* **2020**, *39*, 27. [[CrossRef](#)] [[PubMed](#)]
34. Ohlendorf, D.; Kerth, K.; Osiander, W.; Holzgreve, F.; Fräulín, L.; Ackermann, H.; Groneberg, D.A. Standard reference values of weight and maximum pressure distribution in healthy adults aged 18–65 years in Germany. *J. Physiol. Anthropol.* **2020**, *39*, 39. [[CrossRef](#)] [[PubMed](#)]
35. Peterka, R.J. Sensorimotor integration in human postural control. *J. Neurophysiol.* **2002**, *88*, 1097–1118. [[CrossRef](#)] [[PubMed](#)]

36. Corriveau, H.; Prince, F.; Hébert, R.; Raïche, M.; Tessier, D.; Maheux, P.; Ardilouze, J.L. Evaluation of postural stability in elderly with diabetic neuropathy. *Diabetes Care* **2000**, *23*, 1187–1191. [[CrossRef](#)] [[PubMed](#)]
37. Hijmans, J.M.; Geertzen, J.H.; Dijkstra, P.U.; Postema, K. A systematic review of the effects of shoes and other ankle or foot appliances on balance in older people and people with peripheral nervous system disorders. *Gait Posture* **2007**, *25*, 316–323. [[CrossRef](#)] [[PubMed](#)]
38. López-Moral, M.; Molines-Barroso, R.J.; Álvaro-Afonso, F.J.; Uccioli, L.; Senneville, E.; Lázaro-Martínez, J.L. Importance of footwear outsole rigidity in improving spatiotemporal parameters in patients with diabetes and previous forefoot ulcerations. *J. Clin. Med.* **2020**, *9*, 907. [[CrossRef](#)] [[PubMed](#)]
39. Biscarini, A.; Calandra, A.; Marcucci, A.; Panichi, R.; Belotti, A. Enhanced foot proprioception through 3-minute walking bouts with ultra-minimalist shoes on surfaces that mimic highly rugged natural terrains. *Biomimetics* **2024**, *9*, 741. [[CrossRef](#)] [[PubMed](#)]
40. Yümin, E.T.; Şimşek, T.T.; Bakar, Y. Plantar sensation and balance in patients with type 2 diabetes mellitus with and without peripheral neuropathy. *Acta Clin. Croat.* **2021**, *60*, 191–200. [[CrossRef](#)] [[PubMed](#)]
41. Ullah, S.; Iqbal, K.; Rizwan, M. Gait and postural control deficits in diabetic patients with peripheral neuropathy compared to healthy controls. *Bioengineering* **2025**, *12*, 1034. [[CrossRef](#)] [[PubMed](#)]
42. Kardm, S.M.; Kardm, A.S.; Alanazi, Z.A.; Alnakhli, H.H.; Alkhamis, B.A.; Reddy, R.S. Sensorimotor dysfunction and postural instability in older adults with type 2 diabetes mellitus: The role of proprioception and neuropathy. *Front. Aging Neurosci.* **2025**, *17*, 1615399. [[CrossRef](#)] [[PubMed](#)]
43. Paton, J.; Glasser, S.; Collings, R.; Marsden, J. Getting the right balance: Insole design alters the static balance of people with diabetes and neuropathy. *J. Foot Ankle Res.* **2016**, *9*, 40. [[CrossRef](#)] [[PubMed](#)]
44. Horstink, K.A.; van der Woude, L.H.V.; Hijmans, J.M. Effects of offloading devices on static and dynamic balance in patients with diabetic peripheral neuropathy: A systematic review. *Rev. Endocr. Metab. Disord.* **2021**, *22*, 325–335. [[CrossRef](#)] [[PubMed](#)]
45. Zhuang, Y.; Hong, Z.; Wu, L.; Zou, C.; Zheng, Y.; Chen, L.; Yin, L.; Qin, J. Influence of age on static postural control in adults with type 2 diabetes mellitus: A cross-sectional study. *Front. Endocrinol.* **2023**, *14*, 1242700. [[CrossRef](#)] [[PubMed](#)]

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