



Article

A Biomechanical Comparison of Therapeutic Footwear and Athletic and Low-Cost Generic Shoes: Effects on Plantar Pressure, Lower Extremity Kinematics, and Kinetics

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Abstract: Introduction: Therapeutic footwear has been often prescribed in clinical practice for accommodating foot deformities and preventing the development of ulceration, yet scientific evidence is limited and outdated. This study aimed to investigate the effects of two types of Orthofeet therapeutic footwear in comparison to low-cost generic as well as participants' own athletic shoes on plantar pressure as well as lower extremity kinematics and kinetics. Methods: Twenty healthy participants without foot disorders or pain walked at self-paced speeds under each of the four footwear conditions. In-shoe plantar pressures were measured using F-Scan, and the gait kinematics and kinetics in the sagittal plane were obtained. The foot was divided into eight anatomical zones and three combined zones (forefoot, mid-foot, and hind foot), with peak plantar pressures recorded in each zone. Results: The therapeutic footwear showed significantly greater ankle dorsiflexion during late midstance and less ankle plantar flexion during push-off than generic shoes. Similarly, larger ankle plantar flexor torques were shown when wearing therapeutic footwear. Therapeutic footwear modified the plantar pressure distribution, increasing the peak pressure under the big toe while slightly reducing the peak pressure under the medial heel. The participants' own athletic shoes provided slightly distinct outcome measures yet comparable performance when compared to therapeutic footwear. Conclusions: This study suggests that therapeutic footwear offers some distinct biomechanical modifications compared with generic shoes. Future studies are needed to assess if these changes lead to meaningful clinical outcomes, such as reduced injury risk or improved foot health.



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Keywords: therapeutic footwear; plantar pressure; pressure time integral; gait

1. Introduction

Diabetic foot ulcers pose a significant health risk, leading to severe complications such as infection or even amputation [1–5]. Appropriate footwear plays a crucial role in reducing excessive plantar pressure, a key factor in ulcer formation. Patients with diabetes need footwear that redistributes pressure, provides cushioning, and offers adequate support to minimize the risk of skin breakdown [6,7]. Therapeutic shoes are specifically designed to meet these needs by incorporating features such as extra depth, softer insoles, and specialized midsole structures to reduce localized stress on the foot [8].

The soles of footwear serve as the primary interface between the foot and the ground, and their structure, design, and material can significantly influence load distribution and

gait patterns. For instance, a rocker sole profile can promote ankle plantar flexion, limit the metatarsophalangeal (MTP) joint in the sagittal plane, and reduce plantar pressure under the metatarsal heads [9–13]. Additionally, sole design can influence the distribution of forces during gait, with features like cushioning and stability elements further enhancing comfort and reducing foot stress [14]. A study on Masai Barefoot Technology (MBT) footwear demonstrated significant effects on gait kinematics and kinetics, including a reduced knee extension angle in early stance, decreased hip extension angle, increased ankle dorsiflexion angle in late stance, and lower joint moment and power in late stance [15]. Aside from the outsole design, insole configuration also plays a critical role in therapeutic footwear. The insole affects foot alignment, provides cushioning, and helps distribute plantar pressure more evenly across the foot surface, which is particularly important for individuals with diabetic neuropathy or other foot health concerns [16–21]. Proper insole design can reduce the risk of pressure ulcers and other foot complications, making it a key component of therapeutic footwear. Overall, both the sole and insole characteristics of therapeutic shoes are essential for improving gait, reducing discomfort, and enhancing overall foot health.

Although therapeutic footwear is widely used in diabetic foot care to provide cushioning and reduce plantar pressure, this study does not focus on its preventive effects on ulcers. Instead, this research investigates the biomechanical differences between therapeutic footwear, generic shoes, and athletic shoes in a healthy population. While previous studies have primarily examined plantar pressure reduction in diabetic patients [22] or ulcer recurrence prevention [6,23,24], fewer studies have explored the broader biomechanical properties of therapeutic footwear. Understanding how therapeutic footwear alters gait biomechanics and plantar pressure compared to standard footwear may offer insights into their functional benefits beyond clinical applications.

With a growing number of therapeutic footwear options available, both consumers and clinicians are interested in their potential biomechanical effects. Among commonly used therapeutic footwear, Orthofeet (Orthofeet Inc., Northvale, NJ, USA) footwear features an ergonomic sole without a rocker design and a tie-less lace system integrating laces and straps. However, there is currently no scientific evidence supporting their biomechanical benefits. Most studies on therapeutic footwear have primarily examined either plantar pressure [22] or gait kinematics and kinetics [15,25–27]. Given the close relationship between gait patterns and plantar pressure [9,28], a comprehensive examination of both aspects is essential for a thorough evaluation of therapeutic footwear.

Additionally, cost remains an important consideration. Off-the-shelf therapeutic footwear can be expensive, typically ranging from USD 100 to 200 [29,30], whereas low-cost alternatives are available for about USD 20 [31]. Considering the association between low income and a higher prevalence of diabetes [32], identifying affordable footwear with comparable biomechanical benefits could be valuable. This study aimed to investigate whether Orthofeet therapeutic footwear offers biomechanical benefits over low-cost generic shoes and participants' own athletic shoes. It was hypothesized that Orthofeet therapeutic footwear would influence biomechanical outcome measures, including lower extremity joint kinematics, kinetics, as well as plantar pressure distribution, compared to other types of footwear. Additionally, while gender has been shown to influence both gait temporospatial parameters and plantar pressure, the findings have been inconsistent [28,33,34]. This study also aimed to examine any potential gender effect on these biomechanical measures. This was evaluated through a comprehensive analysis of its effects on plantar pressure, lower extremity kinematics, and kinetics during ambulation in a healthy population.

2. Methods

2.1. Participants

Twenty healthy volunteers (12 men and 8 women; body height: 171.5 ± 8.4 cm; body mass: 69.1 ± 10.7 kg; age: 33.1 ± 6.2 yrs) participated in this study after giving informed consent (the demographics of the participants are presented in Table A3). All participants had no history of low extremity injuries or foot disorders or pains. Before participating, they underwent a brief physical examination, which included body height, weight, and foot size measurements. A podiatrist carefully assessed everyone's foot condition for deformities or injuries to confirm the absence of foot disorders and pain. Afterward, the podiatrist measured each participant's foot length and width using a Brannock device to ensure an appropriate fit.

2.2. Materials and Instruments

Three pairs of shoes were provided, including Orthofeet athletic (men: Monterey Bay; women: Tahoe), Orthofeet dress (men: Avery Island; women: Lake Charles), and low-cost generic (~USD 20 per pair) (Figure 1). Additionally, participants were requested to bring one pair of athletic shoes they commonly used for walking (10 pairs of Nike shoes, 2 pairs of Adidas shoes, and 8 pairs of New Balance shoes; shoe construction materials and weight are presented in Table A2). All shoes were tested with their original pre-fabricated insoles (images of insoles of footwear are presented in Table A1). The athletic shoe has Bio-Fit™ insoles (Orthofeet Inc., Northvale, NJ, USA), consisting of four layers (from top to bottom: (1) polyester mesh lining; (2) soft and moldable foam; (3) cushioning ethyl vinyl acetate (EVA); and (4) a rear foot shell made of high-density EVA), have arch support and deep heel cups. The thickness of the Bio-Fit insole is about 6 mm and 8 mm in the forefoot and rear foot, respectively. The Orthofeet dress shoe has Ortho-Step orthotic insoles with a similar construction and thickness to those of the Bio-Fit insoles, except the top layer is made of leather. The generic shoes' insole, made of a single layer of EVA, has a uniform thickness of 4 mm without visible arch support. The insoles of the participants' own athletic shoes had various constructs and materials but overall had good arch support. Participants were given about one hour to break in the three pairs of shoes, wearing each pair for 20 min in a random order. Afterward, each pair of footwear was worn for approximately five minutes before conducting a walking test.



Figure 1. Footwear ((a) men's; (b) women's) provided in the study: athletic (top), dress (middle), and generic (bottom).

A 10-camera VICON system (MX-T10, VICON Inc., Oxford, UK) and two AMTI force plates (American Mechanical Technology, Inc., Watertown, MA, USA) were used to simultaneously capture gait kinematics and kinetics. The force plates were positioned with a 30-cm-wide wooden block between them. The camera system was carefully calibrated, and the global reference frame was set to the far left corner of the first plate (Figure 2). Additionally, the F-scan in-shoe pressure mapping system (Tekscan Inc., Boston, MA, USA) was used and synchronized with both the camera system and force plates at a sampling rate of 250 Hz. This thin (0.18-mm-thick), film-like sensor contained 954 sensing elements, offering a spatial resolution of 3.88 sensel/cm² (or 25 sensel/in²). The in-shoe sensor was trimmed to accommodate the shoe size of each participant and secured to the insole using double-sided tape. Before conducting the study, the sensors were calibrated, following the recommendations from the manufacture closely.

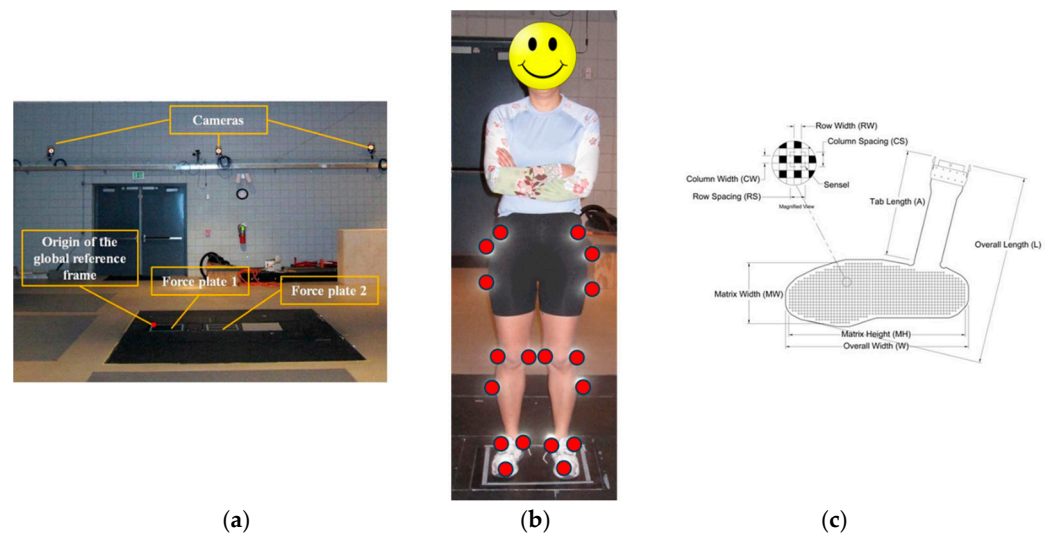


Figure 2. Experimental set-up: (a) motion capture system; (b) marker set (three markers on the back and heels are not shown); and (c) F-scan sensor.

2.3. Procedures

We used the modified Helen Hayes model for lower extremities [35,36]. In total, 21 spherical reflective markers (10 mm in diameter) were placed on specific anatomical landmarks by the same experimenter using double-sided tape. These included three markers on the pelvis (two on the anterior superior iliac spines and one on the sacrum), seven markers on each leg (medial and lateral femoral epicondyle, medial and lateral malleolus, greater trochanter, lateral thigh, and lateral shank), and two on each foot (base of the second metatarsal and calcaneus).

Before the test, the participants were instructed to stand still on the force plate, and a static trial was captured. Participants were allowed to walk across the force plates a few times for familiarization. For each footwear condition, participants walked at a self-paced speed across the walkway (~10 m long) 10 times for each side. As force plates were used to identify a complete gait cycle, each successful trial provided data for a full gait cycle on one side. The best 3 (i.e., with full foot contact) out of the 10 trials, or three complete gait cycles per side, were used for further analyses. To prevent fatigue, a 5-min break was provided between test sessions. Data from the cameras and force plates were simultaneously recorded by the VICON workstation at a preset rate of 250 Hz. After the test, participants evaluated the comfort level of each type of footwear using a visual analogue scale (VAS) ranging from 0 to 100%.

2.4. Data Analysis

Raw data were first processed using a zero-lag fourth-order Butterworth low-pass filter with a cutoff frequency of 30 Hz. Both kinematic and kinetic data in the sagittal plane were processed in Visual3D (C-Motion, Inc., Germantown, MD, USA) and further analyzed with custom MATLAB scripts (Mathworks, Inc., Natick, MA, USA). The three-dimensional joint kinematics were calculated by following the Cardan sequence of X-Y-Z, and the joint torques were obtained using inverse dynamics [37]. Gait events (i.e., heel strike and toe-off) for both sides were automatically identified based on the vertical ground reaction force using a threshold of 10 N. A full gait cycle was defined by consecutive heel strikes with both kinematic and kinetic data normalized to the gait cycle, where one complete gait cycle corresponded to 100%. Data from all three trials were used in data analyses. Gait temporospatial parameters including the speed (m/s), stride length (distance between two consecutive heel strikes on the same side (m)), and double support time (amount of time when both feet are in contact with the ground (s)) were obtained. The following key parameters of lower extremity kinetics and kinematics in the sagittal plane were obtained and marked in Figure 3: ankle joint peak dorsiflexion, peak plantar flexion, range of motion, first and second peaks of knee flexion, and first peak flexion and peak extension of hip joint. In addition, the two peaks of the vertical ground reaction force (GRFz) as well as braking (the area under the negative part of the vertical ground reaction force-time curve) and propulsive impulses (the area under the positive part of the vertical ground reaction force force-time curve) were obtained. The kinetic quantities were normalized to the body mass and reported as the group average and standard deviation. A paired t-test was conducted between sides across the participants and conditions, revealing no significant differences between the left and right sides. Therefore, all analyses were conducted on the right side, which was identified as the dominant side based on each participant's preferred side when kicking a ball.

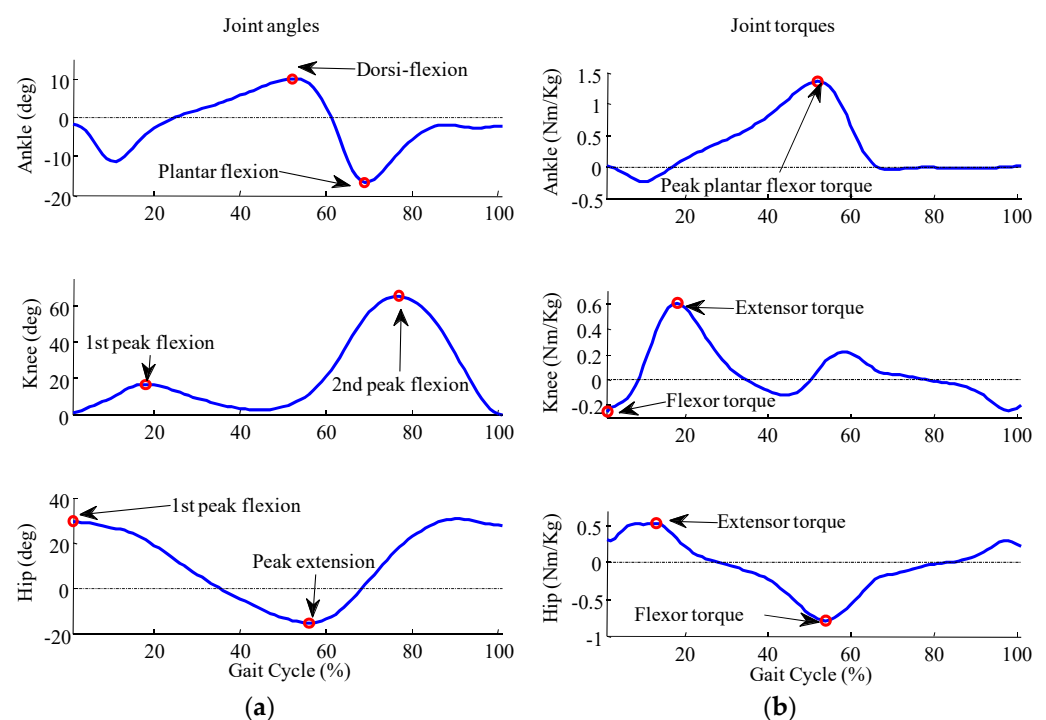


Figure 3. Gait kinematic and kinetic parameters. (a): joint angles and (b) joint torques.

F-scan pressure data were initially analyzed using Tekscan research software and further processed with custom MATLAB scripts (MATLAB R2022). A total of 11 zones were identified, including 8 anatomical zones and 3 combined zones (forefoot, midfoot, and

hindfoot) (Figure 4). The peak pressure was determined within each zone. For each trial, the peak pressures of the selected zones were averaged across multiple steps, excluding the first and last steps. The peak pressures were calibrated with respect to the two peaks of the vertical ground reaction force registered by the force plate and used for further analysis [38].

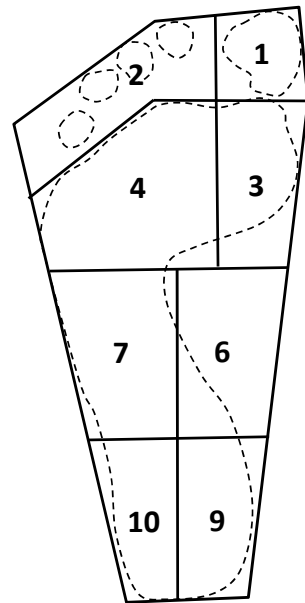


Figure 4. Plantar pressure mask. 1 = big toe; 2 = other toes; 3 = medial forefoot; 4 = lateral forefoot; 5 = forefoot (3 + 4); 6 = medial midfoot; 7 = lateral midfoot; 8 = midfoot (6 + 7); 9 = medial hindfoot; 10 = lateral hindfoot; 11 = hindfoot (9 + 10).

Two-way repeated measures MANOVA was performed with footwear and gender as factors. This analysis was applied for each of the following outcome categories: gait temporospatial characteristics, sagittal plane lower extremity kinematics, sagittal plane lower extremity kinetics, two peaks of GRFz, braking and propulsive impulses, and in-shoe peak plantar pressures. The independent variable, footwear, had four levels: athletic, dress, generic, and the participant's own shoes. MANOVA was conducted first to assess the overall multivariate effect of footwear and gender within each category. Wilks' λ was selected as the multivariate test statistics. When a significant multivariate effect was detected, follow-up repeated measures ANOVAs were performed for individual dependent variables to identify specific sources of variation. When a violation of sphericity was detected, adjustments were applied using the Huynh–Feldt correction for sphericity estimates greater than 0.75 and the Greenhouse–Geisser correction otherwise. Post hoc comparisons were conducted using Tukey's honestly significant difference (HSD) test when significant footwear effects were found in the MANOVA or subsequent ANOVAs. To assess data normality, the Shapiro–Wilk test was conducted for both the peak plantar pressures and gait parameters. After confirming the normality, Pearson product-moment correlation coefficients were then calculated to determine the association between these variables. All statistical analyses were conducted in SPSS (IBM SPSS Statistics for Windows, Version 26.0, IBM Corp., Armonk, NY, USA), and the statistical significance level was set at $\alpha = 0.05$.

3. Results

As no main effect from gender was identified across the categories, outcome measures are reported as the group mean (SD).

3.1. Gait Temporospatial Characteristics

No significant main effects from footwear (Wilks' $\lambda = 0.614$, $F(18,139) = 1.453$, $p = 0.117$) or gender (Wilks' $\lambda = 0.466$, $F(6,13) = 2.479$, $p = 0.080$) were revealed for the temporospatial parameters (Table 1). Walking speeds were fairly consistent across the footwear types ($p = 0.55$), though the participants tended to walk slightly slower when wearing dress footwear (1.23 ± 0.12 m/s) compared with either athletic (1.25 ± 0.13 m/s) or generic footwear (1.27 ± 0.13 m/s). Similarly, the stride length was comparable across the tested conditions ($p = 0.255$). The double-limb support time was slightly longer when wearing therapeutic footwear compared with generic shoes and the participants' own shoes. However, the effect of the footwear type did not reach a statistically significant level ($p = 0.174$).

Table 1. Summary of outcome measures (mean (SD)).

Category	Parameter	Athletic ¹	Dress ²	Generic ³	Own ⁴
Temporospatial	Speed (m/s)	1.25 (0.13)	1.23 (0.12)	1.27 (0.13)	1.24 (0.11)
	Stride length (m)	1.39 (0.12)	1.37 (0.17)	1.38 (0.18)	1.36 (0.10)
	Double support time (s)	0.27 (0.08)	0.27 (0.07)	0.25 (0.06)	0.23 (0.08)
Joint kinematics (°)	Ankle dorsiflexion	13.0 (3.5) ^{3,4}	12.9 (3.4) ^{3,4}	10.5 (3.4) ^{1,2}	10.1 (2.6) ^{1,2}
	Ankle plantar flexion	14.7 (4.9) ²⁻⁴	16.4 (4.8) ^{1,3,4}	17.8 (4.9) ^{1,2}	19.2 (5.4) ^{1,2}
	Ankle range of motion	27.8 (3.7) ^{2,4}	29.3 (4.2) ¹	28.4 (4.2)	29.3 (3.6) ¹
	Knee 1st peak flexion	18.0 (5.4)	16.8 (5.0)	16.9 (5.6)	16.2 (7.3)
	Knee 2nd peak flexion	65.0 (5.8)	66.4 (6.1)	65.8 (6.2)	65.3 (7.0)
	Hip 1st peak flexion	29.0 (3.9)	28.7 (4.3)	29.7 (3.6) ⁴	28.4 (3.6) ³
	Hip peak extension	15.5 (3.1)	15.6 (4.0)	15.3 (2.9)	15.2 (3.5)
	Ankle plantar flexor	1.41 (0.24)	1.43 (0.24) ³	1.38 (0.24) ²	1.39 (0.24)
Joint kinetics (Nm/kg)	Knee flexor	0.28 (0.12)	0.25 (0.12)	0.27 (0.10)	0.28 (0.11)
	Knee extensor	0.64 (0.27)	0.63 (0.25)	0.62 (0.26)	0.64 (0.28)
	Hip flexor	0.87 (0.20)	0.83 (0.23)	0.85 (0.22)	0.86 (0.25)
	Hip extensor	0.74 (0.32)	0.67 (0.27)	0.67 (0.27)	0.66 (0.23)
	GRFz (BW)	1.16 (0.11)	1.15 (0.13)	1.15 (0.12)	1.15 (0.13)
Impulse (BW.GC%)	1st peak	1.12 (0.07)	1.12 (0.08)	1.12 (0.07)	1.13 (0.08)
	Propulsive	4.19 (0.97)	4.36 (1.2)	4.33 (1.06)	4.56 (1.08)
Peak plantar pressure (kPa)	Braking	4.37 (0.65)	4.49 (0.76)	4.5 (0.66)	4.55 (0.69)
	1: Big toe	294.5 (121.1) ²	400.0 (182.9) ^{1,3,4}	270.1 (137.6) ^{2,4}	330.0 (153.2) ^{2,3}
	2: Other toes	134.8 (58.9)	129.2 (64.8)	131.3 (66.7)	128.3 (56.8)
	3: Medial forefoot	267.6 (105.0)	280.7 (118.8)	261.2 (77.9)	302.7 (116.4)
	4: Lateral forefoot	273.1 (97.2)	292.5 (88.5)	299.1 (97.3)	309.0 (103.4)
	5: Forefoot	328.5 (97.3)	352.5 (107.2)	339.4 (89.7)	355.6 (125.5)
	6: Medial midfoot	79.2 (49.9)	106.9 (78.1) ³	52.3 (31.6) ²	83.0 (68.8)
	7: Lateral midfoot	99.1 (43.2)	101.4 (32.7)	111.8 (46.8)	118.9 (46.6)
	8: Midfoot	113.3 (55.7)	133.0 (70.9)	117.4 (46.1)	135.4 (74.8)
	9: Medial hindfoot	240.2 (79.1) ³	266.9 (99.7)	290.6 (76.6) ¹	267.2 (92.2)
	10: Lateral hindfoot	250.6 (92.3)	247.5 (79.6)	260.3 (64.1)	263.6 (116.2)
	11: Hindfoot	272.7 (91.4)	281.9 (100.1)	304.0 (75.6)	291.9 (115.8)
Survey	Comfort rating (%)	56.3 (20.8) ⁴	65.6 (16.4) ^{3,4}	49.4 (17.5) ^{2,4}	82.4 (15) ^{1,2,3}

Note: Superscript ¹⁻⁴ represents athletic, dress, generic, and participants' own shoes, respectively. Significant differences indicated with significant pair comparisons shown in superscript (e.g., 0.41 (0.03)³ indicates significant difference from ³ (i.e., generic)).

3.2. Gait Kinematics and Kinetics

Significant main effects from the footwear were observed for joint kinematics (Wilks' $\lambda = 0.254$, $F(18,139) = 4.814$, $p < 0.001$) but not for joint kinetics (Wilks' $\lambda = 0.691$, $F(15,138) = 1.325$, $p = 0.195$). No significant main effects according to gender were revealed for both joint kinematics (Wilks' $\lambda = 0.668$, $F(6,13) = 1.079$, $p = 0.424$) and kinetics (Wilks' $\lambda = 0.725$, $F(5,14) = 1.063$, $p = 0.421$). In addition, there were no significant interaction effects between footwear and gender for either the joint kinematics (Wilks' $\lambda = 0.668$, $F(18,139) = 1.079$, $p = 0.280$) or kinetics (Wilks' $\lambda = 0.790$, $F(15,138) = 0.824$, $p = 0.650$).

Both the athletic and dress footwear exhibited significantly greater peak ankle dorsiflexion ($p = 0.001$ for both pairwise comparisons) and significantly reduced peak ankle plantar flexion ($p < 0.001$ and $p = 0.012$, respectively) compared with the generic footwear and participants' own shoes. Additionally, the athletic shoes showed significantly lower peak ankle plantar flexion ($p < 0.001$) and a reduced ankle range of motion compared with the dress footwear ($p < 0.001$) and participants' own shoes. Regarding hip joint kinematics, the only significant difference was observed between generic footwear and the participants' own shoes in the first hip peak flexion ($p = 0.008$). For joint kinetics, the only significant pairwise difference was between the dress and generic footwear in terms of ankle plantar flexor torque ($p = 0.021$). The two peaks in the vertical ground reaction force were fairly consistent across the footwear conditions, and no statistical significance was shown. A similar pattern was found for both the propulsive and braking impulses, though the athletic footwear showed slightly lower impulses compared with the rest.

3.3. Peak Plantar Pressure

A significant main effect from the footwear was observed for the peak plantar pressure (Wilks' $\lambda = 0.157$, $F(33,130) = 3.457$, $p < 0.001$). No significant main effect from gender was revealed (Wilks' $\lambda = 0.674$, $F(11,8) = 0.351$, $p = 0.944$). In addition, the interaction effect between footwear and gender was not significant (Wilks' $\lambda = 0.459$, $F(33,130) = 1.197$, $p = 0.237$).

The dress footwear demonstrated the largest peak pressure (i.e., 400.0 ± 182.9 kPa) under the big toe, followed by the participants' own shoes and athletic and generic footwear. Under the medial midfoot, the dress footwear showed the highest peak pressure while the generic footwear showed the lowest value, and their pairwise comparison reached significant level ($p = 0.021$). Under the medial hindfoot, the athletic footwear exhibited a significantly lower peak plantar pressure than the generic footwear ($p = 0.013$).

3.4. Relation Between Peak Plantar Pressure (PPP) and Gait Parameters

The PPP under the big toe was significantly related to the propulsive impulse ($r = 0.267$, $p = 0.017$) and ankle ROM ($r = 0.232$, $p = 0.039$). The PPP under the medial forefoot was strongly associated with the second peak of the vertical ground reaction force ($r = 0.53$, $p = 0.023$), ankle dorsi-flexion ROM ($r = 0.263$, $p = 0.018$), and hip extension ROM ($r = -0.225$, $p = 0.044$). The PPP under the heel was found to be significantly related to the braking impulse ($r = 0.308$, $p = 0.005$), first peak of knee flexion ($r = -0.244$, $p = 0.029$), peak knee flexor torque ($r = 0.250$, $p = 0.025$), peak knee extensor torque ($r = -0.249$, $p = 0.026$), and peak hip extensor torque ($r = 0.378$, $p = 0.004$).

3.5. Comfort

A significant effect of footwear on perceived comfort was confirmed (Wilks' $\lambda = 0.195$, $F(3,16) = 22.057$, $p < 0.001$). No significant main effect from gender was revealed ($F(1,18) = 1.045$, $p = 0.320$). In addition, there was no significant interaction effect between footwear and gender (Wilks' $\lambda = 0.998$, $F(3,16) = 0.012$, $p = 0.998$). The participants' own shoes received the highest comfort rating (82.4 ± 15), followed by dress (65.6 ± 16.4), athletic (56.3 ± 20.8), and generic footwear (49.4 ± 17.5).

4. Discussion

To the best of our knowledge, this is the first study to extensively investigate the biomechanical effects of therapeutic footwear in comparison to low-cost generic shoes as well as participants' own athletic shoes by evaluating both gait kinematics and kinetics and plantar pressure.

Our findings indicate that the footwear type did not significantly impact the gait temporospatial characteristics, as self-selected walking speeds remained consistent across footwear conditions, allowing a comparison of variables. However, therapeutic footwear had a notable effect on the gait kinetics and kinematics, particularly at the ankle joint, with diminishing effects at the knee and hip. Specifically, therapeutic footwear resulted in significantly reduced plantar flexion and increased dorsiflexion compared with the generic and participants' own shoes. The greatest ankle range of motion was observed for the dress footwear.

Toe-only rocker sole shoes have been reported to have significantly increased ankle dorsiflexion during the loading phase and greater ankle plantar flexion during the terminal stance [26], suggesting that the rocker sole plays a key role in ankle kinematics. However, the therapeutic footwear in our study featured a sole design similar to that of the generic footwear and participants' own shoes. The differences in ankle joint kinematics may instead be attributed to the insole design. Unlike the relatively flat insoles of the generic and participants' own shoes, the therapeutic footwear incorporated a graded insole with an inclination beginning near the midfoot. This design positioned the ankle in slight plantar flexion while standing, allowing for greater ankle dorsiflexion during walking.

Knee flexion plays a crucial role in shock absorption during the loading phase, with the first peak occurring in this phase [39] and the second peak aligning with knee flexion during the mid-swing phase. The footwear type appeared to influence the knee biomechanics, as the athletic footwear demonstrated slightly greater first-peak knee flexion, although pairwise comparisons did not reveal statistical significance. Additionally, the footwear type had no effect on hip extension in this study. However, prior research on toe-only rocker sole shoes [26] reported increased hip extension, while a study on MBT shoes [15] showed decreased hip extension. This suggests that footwear with at least moderate rocker outsoles can influence proximal joint biomechanics. Regarding joint kinetics, the therapeutic footwear exhibited higher peak ankle plantar flexor torques compared with the generic shoes. In contrast, previous studies on toe-only rocker sole and MBT shoes reported reduced ankle plantar flexor torques during the terminal stance, likely due to the rocker sole enhancing the forefoot rocker function [40]. The absence of a rocker sole in the therapeutic footwear used in this study may have limited its ability to assist with this function. As a result, participants may have increased their ankle joint torque to compensate for reduced ankle plantar flexion while maintaining a consistent gait pattern (e.g., speed and stride length).

Therapeutic footwear also significantly impacted the plantar pressure distribution. In comparison with the generic shoes, the athletic shoes significantly lowered the peak pressure under the medial heel. Prior research on therapeutic footwear also reported significant reductions in plantar pressure under the big toe and metatarsals in individuals with neuropathic feet [22]. However, in our study, the plantar pressure under the big toe was significantly higher, particularly for the dress footwear. This suggests that while therapeutic footwear alleviated the plantar pressure under the medial heel, it did so at the expense of increased plantar pressure beneath the big toe. Despite this increase, the mean peak plantar pressure under the big toe in this study was approximately 400 kPa, which remains below previously established thresholds for ulceration (e.g., 1100 kPa, reported by Boulton et al., and 875 kPa, reported by Lavery et al.) [41,42]. However, these thresholds were based on barefoot pressure measurements using a pressure mat. Given that plantar pressure measurements are highly sensitive to factors such as the sensor size and measurement technique, caution should be taken when comparing these thresholds to the current study [43]. Prolonged and elevated pressure under the big toe could contribute

to bunion development or other foot complications [44]. Future research should explore the long-term effects of this pressure redistribution on foot health.

The overall performance of the participants' own shoes was comparable to the therapeutic footwear in most of the measures, although they showed slightly higher peak pressures under the first metatarsal head and midfoot. These results align with previous research in which athletic shoes were shown to be as effective as commonly prescribed therapeutic shoes [22].

Our study identified some strong relationships between the peak plantar pressures and gait parameters. In particular, we found a strong association between the PPP under the medial forefoot and the ankle dorsi-flexion ROM. In addition, we showed that the therapeutic footwear allowed for a significantly larger range of motion in ankle dorsi-flexion when compared with either the generic or participants' own shoes. Taken together, these findings indicate that footwear which alters foot-ankle kinematics may potentially impact the peak plantar pressure. Although we did not find significant differences in the peak plantar pressure under the medial forefoot between footwear types, our results are in agreement with previous studies showing a strong relation between elevated peak plantar pressure under the medial forefoot and ankle equinus deformity (i.e., ankle placed in a more plantar flexion) in the diabetic population [45–47]. In addition, we found a strong relationship between the peak plantar pressure under the heel and the braking impulse. Considering that the therapeutic footwear showed a slightly lower braking impulse, it is reasonable to predict lower plantar pressure under the heel. This prediction was supported by our results, though the differences between the footwear types did not reach the level of significance.

Finally, the ratings for footwear comfort showed interesting results; the participants were predominantly in favor of their own shoes and consistently rated the low-cost generic shoes as the least comfortable ones. The therapeutic footwear received moderate ratings for comfort, and this finding is consistent with recent studies reporting effective reductions in foot pain when using Orthofeet shoes [48,49]. Surprisingly, the dress footwear received higher ratings than the athletic footwear, despite the latter demonstrating better overall biomechanical performance. This discrepancy may be attributed to differences in construction materials, as the dress shoes were made of soft leather, whereas the athletic shoes were made of synthetic materials with a laceless design. It should be noted that familiarity and proprioceptive adaptation to one's own shoes can influence comfort perception, potentially leading to higher ratings for their own footwear [50].

Although previous studies have reported gender-related differences in temporospatial gait parameters and plantar pressure profiles [28,33], the present study did not identify significant gender effects on the biomechanical outcome measures. This lack of effect may be attributed to the dominant influence of the therapeutic footwear on lower limb biomechanics. Specifically, the footwear elicited consistent alterations across participants, including increased ankle dorsiflexion during late mid-stance, reduced ankle plantar flexion during push-off, and greater ankle plantar flexor torques compared with generic footwear. Furthermore, the redistribution of plantar pressures—characterized by an elevated peak pressure beneath the hallux and reduced pressure under the medial heel—suggests a systematic mechanical adaptation that likely overrides more subtle, gender-specific gait variations. The similarity in performance between the therapeutic footwear and the participants' own athletic shoes suggests that individual footwear properties may exert a greater impact on gait biomechanics than gender alone. This lack of a gender effect may also be partially attributed to the relatively small sample size of each group (i.e., 12 males and 8 females), which may have limited the statistical power for detecting significant differences.

The limitations of this study are acknowledged. First, participants were recruited through convenience sampling with a relatively small sample size, which limits the generalizability of the findings. Additionally, the study population, aged 24–48 years, may not represent the typical demographic of individuals with diabetes well, which is the primary target group for therapeutic footwear. The use of a healthy population instead of individuals with diabetes could also influence the results, as therapeutic footwear is specifically designed for patients with diabetic foot conditions. Another limitation is the placement of markers on the shoe, which may not accurately capture the true foot motion and could introduce measurement errors into foot and ankle kinematics. Furthermore, the gait analysis was conducted in a controlled laboratory setting, which may not fully reflect real-world gait patterns. The study's relatively short duration primarily captures acute effects. Participants had only a brief adaptation period for the test shoes (approximately 20 min for each pair), whereas long-term effects are of greater relevance to consumers, manufacturers, and clinicians. Aside from the gait kinetics and kinematics and insole plantar pressure, future research should incorporate functional performance assessments using clinical instruments such as the 6-min walking test and the Berg balance scales. This would provide a more comprehensive evaluation of the effectiveness of therapeutic footwear. Comfort assessment was based on participants' subjective ratings using VAS. Future studies should consider using standardized comfort scales to enhance the reliability and generalizability of user experience data.

5. Conclusions

This study suggests that therapeutic footwear may introduce some biomechanical modifications compared with low-cost generic shoes, particularly in enhancing ankle motion control and altering plantar pressure distribution. The participants' own athletic shoes also showed comparable performance to therapeutic footwear. However, given the wide variability in athletic shoe designs, caution should be taken when considering them as substitutes for therapeutic footwear. Importantly, it remains unclear whether the observed biomechanical modifications constitute a true advantage, especially considering the short-term nature of this study. These findings reflect immediate gait responses and should be interpreted within that context. While therapeutic footwear elicited measurable biomechanical changes, their clinical relevance, especially over the long term and among individuals with foot pathologies, has yet to be determined. Future longitudinal studies are needed to assess if these changes lead to meaningful clinical outcomes, such as reduced injury risk or improved foot health.

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Abbreviations

The following abbreviations are used in this manuscript:

MTP	Metatarsophalangeal
MBT	Masai Barefoot Technology
EVA	ethyl vinyl acetate
GRFz	vertical ground reaction force
PPP	peak plantar pressure

Appendix A

Table A1. Images of insoles (top and side views) of footwear used in the study.

Type of Shoes	Insole
Generic	
Orthofeet—Athletic	
Orthofeet—Dress	
Participants’ shoes (Nike)	

Table A2. Shoe construction materials and weight.

Shoe Type	Upper Material	Midsole Material	Outsole Material	Weight (Men's Shoe Size)
OrthoFeet Dress	Leather	EVA	Rubber	365 g (9M)
OrthoFeet Athletic	Synthetic mesh	EVA	Rubber	387 g (9M)
Low-cost Generic	Synthetic mesh	EVA	Rubber	298 g (9M)
Participants' shoes (Nike)	Synthetic mesh	EVA	Rubber	286 g (9M)
Participants' shoes (New Balance)	Synthetic mesh	EVA	Rubber	280 g (9M)

Table A3. Demographics of participants.

Participant #	Body Height (cm)	Body Mass (kg)	Shoe Size	Age (yrs)	Gender	Type of Participant's Shoes
1	172	68	8	36	F	New balance
2	170	65	8	41	F	New balance
3	165	57	7.5	27	F	New balance
4	152	78	7.5	26	F	Nike
5	159	53	7.5	26	F	Nike
6	161	49	8	28	F	Nike
7	167	61	8.5	30	F	Nike
8	170	65	8	39	F	New balance
9	172	54	8	24	M	Addidas
10	174	78	7.5	35	M	Nike
11	175	73	9.5	36	M	Nike
12	186	86	10.5	26	M	Nike
13	172	70	9.5	48	M	Addidas
14	180	78	10.5	39	M	New balance
15	177	73	10.5	34	M	New balance
16	177	85	9.5	33	M	Nike
17	163	61	7.5	36	M	Nike
18	178	73	9.5	28	M	Nike
19	180	75	9.5	32	M	New balance
20	180	80	10.5	38	M	New balance
Mean (SD)	171.5 (8.4)	69.1 (10.7)	8.8 (1.2)	33.1 (6.2)		

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