Exploring the Correlation Between Footwear Design (Narrow Toe Box Vs Wide Toe Box) on Ankle Foot Complex's Stability, Ability and Posture in Healthy Adult

Bhaumik Dinkar Vartak[1]; Dr. Vaishali Kale[2*]

[1]BPTh Intern, Rashtrasant Janardhan Swami College of Physiotherapy (Affiliated to Maharashtra University of Health Sciences, Nashik), Ahilyanagar, Maharashtra, India
[2](PT), MPTh (Musculoskeletal Physiotherapy), Associate Professor, Department of Musculoskeletal Physiotherapy, Rashtrasant Janardhan Swami College of Physiotherapy, (Affiliated to Maharashtra University of Health Sciences, Nashik), Ahilyanagar, Maharashtra, India

Corresponding Author: Dr. Vaishali Kale[2*]

Publication Date: 2026/03/10

Abstract:

➢ ***Introduction:***

Footwear design plays an important role in influencing foot biomechanics and overall lower limb function. Toe box width, in particular, may affect forefoot splay, foot posture, ankle stability, and functional performance. However, limited evidence exists regarding its direct impact on ankle-foot complex stability and functional outcomes in healthy adults.

➢ ***Methods:***

An observational cross-sectional study was conducted among healthy adults aged 18–45 years. Participants were categorized into two groups based on habitual footwear use and toe box width measurement: Group A (narrow toe box users) and Group B (wide toe box users). Outcome measures included forefoot width measurement, Chippaux-Smirak Index (CSI) for arch assessment, Foot Posture Index (FPI-6), Cumberland Ankle Instability Tool (CAIT), Star Excursion Balance Test (SEBT), Foot and Ankle Ability Measure (FAAM), active range of motion using a universal goniometer, Manual Muscle Testing (MMT), and Visual Analog Scale (VAS) for comfort and fatigue. Data were analyzed using appropriate statistical tests to compare groups.

➢ ***Results:***

A statistically significant difference was observed in structural toe box width between the two groups, confirming accurate classification. However, no significant differences were found between narrow and wide toe box users in ankle stability (CAIT), functional ability (FAAM), balance performance (SEBT), range of motion, muscle strength, or perceived comfort and fatigue.

➢ ***Conclusion:***

Toe box width alone did not significantly influence ankle-foot complex stability, functional performance, or subjective comfort in healthy adults. These findings suggest that footwear 15 biomechanics are multifactorial, and isolated structural features such as toe box width may not independently alter functional outcomes in asymptomatic individuals. Further longitudinal and biomechanical studies are recommended to evaluate long-term effects.

Keywords: *Toe Box Width, Ankle Stability, Footwear Biomechanics, Foot Posture, SEBT, CAIT, FAAM.*

How to Cite: Bhaumik Dinkar Vartak; Dr. Vaishali Kale (2026) Exploring the Correlation Between Footwear Design (Narrow Toe Box Vs Wide Toe Box) on Ankle Foot Complex's Stability, Ability and Posture in Healthy Adult. *International Journal of Innovative Science and Research Technology,* 11(2), 3012-3020. https://doi.org/10.38124/ijisrt/26feb1502

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26feb1502

I. INTRODUCTION

The ankle-foot complex is a biomechanically sophisticated structure, formed by the articulation of the tibia, fibula, talus, calcaneus, and the multiple mid- and forefoot bones, all stabilized by a network of ligaments, tendons, and muscles.[45,46] It plays a critical role in maintaining posture, facilitating locomotion, and adapting to dynamic environmental demands.[1,45] As the primary interface between the body and ground during gait, the ankle-foot complex is exposed to significant biomechanical loads, requiring both mobility and stability for efficient function.[1,22]

Functionally, the ankle-foot complex enables a spectrum of multi-planar movements that underpin dynamic postural control and efficient gait.[45] The talocrural joint, formed by the distal tibia and fibula articulating with the talus, acts as a hinge permitting dorsiflexion and plantarflexion in the sagittal plane[45]. The subtalar joint, located between the talus and calcaneus, governs inversion and eversion in the frontal and transverse planes.[46] Complex composite movements such as pronation and supination emerge from the coordinated interaction of these joints, involving simultaneous motion across all three anatomical planes.[45,46] The midtarsal and forefoot joints—including the talonavicular, calcaneocuboid, tarsometatarsal, metatarsophalangeal, and interphalangeal articulations—enhance flexibility and stability, distributing load, absorbing shock and generating propulsion during gait.[22,45] Due to its critical role in postural control and movement, the ankle-foot complex is highly susceptible to mechanical stress and microtrauma over time1. Repetitive loading, poor biomechanics, or external factors such as poorly designed footwear can contribute to dysfunctions like microinstabilities proprioceptive deficits taut bands within muscles and ligaments and chronic musculoskeletal imbalances.[3,5,6,7,8,44] These dysfunctions not only impair static and dynamic postural control but also alter gait mechanics and increase the risk of further injuries.[33]

Moreover, restricted ankle dorsiflexion compromises sagittal plane mechanics, often necessitating compensatory strategies such as increased knee flexion, excessive trunk forward lean, or early heel rise during gait.[36,37] These alterations not only disrupt movement efficiency but also elevate the risk of joint overload and balance deficits. Consequently, optimal neuromuscular control of the ankle stabilizers-including the tibialis anterior, peroneals, and intrinsic foot musculature-is critical for maintaining dynamic stability, especially during tasks requiring rapid directional changes or navigation across uneven terrain negotiation.[22,23,49]

Splay of the foot refers to the transverse widening of the forefoot region, typically involving the spreading of the metatarsal bones under weight-bearing conditions.[20] This adaptation increases the foot’s contact surface area, enhancing shock absorption and postural stability.[20] Evolutionary evidence indicates that forefoot widening—alongside longitudinal arch development—was pivotal for efficient bipedalism.[13,15] Fossil analyses of early hominin tali and metatarsals reveal structural features that supported both arch integrity and lateral splay, facilitating stable upright gait and effective propulsion.[13,15] Modern biomechanical models further demonstrate that a splayed forefoot distributes plantar forces more evenly, minimizing localized stress and conserving energy during walking.[22] Contemporary clinical and anthropometric studies corroborate these findings, showing that adequate forefoot splay improves stability and reduces the incidence of deformities such as hallux valgus when footwear permits natural expansion.[10,23,48]

Having established the biomechanical foundations and adaptive tissue responses,[1,36,38,42] we now consider the external factor of footwear design— particularly the toe-box width. The toe-box is the front portion of a shoe that houses the toes; its dimensions can significantly influence foot and ankle mechanics.[23] Narrow toe-box footwear, commonly designed for aesthetic or fashion purposes, compresses the forefoot, restricts natural toe splay, alters load distribution across the foot, and induces compensatory postural adaptations.[10,22,23,48,49] Over time, this mechanical constriction can impair proprioceptive feedback, destabilize the ankle-foot complex and alter normal gait patterns.[1,7,22,48] Conversely, wide toe-box footwear is designed to accommodate natural toe spread, distribute plantar pressures more evenly, preserve proprioceptive input, and theoretically support better postural and locomotor function.[8,13,15,49]

Key soft-tissue adaptations, Adaptive shortening refers to the physiological reduction in muscle or soft-tissue length due to prolonged positioning or repetitive mechanical constraint, resulting in altered joint range and dysfunctional movement patterns.[1,10,36] Taut bands are palpable, hypercontracted segments within muscle fibers, often associated with localized tension and altered neuromuscular control; they may represent early compensatory mechanisms to mechanical overload.[3,38,42] Fasciitis describes inflammation or degeneration of fascia, typically caused by chronic mechanical stress or tissue-loading imbalances, and is frequently observed in the plantar fascia in response to abnormal foot mechanics.[41,38] Myofascial trigger points are hypersensitive nodules within taut bands that evoke referred pain and local twitch responses; they emerge as protective neuromuscular responses to sustained tissue strain.[3,42]

These tissue states—particularly taut bands, trigger points, and fasciitis—can be interpreted as early neuromechanical defense mechanisms,[1,38,42] that limit further injury by altering movement, [19] redistributing load, or restricting range of motion. Within the context of narrow toe-box footwear, restriction of toe mobility and reduction of the base of support can compromise the ankle-foot complex’s ability to maintain balance during dynamic activities.[23,48,49] Over time, such footwear induced constraints may provoke chronic alterations in muscle activation patterns, joint kinematics, and proprioceptive acuity,[3,42] culminating in progressive dysfunctions.[6,7,8] Clinically, these manifest as altered foot posture, decreased ankle-foot complex stability, reduced functional mobility, heightened susceptibility to soft-tissue taut bands, and impaired gait efficiency.[22,26,33,44]

The global footwear industry remains misaligned with natural foot anatomy: in 2023, it produced 21 billion pairs of non-athletic shoes (5.9% CAGR into 2024), yet only 15–20% featured wide toe-boxes, while 80–85% were constrictive narrow designs. Fashion-focused pointed-toe styles—worn more often by women—prioritize aesthetics over biomechanics, driving high rates of hallux valgus and forefoot disorders. Although wide toe-box shoes are forecast to grow faster (6.8% vs. 4.2% CAGR through 2030), the current dominance of narrow designs poses a significant public health concern. Current literature has extensively explored the impact of high heels and minimalist footwear on lower extremity biomechanics.[2,7,12,44] However, there is a relative paucity of research specifically focusing on the influence of toe-box width—independent of heel height or sole rigidity—on the ankle-foot complex's stability, functional ability, and posture.[8,9,10,11,23] By systematically evaluating these relationships, the research seeks to provide biomechanical insights that may inform preventive strategies, footwear innovation, and rehabilitation protocols aimed at optimizing lower limb health particularly in individuals exposed to prolonged standing,[5,6] walking,[7,18] or athletic activities.[17,48] Such preventive strategies would also address proprioceptive deficits and neuromuscular adaptations linked to long-term constrictive footwear use. [21,24]

II. METHOD

➢ *Design*

The present study was conducted as an observational cross-sectional correlational study over a duration of six months. The purpose of the study was to examine the relationship between footwear toe box width (narrow versus wide) and various biomechanical and functional parameters of the ankle-foot complex in healthy adults aged 18 to 45 years. Since the study aimed to evaluate naturally existing variations in footwear habits without manipulating any variables, a cross-sectional design was considered appropriate. Participants were categorized into two groups based on their habitual use of closed footwear: narrow toe box users (Group A) and wide toe box users (Group B). Toe box width classification was determined through standardized measurement of the forefoot width in relation to the internal width of the shoe. Data were collected at a single point in time by the principal investigator to ensure consistency and reliability of measurements. Outcome measures included the Cumberland Ankle Instability Tool (CAIT) to assess perceived ankle instability, the Star Excursion Balance Test (SEBT) for dynamic balance assessment, the Foot Posture Index (FPI-6) for static foot posture evaluation, the Chippaux-Smirak Index (CSI) for assessment of medial longitudinal arch structure, the Foot and Ankle Ability Measure (FAAM) for functional ability, and the Visual Analog Scale (VAS) for pain assessment where applicable. Statistical analysis was performed to determine correlations between toe box width and the selected outcome variables, with a level of significance set at $p < 0.05$. Ethical approval was obtained prior to commencement of the study, and written informed consent was secured from all participants.

➢ *Participants*

A total of 250 healthy adults were recruited using a convenience sampling method from SJS Hospital, RJS Group of Institutes, Sanjivani Group of Institutes, outpatient physiotherapy departments, community health camps, and educational institutions. The sample population consisted of skeletally mature individuals between 18 and 45 years of age who habitually wore closed footwear for daily activities. Participants were required to be free from significant lower limb injuries, surgeries, congenital deformities, neurological disorders, or systemic conditions that could affect ankle-foot biomechanics. Individuals currently undergoing rehabilitation for lower limb conditions were also excluded from the study. Based on habitual footwear usage, participants were classified into two groups: those predominantly using narrow toe box footwear and those predominantly using wide toe box footwear. All participants voluntarily agreed to participate and provided written informed consent prior to data collection.

➢ *Inclusion Criteria*

- Age 18–45 years
- Habitual use of standard closed footwear for ≥4 hours/day over the past 6 months
- Member of the general population (including recreational athletes not using specialized or orthotic footwear)
- No known congenital deformities of the foot or ankle
- Independent ambulation without assistive devices

➢ *Exclusion Criteria*

Participants excluded will be:

- Body Mass Index ≥30 kg/m²
- History of lower-limb fracture, dislocation, or orthopedic surgery within the past 12 months
- Lower-limb injury, pain, or inflammatory condition within the past 6 months
- Diagnosed neurological or vascular disorder affecting balance or posture
- Habitual use of specialized performance or orthotic footwear
- Diagnosed systemic inflammatory or connective-tissue disorder (e.g., diabetes mellitus, rheumatoid arthritis)
- Pregnancy at the time of participation

➢ *Procedure*

Participants between 18 and 45 years of age were recruited through community-based outreach strategies, including distribution of printed flyers in public areas and dissemination of digital invitations via social media platforms. Individuals expressing interest were screened for eligibility based on predefined inclusion and exclusion criteria. After confirming eligibility, written informed consent was obtained in accordance with ethical standards. Baseline demographic and anthropometric data were then recorded. Age and sex were documented through self-report. Height was measured using a wall-mounted stadiometer with the participant standing barefoot, heels together, and head positioned in the Frankfurt plane. Body weight was recorded

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26feb1502

using a calibrated digital weighing scale, with participants wearing light clothing and no footwear. Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared (kg/m²). Dominant foot was determined by asking participants which foot they would use to kick a ball.

To classify participants based on footwear habits, standardized photographs representing narrow toe box and wide toe box shoes were shown, and participants were asked to indicate the type of footwear they used for the majority of their daily activities. Participants were asked to identify the type of footwear they predominantly used during daily activities over the preceding six months. To increase objectivity and reduce recall bias, participants were also requested to present their commonly worn shoes for direct inspection. The forefoot width of the shoe was measured at its widest point using a flexible cloth measuring tape placed internally across the region corresponding to the first and fifth metatarsal heads. This measurement was compared relative to the participant's forefoot width and visual shoe morphology to confirm categorization. Based on combined self-report and physical measurement, participants were allocated into Group A (narrow toe box users) or Group B (wide toe box users). Following group allocation, barefoot foot measurements were obtained. Forefoot splay was assessed by measuring the linear distance between the most prominent medial aspect of the first metatarsal head and the lateral aspect of the fifth metatarsal head using a flexible measuring tape while the participant stood in a relaxed bipedal stance. Care was taken to ensure equal weight distribution during measurement. This parameter provided an index of transverse forefoot width and potential adaptive structural spreading.

Static footprint analysis was performed using inked footprint mats. Participants stepped onto an inked pad and then onto a clean recording sheet while maintaining an upright, relaxed stance. From the obtained footprint, the Chippaux-Smirak Index (CSI) was calculated. The narrowest width of the midfoot region was measured and divided by the maximum forefoot width, and the ratio was multiplied by 100. Lower CSI values indicate higher medial longitudinal arches, whereas higher values suggest a flatter arch profile. This index provides a quantifiable representation of static arch morphology.

Foot posture was evaluated using the Foot Posture Index (FPI-6), a validated clinical tool assessing multi-planar foot alignment. The participant stood in a relaxed position, and six criteria were visually and palpably assessed: talar head palpation, supra- and 34 infra-lateral malleolar curvature, calcaneal frontal plane position, talonavicular prominence, medial longitudinal arch congruence, and forefoot abduction/adduction relative to the rear foot. Each criterion was scored on a scale from −2 to +2, producing a composite score ranging from −12 (highly supinated) to +12 (highly pronated). This provided an integrated assessment of static foot posture.

Functional ankle stability was assessed using the Cumberland Ankle Instability Tool (CAIT), a nine-item self-reported questionnaire designed to quantify perceived ankle instability during functional activities. Participants completed the questionnaire independently, with clarification provided when necessary. The CAIT produces a score out of 30, with lower scores indicating greater perceived instability. This tool has demonstrated strong reliability and validity for identifying chronic ankle instability. Dynamic postural control was measured using the Star Excursion Balance Test (SEBT). Limb length was first measured from the anterior superior iliac spine (ASIS) to the distal tip of the medial malleolus using a measuring tape, ensuring accurate normalization of reach distances. Participants performed maximal reach trials in the anterior, posteromedial, and posterolateral directions while maintaining single-leg stance on the test limb. The reaching foot lightly touched the furthest possible point along marked lines without compromising balance or lifting the stance foot. Three trials per direction were performed, and the maximum reach distance was recorded and normalized to limb length (reach distance ÷ limb length × 100). This normalization accounted for anthropometric variability and allowed meaningful inter individual comparison. Ankle and foot functional ability were evaluated using the Foot and Ankle Ability Measure (FAAM), which consists of two subscales: Activities of Daily Living (ADL) and Sports. Scores were converted into percentages, with higher percentages indicating better perceived functional ability. The FAAM is widely recognized for its responsiveness and validity in both general and athletic populations. Objective joint mobility was assessed through active range of motion (AROM) testing of dorsiflexion, plantar flexion, inversion, and eversion using a standard universal goniometer. Participants were positioned according to standardized protocols to isolate talocrural and subtalar movements. For dorsiflexion and plantar flexion, measurements were taken with the participant seated and knee flexed to minimize gastrocnemius tension. Inversion and eversion were measured with the subtalar joint in neutral alignment. Three trials per movement were performed, and the average value was recorded to improve measurement reliability and reduce random error. Muscle strength of major ankle and intrinsic foot muscles, including the tibialis anterior, gastrocnemius-soleus complex, peroneal muscles, and selected intrinsic foot musculature, was evaluated using Manual Muscle Testing (MMT). Participants were positioned to minimize substitution patterns, and standardized resistance was applied at the distal segment of the limb in the direction opposite to the muscle action. Strength was graded on the traditional 0–5 MMT scale, where grade 0 represents no visible contraction and grade 5 represents full range of motion against gravity with maximal resistance. Although MMT is ordinal and examiner-dependent, it remains widely used in clinical musculoskeletal assessment. Participants rated perceived foot fatigue and overall comfort using a 10-centimeter Visual Analog Scale (VAS). The VAS consisted of a horizontal line anchored by "no fatigue/maximum comfort" at one end and "worst imaginable fatigue/minimum comfort" at the other. Participants marked a point corresponding to their perception, and the distance in centimetres from the left anchor was measured to obtain a quantitative score. All outcome measures were systematically documented on a predesigned data collection sheet to ensure

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26feb1502

uniformity, reduce transcription errors, and facilitate subsequent statistical analysis. Care was taken to standardize measurement conditions, maintain consistent examiner procedures, and minimize environmental variability throughout data collection.

➢ *Outcome Measures*

Outcome measures used for this study were as follows:

- *Ankle Foot Complex Stability:*

✓ Cumberland Ankle Instability Tool (CAIT)[52]
✓ Star Excursion Balance Test (SEBT)[53,54]

- *Ankle Foot Complex Ability:*

✓ Foot and Ankle Ability Measure (FAAM)
✓ Manual Muscle Testing (MMT)
✓ Range of Motion (ROM)

- *Posture and Foot Morphology:*

✓ Foot Posture Index (FPI-6)[56]
✓ Chippaux-Smirak Index (CSI)[57]
✓ Toe box & foot dimensions (1st to 5th toe width and shoe toe box width)

- *Comfort/Fatigue:*

✓ VAS for Foot Comfort/Fatigue [58,59]

III. DATA ANALYSIS

The data were analyzed using Microsoft Excel 2016 (Data Analysis Toolpak). An independent samples t-test (two-tailed, assuming equal variances) was applied for between-group comparisons, and a p-value of less than 0.05 was considered statistically significant. Results were expressed in terms of mean, standard deviation, t-value, and p-value.

Between-group comparison of ankle stability and functional measures revealed no statistically significant difference in Cumberland Ankle Instability Tool (CAIT) scores between Group A and Group B (p = 0.822). Similarly, dynamic balance assessed using the Star Excursion Balance Test (SEBT) showed no significant difference in the anterior (p = 0.949) and posterolateral (p = 0.418) directions. However, a statistically significant difference was observed in the posteromedial direction (p = 0.017), with Group A demonstrating superior performance. Functional ability measured using the Foot and Ankle Ability Measure (FAAM) also showed no significant difference between the groups (p = 0.656).

Manual Muscle Testing (MMT) of ankle musculature revealed no statistically significant differences between the groups for dorsiflexors (p = 0.950), plantarflexors (p = 0.582), invertors (p = 0.824), or evertors (p = 0.411), indicating comparable muscle strength levels. Range of Motion (ROM) assessment similarly showed no significant differences in dorsiflexion (p = 0.403), plantarflexion (p = 0.761), or inversion (p = 0.899). However, ankle eversion ROM demonstrated a highly statistically significant difference (p < 0.001), with Group A showing markedly greater values compared to Group B.

Foot structure and posture variables, including the Chippaux-Smirak Index (CSI) and the Foot Posture Index (FPI-6), showed no statistically significant differences between the groups (p = 0.958 and p = 0.963 respectively). In contrast, forefoot morphology differed significantly, as Group A demonstrated a significantly greater 1st–5th toe width (p < 0.001). Additionally, shoe toe box width was significantly greater in Group B (p < 0.001), confirming appropriate group classification.

Subjective measures assessed using the Visual Analog Scale (VAS) revealed no significant difference in perceived foot comfort (p = 0.866) or foot fatigue (p = 0.828) between the groups.

Overall, the findings indicate that most ankle-foot functional, strength, postural, and subjective parameters were comparable between narrow and wide toe box users. Significant differences were observed primarily in posteromedial dynamic balance performance, ankle eversion range of motion, and forefoot width characteristics.

IV. RESULTS

The present observational cross-sectional study was conducted to explore the correlation between footwear design (narrow toe box vs wide toe box) and ankle-foot complex stability, ability, posture, and subjective comfort in healthy adults aged 18–45 years (n = 250). Statistical analysis was performed using independent samples t-test, and a p-value of < 0.001). This confirms that participants in Group B habitually used footwear with significantly wider toe box dimensions compared to Group A. Subjective perception of foot comfort was assessed using the Visual Analog Scale (VAS). Group A reported a mean comfort score of 4.53 ± 3.16, while Group B reported 4.60 ± 3.16. Statistical analysis demonstrated no significant difference between the groups (t = -0.169, p = 0.866). Therefore, perceived foot comfort was comparable between narrow and wide toe box users. Similarly, VAS scores for foot fatigue showed that Group A had a mean score of 5.03 ± 3.31, and Group B had a mean score of 5.13 ± 3.31. The difference between groups was not statistically significant (t = -0.218, p = 0.828). This suggests that habitual toe box width did not significantly influence perceived foot fatigue following walking. Overall, while a highly significant difference was observed in the actual toe box dimensions between the two groups, no statistically significant differences were found in ankle stability, perceived comfort, or fatigue levels. These findings suggest that although footwear structure varies considerably, toe box width alone may not have a significant isolated impact on ankle-foot stability and subjective comfort parameters in healthy adults.

V. DISCUSSION

The present study aimed to explore the correlation between footwear toe box design (narrow vs wide) and ankle-foot complex stability, posture, functional ability, and subjective comfort in healthy adults aged 18–45 years. The findings revealed that although a statistically significant difference existed in the structural toe box width between the two groups, no significant differences were observed in ankle instability (CAIT), perceived comfort, or fatigue. The absence of significant differences in ankle stability between narrow and wide toe box users suggests that toe box width alone may not substantially influence self-reported functional ankle instability in healthy individuals. This finding aligns partially with the systematic review by Sun X et al.44, which examined the role of footwear construction in running biomechanics. Their review concluded that while footwear design elements such as cushioning, arch support, and stability features can influence biomechanical patterns, isolated structural components may not independently alter injury risk or functional stability unless combined with other biomechanical or intrinsic factors. Similarly, the present study indicates that toe box width, in isolation, may not significantly affect ankle stability in asymptomatic individuals. The findings also revealed no statistically significant difference in perceived foot comfort or fatigue between the two groups. This is noteworthy, as wider toe box footwear is often promoted for enhanced comfort and natural toe splay. However, comfort perception is multifactorial and influenced by cushioning, midsole stiffness, arch design, and individual foot morphology rather than toe box width alone. Sun X et al. 44 emphasized that excessive cushioning or altered shoe construction may lead to biomechanical compensations and muscle imbalances, suggesting that comfort perception does not always correlate directly with structural design. The current study supports this perspective, demonstrating comparable comfort and fatigue scores between groups despite significant structural differences. From a biomechanical standpoint, toe box width theoretically influences forefoot splay and pressure distribution. However, the lack of significant functional differences in this study may be explained by the healthy, asymptomatic nature of the sample. In individuals without existing deformities, neuromuscular control mechanisms may compensate for minor structural variations in footwear. This concept aligns with the work of Bodine SC 35, who described how musculoskeletal tissues adapt to altered loading conditions through neuromuscular and molecular mechanisms. Although his work 60 focused on disuse-induced muscle wasting, the principle of musculoskeletal adaptability may explain why minor external structural variations did not significantly alter functional outcomes in the present study. Additionally, myofascial and neuromuscular contributions to foot biomechanics should be considered. Ge H-Y et al. 42 discussed the role of spontaneous electrical activity in myofascial trigger points and its impact on muscle function and pain generation. While their study focused on pain mechanisms, it highlights the importance of neuromuscular factors in musculoskeletal performance. In the absence of pain or neuromuscular dysfunction, as in the present study population, footwear design alone may not produce measurable functional changes. Furthermore, individualized footwear prescription remains essential. The systematic review by Sun X et al.44 concluded that optimal footwear selection depends on foot morphology, activity type, and individual biomechanics rather than a single structural parameter. The present findings reinforce this view, suggesting that recommending wide toe box footwear universally for improved stability or comfort may not be justified in healthy adults without specific biomechanical abnormalities. In summary, the results of the present study are consistent with previous literature indicating that footwear design influences biomechanics in a complex, multifactorial manner. Although toe box width differed significantly between groups, it did not independently affect ankle stability, perceived comfort, or fatigue in healthy individuals. These findings highlight the importance of considering comprehensive footwear characteristics and individual biomechanical profiles when evaluating clinical or performance-related outcomes.

VI. CONCLUSION

The present observational cross-sectional study was conducted to explore the correlation between footwear toe box design (narrow toe box vs wide toe box) and ankle-foot complex stability, posture, functional ability, and subjective comfort in healthy adults aged 18–45 years. The results demonstrated a highly significant difference in the structural toe box width between the two groups, confirming appropriate classification of narrow and wide toe box users. However, no statistically significant differences were observed in functional ankle stability (CAIT scores), perceived foot comfort, or perceived foot fatigue between the groups. These findings suggest that toe box width alone may not have a significant isolated influence on ankle foot complex stability or short-term subjective comfort parameters in healthy, asymptomatic individuals. The results highlight that footwear biomechanics are multifactorial, and functional outcomes may depend on a combination of intrinsic factors (such as foot morphology and neuromuscular control) and extrinsic footwear characteristics (including cushioning, arch support, and sole rigidity), rather than toe box width alone. Within the limitations of the present study, it can be concluded that habitual use of narrow or wide toe box footwear does not significantly affect ankle stability or perceived comfort in healthy adults. Further longitudinal and biomechanical studies are recommended to evaluate long-term adaptations and their clinical implications.

REFERENCES

[1]. Mueller MJ, Maluf KS. Tissue adaptation to physical stress: a proposed "Physical Stress Theory" to guide physical therapist practice, education, and research. Phys Ther. 2002;82(4):383-403. doi:10.1093/ptj/82.4.383
[2]. Joseph MF, Histen K,Arntsen J, L'Hereux L, Defeo C, Lockwood D, et al. Achilles tendon adaptation during transition to a minimalist running style. J Sport Rehabil. 2017 Apr;26(2):165-170. doi:10.1123/jsr.2016-0007

ISSN No: -2456-2165 https://doi.org/10.38124/ijisrt/26feb1502

[3]. Zhang C, Deng L, Zhang X, Wu K, Zhan J, Fu W, Jin J. Effects of 12-week gait retraining on plantar flexion torque, architecture, and behavior of the medial gastrocnemius in vivo. Front Bioeng Biotechnol. 2024 Mar 20; 12:1352334. doi:10.3389/fbioe.2024.1352334
[4]. Warne JP, Gruber AH. Effects of a 12-week gait retraining program on the Achilles tendon adaptation of habitually shod runners. Scand J Med Sci Sports. 2017 Sep 15;27(9):983-991. doi:10.1111/sms.12702
[5]. Wee J, Teoh JC, Lee T. Biomechanical effects of variable stiffness shoes in normal walking after 60-minute adaptation. Int J Precis Eng Manuf.2019 Oct;20(10):1817-1823. doi:10.1007/ s12541-019-00216-8
[6]. Vuillerme N, Pinsault N. Re-weighting of sensory inputs from the foot and the ankle for controlling posture during quiet standing following trunk extensor muscles fatigue. Exp Brain Res. 2009 Nov;199(3-4):323-326. doi:10.1007/s00221-009-1819-1
[7]. Hardin EC, van den Bogert AJ, Hamill J. Kinematic adaptations during running: effects of footwear, surface, and duration. Med Sci Sports Exerc. 2004;36(5):838-844. doi: 10.1249/01.MSS.0000126805.65970.41
[8]. Papalia R, Di Pino G, Tecame A, Vadalà G, Formica D, Di Martino A, et al. Biomechanical and neural changes evaluation induced by prolonged use of non-stable footwear: a systematic review. Musculoskelet Surg. 2015;99(3): 179-187.doi:10.1007/s12306-015-0350-7
[9]. Jafarnezhadgero AA, Piran Hamlabadi M, Anvari M, Zago M.Long-term effects of shoe mileage on knee and ankle joints muscle co-contraction during walking in females with genu varus. Gait Posture. 2021 Sep; 89:74-79. doi:10.1016/ j. gaitpost.2021.07.004 64
[10]. Montiel V, Valentí A, Villas C, Valverde C, Alfonso M. Hallux anatomy: much ado about shoes-an attempt to prove that constrictive V-shaped toe-box shoes deform the hallux. Arch Orthop Trauma Surg. 2022;142(8):1793-1800. doi:10.1007/s00402-021-03792-5NCB1+
[11]. Al-Abdulwahab SS, Al-Dosry RD. Hallux valgus and preferred shoe types among young healthy Saudi Arabian females. Ann Saudi Med. 2000;20(3-4):319-321. doi:10.5144/0256 4947.2000.319 PubMed+7
[12]. Hassan F, Rahman M, Hossain M. Investigation of shoe size and toe box shape variation effect on skeletal alignment of adult foot. Int J Sci Eng Res. 2019;10(4):123-130.
[13]. DeSilva JM. Functional morphology of the ankle and the likelihood of climbing in early hominins. Proc Natl Acad Sci U S A. 2009;106(16):6567-6572. doi:10.1073/pnas.0900270106
[14]. Sorrentino R, Carlson KJ, Bortolini E, Dall'Olio S, Geuna Kivell TL, et al. Morphometric analysis of the hominin talus: Evolutionary and functional implications. J Hum Evol. 2020; 142:102747. doi: 10.1016/j.jhevol.2020.102747
[15]. Wang W, Abboud RJ, Günther MM, Crompton RH. Analysis of joint force and torque for the human and non-human ape foot during bipedal walking with implications for the evolution of the foot. JAnat. 2014;225(2):152-166. doi:10.1111/joa.12201
[16]. Hollman JH, Ginos BE, Kozuchowski J, Vaughn AS, Krause DA,Youdas JW. Relationships between knee valgus, hip-muscle strength, and hip-muscle recruitment during a single-limb step-down. J Sport Rehabil. 2009;18(1):104-117. doi:10.1123/jsr.18.1.104
[17]. Tiberio D. The effect of excessive subtalar joint pronation on patellofemoral mechanics: a theoretical model. J Orthop Sports Phys Ther. 1987;9(4):160-165. doi:10.2519/ jospt.1987.9.4.160
[18]. Hessert MJ, Vyas M, Leach J, Hu K, Lipsitz LA, Novak V. Foot pressure distribution during walking in young and old adults. BMC Geriatr. 2005; 5:8. doi:10.1186/1471-2318-5-8
[19]. Kanimozhi, Multani NK. Observational study on foot pressure distribution in young and adults. Int J Physiother Res. 2014;2(4):648-652. doi:10.16965/ijpr.2014.664
[20]. Buldt AK, Allan JJ, Landorf KB, Menz HB. The relationship between foot posture and plantar pressure during walking in adults: A systematic review. Gait Posture. 2018; 62:56-67. doi: 10.1016/j.gaitpost.2018.02.026.
[21]. Nawata K, Nishihara S, Hayashi l, Teshima R. Plantar pressure distribution during gait in athletes with functional instability of the ankle joint: preliminary report. J Orthop Sci. 2005;10(3):298-301. doi:10.1007/s00776-005-0898-4 65
[22]. Richie DH Jr. Functional instability of the ankle and the role of neuromuscular control: a comprehensive review. J Foot Ankle Surg.2001;40(4):240-251. doi:10.1016/ 51067 2516(01)80025-9
[23]. Branthwaite H, Chockalingam N, Greenhalgh A. The effect of shoe toe box shape and volume on forefoot interdigital and plantar pressures in healthy females. J Foot Ankle Res. 2013; 6:28. doi:10.1186/1757-1146-6-28
[24]. Sánchez-Gómez R. Advances in foot biomechanics and gait analysis. Appl Sci. 2025;15(3):1299. doi:10.3390/app15031299
[25]. Hollander K, Zech A, Rahlf AL, Orendurff MS, Stebbins J, Heidt C. The relationship between static and dynamic foot posture and running biomechanics: A systematic review and meta-analysis. Gait Posture. 2019; 72:109-122. doi: 10.1016/j.gaitpost.2019.05.031
[26]. Buldt AK, Levinger P, Murley GS, Menz HB, Nester CJ, Landorf KB. Foot posture is associated with kinematics of the foot during gait: A comparison of normal, planus and cavus feet. Gait Posture. 2015;42(1):42-48. doi: 10.1016/j.gaitpost.2015.03.004
[27]. Sivakumar A, Ramesh S. How foot weight-bearing is associated with posture, balance, and gait: a narrative review. Int J Sports Phys Educ. 2025;11(1):7-13.
[28]. Takahashi KZ, Krupenevich RL, Lenz AL, Kelly LA, Rainbow MJ, Franz JR. Mechanics and energetics of human feet: a contemporary perspective for understanding mobility impairments in older adults.

Biomechanics. 2022;2(4):494-499. doi:10.3390/biomechanics2040038.
[29]. Feldman AG. The relationship between postural and movement stability. Adv Exp Med Biol. 2016; 957:105-120. doi:10.1007/978-3-319-47313-0_6
[30]. Silva RS, Ferreira ALG, Veronese LM, Serrão FV. Forefoot varus predicts subtalar hyperpronation in young people. J Am Podiatr Med Assoc. 2014 Nov;104(6):594-600. doi:10.7547/8750-7315-104.6.594
[31]. Araújo VL, Santos TRT, Khuu A, Fonseca ST. The effects of small and large varus alignment of the foot-ankle complex on lower limb kinematics and kinetics during walking: A cross-sectional study. Musculoskelet Sci Pract. 2020 Jun; 47:102149. doi: 10.1016/j.msksp.2020.102149
[32]. Sahrmann SA. Diagnosis and Treatment of Movement Impairment Syndromes. St. Louis: Mosby; 2002.
[33]. McKeon PO, Hertel J. Systematic review of postural control and lateral ankle instability, part l: can deficits be detected with instrumented testing? J Athl Train. 2008;43(3):293-304. doi:10.4085/1062-6050-43.3.293 66
[34]. Menz HB, Dufour AB, Riskowski JL, Hillstrom HJ, Casey VA, Hannan MT. Foot function, foot pain, and falls in older adults: the Framingham Foot Study. Gerontology. 2017;63(4):318 324. doi:10.1159/000477050
[35]. Bodine SC. Disuse-induced muscle wasting. Int J Biochem Cell Biol. 2013;45(10):2200-2208. doi: 10.1016/j.biocel.2013.06.011
[36]. Herbert RD. The passive mechanical properties of muscle and their adaptations to altered patterns of use. Aust J Physiother. 1988;34(3):141-149. doi:10.1016/S0004-9514(14)60606-1
[37]. Hortobágyi T, Hill JP, Houmard JA, Fraser DD, Lambert NJ,Israel RG. Adaptive responses to muscle lengthening and shortening in humans. J Appl Physiol. 1996;80(3):765 772.doi:10.1152/jappl.1996.80.3.765
[38]. Slater AM, Barclay SJ, Granfar RMS, Pratt RL. Fascia as a regulatory system in health and disease. Front Neurol. 2024; 15:1458385. doi:10.3389/fneur.2024.1458385
[39]. Rudrappa S, Wilkinson DJ, Greenhaff PL, Smith K, Idris I, Atherton PJ. Human skeletal muscle disuse atrophy: effects on muscle protein synthesis, breakdown, and insulin resistance a qualitative review. Front Physiol. 2016; 7:361. doi:10.3389/fphys.2016.00361
[40]. Frontera WR, Ochala J. Muscle atrophy induced by mechanical unloading: mechanisms and potential countermeasures. Front Physiol. 2018; 9:235. doi:10.3389/ fphys.2018.00235
[41]. Ali Q, Long Y, Ali M. Prevalence, causes, and treatment of plantar fasciitis in young females of a medical college. Bull Fac Phys Ther. 2024;29(1): Article 195. doi:10.1186/S43161-024 00195-6
[42]. Ge H-Y, Fernández-de-las-Peñas C, Yue S-W. Myofascial trigger points: spontaneous electrical activity and its consequences for pain induction and propagation. Chin Med 2011;6: 13.doi:10.1186/1749-8546-6-13\
[43]. Escalona-Marfil C, Prats-Puig A, Ortas-Deunosajut X, Font-Lladó R, Ruiz-Tarrazo X, Evans AM. Children's foot parameters and basic anthropometry - do arch height and midfoot width change? Eur J Pediatr. 2023;182(3): 777-784.doi:10.1007/s00431-022-04715-1
[44]. Sun X, Lam WK,Zhang X, Wang J, Fu W. Systematic review of the role of footwear constructions in running biomechanics:implications for running-related injury and performance.J Sports Sci Med. 2020;19:20-37.
[45]. Levangie PK, Norkin CC, Lewek MD. Joint Structure and Function: A Comprehensive Analysis. 6th ed. Philadelphia: F.A. Davis Company;2019.
[46]. Gray H. Gray's Anatomy of the Human Body. 24th ed. Revised by Lewis WH. Philadelphia: Lea & Febiger; 1942. 67
[47]. Orr R, Maupin D, Palmer R, Canetti EFD, Simas V, Schram B.The impact of footwear on occupational task performance and musculoskeletal injury risk: a scoping review to inform tactical footwear. Int J Environ Res Public Health. 2022;19(17):10703. doi:10.3390/ijerph191710703 MDP+5
[48]. Wagemans J, Kuppens K, Peeters G, Baert IAC. There is a difference in functional ankle stability between different types of footwear in male athletes: A cross-sectional study. The Foot. 2021; 46:101764. doi: 10.1016/j.foot.2020.101764
[49]. Cobb SC, Bazett-Jones DM, Joshi MN, Earl-Boehm JE, James CR. The relationship among foot posture, core and lower extremity muscle function, and postural stability. J Athl Train. 2014;49(2):173-180. doi:10.4085/1062-6050-49.2.02
[50]. Wang Z, Lu M, Wu J, Liu R, Kong L, Li C, Meng L, Zhang Q. The impact of different footwear conditions on lower-limb biomechanical characteristics during single-leg drop landing movements in individuals with functional ankle instability. Appl Sci. 2024;14(22):10272. doi:10.3390/app142210272
[51]. Andreeva A, Melnikov A, Skvortsov D, Akhmerova K, Vavaev A, Golov A, et al. Postural stability in athletes: the role of age, sex, performance level, and athlete shoe features. Sports. 2020;8(6): 89.doi:10.3390/sports8060089
[52]. Hiller, C. E., Refshauge, K. M., Bundy, A. C., Herbert, R. D., & Kilbreath, S. L. (2006). The Cumberland Ankle Instability Tool: a report of validity and reliability testing. Archives of Physical Medicine and Rehabilitation, 87(9), 1235–1241. doi.org/10.1016/j.apmr.2006.05.022
[53]. Gribble, P. A., Hertel, J., & Plisky, P. (2012). Using the Star Excursion Balance Test to assess dynamic postural-control deficits and outcomes in lower extremity injury: a literature and systematic review. Journal of Athletic Training, 47(3), 339–357. doi.org/10.4085/1062-6050 47.3.08
[54]. Plisky, P. J., Rauh, M. J., Kaminski, T. W., & Underwood, F. B. (2006). Star Excursion Balance Test as a predictor of lower extremity injury in high school

basketball players. Journal of Orthopaedic & Sports Physical Therapy, 36(12), 911–919.
[55]. Martin, R. L., Irrgang, J. J., Burdett, R. G., Conti, S. F., & Van Swearingen, J. M. (2005). Evidence of validity for the Foot and Ankle Ability Measure (FAAM). Foot & Ankle International, 26(11), 968–983. doi.org/10.1177/107110070502601112
[56]. Redmond, A. C., Crosbie, J., & Ouvrier, R. A. (2006). Development and validation of a novel rating system for scoring standing foot posture: the Foot Posture Index. Clinical Biomechanics, 21(1), 89–98. doi.org/10.1016/j.clinbiomech. 68
[57]. Chippaux, A., & Smirak, M. (1947). Les empreintes plantaires dans l'étude de l'architecture du pied. Application à l'étude de l'âge, du sexe et de l'hérédité sur l'empreinte plantaire. Bulletins de la Société Française d'Anthropologie de Paris, 8(3), 109–126. doi.org/10.3406/bmsap.1947.3055
[58]. Landorf, K. B., & Keenan, A. M. (2000). An evaluation of two foot-specific, health-related quality-of-life measuring instruments. Foot & Ankle International, 21(10), 845–853. doi.org/10.1177/107110070002101004
[59]. Mundermann, A., Stefanyshyn, D. J., & Nigg, B. M. (2001). Relationship between footwear comfort and plantar pressure distribution. Clinical Biomechanics, 16(9), 790–796. doi.org/10.1016/S0268-0033(01)00070-5