



QUALITY IN SPORT

eISSN 2450-3118 · Open Access · Peer-reviewed

apcz.umk.pl/QS Nicolaus Copernicus University in Toruń



BEKRYCHT, Benjamin, TRZEPIZUR, Paweł Arkadiusz, SAMP, Nikola Agnieszka, FORYŃSKI, Jędrzej, STACHURSKA Michelle Martina, ZERA, Kamila, PIEKARSKA, Weronika, ROGALA, Karolina and WILCZYŃSKI, Rafał. The Impact of Minimalist Footwear on the Kinetic Chain: Biomechanics and Clinical Conditions of the Foot, Knee, Pelvis, and Spine - A Narrative Review. Quality in Sport. 2026;77:75565. <https://doi.org/10.12775/QS.2026.77.75565>

ARTICLE TIMELINE

Received: 21.08.2026. Accepted: 14.09.2026. Published: 28.09.2026.

The journal has been awarded 20 points in the parametric evaluation by the Polish Ministry of Higher Education and Science (Annex to the announcement of 05.01.2024, No. 32553). Unique Journal Identifier: 201398. Scientific disciplines assigned: Economics and Finance (Field of Social Sciences); Management and Quality Sciences (Field of Social Sciences).

Punkty Ministerialne z 2019 – aktualny rok 20 punktów. Załącznik do komunikatu Ministra Szkolnictwa Wyższego i Nauki z dnia 05.01.2024 Lp. 32553. Posiada Unikatowy Identyfikator Czasopisma: 201398. Przypisane dyscypliny naukowe: Ekonomia i finanse (Dziedzina nauk społecznych); Nauki o zarządzaniu i jakości (Dziedzina nauk społecznych). © The Authors 2026.

OPEN ACCESS · CC BY-NC-SA 4.0 This article is published with open access under the License Open Journal Systems of Nicolaus Copernicus University in Toruń, Poland, and is distributed under the terms of the Creative Commons Attribution Non-commercial Share Alike License (<http://creativecommons.org/licenses/by-nc-sa/4.0/>), which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the work is properly cited. The authors declare no conflict of interest regarding the publication of this paper.

The Impact of Minimalist Footwear on the Kinetic Chain: Biomechanics and Clinical Conditions of the Foot, Knee, Pelvis, and Spine - A Narrative Review

Benjamin Bekrycht [BB]

ORCID: <https://orcid.org/0009-0004-7773-1597>

E-mail: benjaminbekrycht@gmail.com

Central Teaching Hospital of the Medical University of Lodz, Pomorska 251, 92-213 Łódź, Poland

Paweł Arkadiusz Trzepizur [PT]

ORCID: <https://orcid.org/0009-0008-1924-3869>

E-mail: patrzepizur@gmail.com

Independent researcher, 03-982 Warszawa, Poland

Nikola Agnieszka Samp [NS]

ORCID: <https://orcid.org/0009-0003-3955-7535>

E-mail: nikolasamp21@gmail.com

Medical University of Gdańsk, M. Skłodowskiej-Curie 3a, 80-210 Gdańsk, Poland

Jędrzej Marek Foryński [JF]

ORCID: <https://orcid.org/0009-0007-5339-9149>

E-mail: jedrzej.forynski@gmail.com

Independent researcher, 62-081 Baranowo, Poland

Michelle Martina Stachurska [MS]

ORCID: <https://orcid.org/0009-0005-9445-7101>

E-mail: smichelle@interia.pl

Szpital Psychiatryczny Węgorzewo, Generała Józefa Bema 24, 11-600 Węgorzewo, Poland

Kamila Zera [KZ]

ORCID: <https://orcid.org/0009-0006-8510-4803>

E-mail: kamilazera672@gmail.com

Independent researcher, 01-320 Warszawa, Poland

Weronika Piekarska [WP]

ORCID: <https://orcid.org/0009-0004-1074-1811>

E-mail: weronikapiekarska15@gmail.com

Szpital Zachodni im. św. Jana Pawła II, Daleka 11, 05-825 Grodzisk Mazowiecki, Poland

Konstancja Radiczew [KR]

ORCID: <https://orcid.org/0009-0008-7114-8586>

E-mail: Kradiczew@gmail.com

Independent researcher, 00-430 Warszawa, Poland

Karolina Rogala [KR]

ORCID: <https://orcid.org/0009-0004-1942-4310>

E-mail: rogalakarolina99@gmail.com

Independent researcher, 05-830 Nadarzyn, Poland

Rafał Wilczyński [RW]

ORCID: <https://orcid.org/0009-0006-8459-4740>

E-mail: raf.wilczynski11@gmail.com

Independent researcher, 50-443 Wrocław, Poland

Corresponding Author

Beniamin Bekrycht

E-mail: beniaminbekrycht@gmail.com

Abstract

Background/aim. Minimalist footwear represents a growing focus in public health debate and scientific research. This paper aims to summarize current literature regarding the subject, organizing findings across the segments of the lower limb kinetic chain.

Materials and methods. Narrative review. Main search in the PubMed database.

Results. Studies show various benefits of minimalist footwear for multiple elements of the kinetic chain. The main risks include transition injuries and exacerbation of pre-existing conditions. Strength of evidence is variable, including an insufficient number of longitudinal trials.

Conclusions. In most studies, minimalist footwear outperforms conventional shoes in terms of biomechanical and clinical outcomes. Healthy individuals are expected to benefit from the transition. Future extended research in the field may establish a new standard in footwear to prevent foot and lower limb conditions and maintain optimal gait biomechanics. Several musculoskeletal pathologies may be manageable by changing footwear type. Application must be gradual; pre-existing foot or systemic conditions warrant increased caution or contraindication.

Keywords: minimalist footwear, shoes, foot, biomechanics, walking, running, kinetic chain

1. Introduction

1.1. Historical Context and First Studies

The topic of minimalist footwear has been present within certain sport and lifestyle communities ever since the development of cushioned technical athletic shoes technology in the early 1970s. While gradually growing in popularity, it received limited attention in scientific research up until 2010. This status changed when Lieberman et al. published the article titled *Foot strike patterns and collision forces in habitually barefoot versus shod runners* in the renowned journal *Nature*[1]. This paper sparked the modern minimalist footwear movement in science by demonstrating that conventional shoes inherently alter natural kinematics. The human foot evolved as a specialized anatomical structure designed for sustained barefoot locomotion without external stabilization. The authors focused on running, when dense heel cushioning and elevation promote a heavy rearfoot strike by artificially attenuating the impact transient. Conversely, removing conventional shoes forces the body to adopt a mid-foot or forefoot strike. This shift utilizes the intrinsic elastic structures of the foot and ankle to naturally dampen collision transients without artificial support. Subsequent literature expanded on this concept, approaching the ubiquitous adoption of cushioned, restrictive, inflexible modern footwear as an evolutionary mismatch [2].

1.2. Standardizing Footwear Definitions

To critically evaluate the literature, an objective distinction must be established between conventional and minimalist footwear. Esculier et al. [3] developed the Minimalist Index (MI) through an international Delphi consensus to standardize this classification. The MI defines minimalist footwear by specific physical parameters. These criteria include a zero heel-to-toe drop, longitudinal and torsional flexibility, an anatomical toe box, low stack height, and absence of motion control structures. In contrast, conventional shoes rely heavily on passive shock absorption, elevated heels, and rigid medial posts to externally control foot kinematics.

1.3. Biomechanical Foundation: The Closed Kinetic (Kinematic) Chain

The central framework of this review is grounded in the closed kinetic chain concept. During the stance phase of human locomotion, the lower extremity operates as a closed chain because the distal segment is fixed to a solid surface [4]. In this state, mechanical forces and structural alignments cannot remain localized. Any structural deficit or angular adjustment at the ground level reciprocally alters the angles of the adjacent joints. This closed-chain environment dictates that altered foot mechanics inevitably propagate upward, forcing predictable compensatory movement patterns at the proximal joints, specifically the knee, pelvis, and lumbar spine.

1.4. Bibliometric Trends and the Clinical Shift

Research regarding footwear biomechanics demonstrates a sustained upward trend from 2005 to 2024 [5]. The scientific paradigm has shifted significantly during this period. Initial studies focused predominantly on the kinematics and oxygen economy of elite runners. Current bibliometric hotspots center on clinical musculoskeletal health, intrinsic muscle strength, and systemic rehabilitation. Minimalist footwear is now widely evaluated as a conservative intervention tool for broad clinical populations rather than strictly athletic cohorts.

2. Materials and Methods

The primary aim of this narrative review is to synthesize the current literature on minimalist footwear and its impact on human biomechanics. This paper maps the bottom-up biomechanical adaptations induced by removing external foot support. It successively evaluates the subsequent clinical impact of these adaptations on general musculoskeletal health and specific pathologies of the foot, knee, pelvis, and spine. Finally, this review details the risks, uncertainties and controversies associated with minimalist shoes adoption. In addition to being a summary for researchers, it aims to serve as a guide for clinical practitioners as well as casual users willing to consciously implement footwear with minimalistic design.

The initial literature search for this article was conducted in the PubMed database using the phrase “minimalist shoes OR minimalist footwear”. After establishing a detailed structural plan, the search was narrowed by adding the following terms: “AND muscle”, “AND hallux valgus”,

“AND plantar fasciitis”, “AND knee”, “AND osteoarthritis”, “AND pelvis”, “AND spine”, and “AND injuries”. To elaborate on specific concepts, the terms “kinetic chain”, “foot measurements” were also searched. Several additional sources were identified through reference list cross-checking or key words tracking, strictly limited to peer-reviewed scientific journals.

For structural clarity the content of this paper is subdivided into several sections. Section 3 introduces the foot structural development and impact of footwear on biomechanics and health. Sections 4-7 deal with subsequent elements of the kinetic chain. Section 8 deals with the risk and uncertainties related to the topic.

3. Foot Biomechanics and Structural Development in the Context of Footwear Type

3.1. The Foot Core Paradigm and Arch Control

In 2015, McKeon et al. [6] introduced the "foot core" paradigm, proposing that intrinsic foot muscles function as local stabilizers homologous to the lumbopelvic core. Conventional footwear provides external passive support that chronically offloads this musculature. Prolonged use of such shoes leads to intrinsic muscle atrophy and functional degradation. Furthermore, Kelly et al. [7] demonstrated that the medial longitudinal arch is not a rigid structure. Intrinsic foot muscles actively modulate arch deformation during dynamic load-bearing. These studies showed that muscle activation directly increases arch stiffness, which is essential for natural force absorption and mechanical propulsion during gait.

3.2. Pediatric Development and Structural Maturation

Mechanical loading during developmental years profoundly influences foot morphology. Hollander et al. [8] demonstrated that habitual barefoot locomotion drives distinct structural maturation in children and adolescents. Barefoot youths develop significantly wider feet and higher medial longitudinal arches. Conversely, the early introduction of conventional, restrictive footwear interrupts this natural structural maturation. The findings suggest that restrictive footwear contributes to an artificially narrowed foot morphology and limits optimal arch development.

3.3. Morphological Differences in Shod versus Unshod Populations

Morphological characteristics differ significantly based on lifetime footwear habits. Holowka et al. [9] showed that minimally shod populations exhibit greater intrinsic foot muscle volume and increased longitudinal arch stiffness compared to conventionally shod populations. This increased arch stiffness correlates directly with improved mechanical efficiency during locomotion. Mei et al. [10] observed that habitually unshod individuals demonstrate significantly wider forefeet. This specific morphological adaptation distributes plantar loads more evenly across the metatarsal heads. Consequently, it reduces the localized high-pressure areas that are commonly observed in conventionally shod individuals.

3.4. Clinical Reversibility

Curtis et al. [11] demonstrated that walking in minimalist footwear during routine daily activities significantly increases foot muscle strength and cross-sectional size. Their study showed a 57.4% increase in foot muscle strength after six months. Furthermore, the strength of participants after this time period was comparable to experienced minimalist shoes users with an average 2.5 years usage history. The researchers observed that this structural and functional adaptation does not require targeted athletic training or isolated foot exercises. Therefore, current evidence suggests that transitioning to minimalist footwear serves as a viable clinical intervention to reverse footwear-induced muscular degradation and near-maximal effect is achieved after six months.

4. The Foot – Clinical Conditions Benefiting from Minimalist Footwear

4.1. Hallux Valgus and Abductor Hallucis Function

Hallux valgus pathology is directly associated with weakness and atrophy of the abductor hallucis muscle. Conventional footwear utilizes narrow, restrictive toe boxes. These structures constrain natural toe splay and induce intrinsic muscular degradation. Interventions promoting active toe-spreading significantly increased the cross-sectional area of the abductor hallucis and effectively decreased the hallux valgus angle [12]. Minimalist footwear features a wide, anatomical toe box. As established, walking in minimalist shoes actively strengthens the overall intrinsic foot musculature during routine daily activities [6,11]. Consequently, minimalist

footwear provides the necessary mechanical environment to restore abductor hallucis function and counteract hallux valgus progression.

4.2. Plantar Fasciitis

Plantar fasciitis results from repetitive biomechanical overload of the passive plantar fascia. As established, minimalist footwear shifts mechanical demand away from this passive structure and onto the active intrinsic foot musculature [11]. Furthermore, it facilitates a more even plantar load distribution [10]. Ribeiro and João [13] demonstrated the efficacy of this mechanism in a clinical population. The randomized controlled trial showed that utilizing minimalist flexible shoes significantly improved foot function and reduced pain in women with plantar fasciitis. MacGabhann et al. [14] provided further evidence for barefoot biomechanics as a direct intervention. The prospective case series revealed that a six-week barefoot running protocol on grass significantly decreased morning pain in symptomatic runners. This clinical improvement was maintained at a twelve-week follow-up. By requiring active muscular load absorption, removing conventional footwear constraints effectively offloads the inflamed plantar fascia. This facilitates long-term functional restoration rather than solely providing passive structural support.

4.3. Unaddressed Pathologies - Example of Digital Deformities

Minimalist footwear utilizes a wide toe box intended to facilitate natural toe splay. Although habitually unshod populations exhibit wider forefoot reinforcing plantar load distribution [10], direct clinical trials linking specific digital deformities to conventional footwear remain scarce. Pathologies such as hammer toes typically develop from flexor-extensor muscle imbalances. These mechanical imbalances are plausibly exacerbated by the elevated heels and restrictive toe boxes characteristic of conventional footwear [3]. Minimalist shoes eliminate these structural constraints by providing a zero heel-to-toe drop and an anatomical toe box. This design theoretically restores proper flexor-extensor resting lengths. However, empirical clinical research is required to validate minimalist footwear as a direct interventional tool for hammer toes and similar digital syndromes. This represents a trajectory for future biomechanical studies.

5. The Knee

5.1. Knee Osteoarthritis

Mechanical overload drives joint degeneration in medial compartment knee osteoarthritis. Shakoor et al. [15] noticed that conventional shoes with elevated heels and rigid soles actively increase knee joint loads across the intra-articular space. Conversely, flat, highly flexible footwear closely mimics barefoot kinematics and provides a favorable reduction in cumulative joint loading. This load reduction extends to mechanically demanding activities of daily living. Wearing inexpensive, minimalist footwear significantly decreased peak knee joint loads during stair descent when compared to conventional, structured footwear in elderly women with osteoarthritis [16]. By removing artificial structural elevations, minimalist footwear acts as a passive, daily biomechanical intervention that safely offloads the compromised joint without requiring active gait modification.

5.2. Patellofemoral Stress

Conventional, heavily cushioned footwear facilitates a rearfoot strike running pattern [1]. This kinematic profile transmits a rapid, high-magnitude impact transient straight up the kinetic chain to the patellofemoral joint. Minimalist footwear intrinsically encourages a mid-foot or forefoot strike. A twelve-week period of gait retraining utilizing minimalist shoes shifted this strike pattern and reduced peak patellofemoral joint stress by over 13% [17]. This clinical improvement occurred via a proximal-to-distal force redistribution. Adopting a forefoot strike actively decreased patellofemoral contact force while proportionally increasing the load managed by the Achilles tendon [18]. By forcing the foot and calf complex to actively absorb collision energy, minimalist footwear significantly reduces proximal mechanical stress on the knee.

6. Pelvis and Lumbar Spine

The proximal segments of the kinetic chain remain the least directly studied structures regarding minimalist footwear interventions. Current clinical rationale relies on linking established distal

mechanics to lumbopelvic responses. Betsch et al. [19] demonstrated that artificial heel elevations alter anterior pelvic tilt and torsion. Furthermore, Menz et al. [20] established a significant epidemiological association between dynamic foot overpronation and low back pain. Minimalist shoes feature a zero heel-to-toe drop and facilitate intrinsic arch stiffness, directly targeting these foot biomechanics deviations [3,11]. This creates a plausible biomechanical pathway for optimizing lumbopelvic alignment. However, the exact clinical magnitude and consistency of proximal symptom relief derived from these distal footwear changes remain undetermined. Establishing a definitive empirical link between minimalist footwear and lumbopelvic health represents a promising area for future clinical research.

7. Sensory Input and Proprioception

7.1. Neuromuscular Feedback

Beyond structural biomechanics, plantar neural input is another factor that dictates gait efficiency and is directly modulated by footwear, specifically sole thickness and rigidity. The safe execution of complex movements requires precise sensorimotor integration. As an example of this mechanical demand, Xu et al. [20] analyzed the stair-to-ground transition. When visual sensory input was compromised by altered illumination, the central nervous system increased its reliance on plantar proprioception. The footwear interface directly determined the quality of this tactile feedback. Altering footwear structure directly modulated muscle cocontraction strategies and redistributed joint work during descent. Essentially, uncompromised plantar feedback allows the neuromuscular system to adapt its mechanical strategy to environmental challenges rapidly and effectively.

7.2. Postural Control and Fall Prevention

Consistently, Gabriel et al. [21] highlight that the plantar surface contains high densities of cutaneous receptors responsible for somatosensory feedback. Conventional, heavily cushioned shoes artificially attenuate this critical neural input. Minimalist footwear removes thick midsoles and rigid shanks. This structural reduction restores the necessary transmission of tactile ground feedback. Enhanced sensory input translates directly to improved clinical balance

across populations. In their study on healthy young adults, a four-week transition to minimalist shoes significantly improved static single-leg stance balance. This sensory enhancement is presumably highly critical for aging populations experiencing natural sensory decline. Furthermore, Cudejko et al. [22] reported that minimalist footwear significantly improved both standing and walking stability compared to conventional footwear in older adults with a documented history of falls. Maximizing plantar somatosensory feedback via minimalist footwear serves as an evidence-based biomechanical intervention for enhancing postural control and preventing falls.

8. Risks, Contraindications, and Controversies

8.1. Transition Injuries and Metatarsal Overload

The therapeutic benefits of minimalist footwear depend heavily on the body's structural capacity to absorb load. Multiple studies show that rapid withdrawal of conventional cushioning highly increases the risk of acute injury. Runners transitioning to minimalist footwear experience significantly higher injury rates and pain perception compared to those remaining in traditional shoes [23]. The removal of thick midsoles directly increases mechanical strain on the forefoot. Running in minimalist footwear elevates metatarsal strain and accelerates the risk of structural failure [24]. Clinically, this mechanical overload manifests predominantly as metatarsal stress fractures and severe bone marrow edema [25]. These transition injuries occur because cortical bone remodeling requires substantially more time than neuromuscular adaptation [26]. Therefore, a structured, progressive transition protocol is mandatory to prevent skeletal overload.

8.2. Soft Tissue Overload

Minimalist footwear intrinsically encourages a transition from a rearfoot to a non-rearfoot strike pattern. While this kinematic shift unloads proximal joints, it transfers a massive eccentric load to the distal soft tissues. The triceps surae and the Achilles tendon must absorb the kinetic energy previously dissipated by the conventional heel cushioning. Biomechanical analysis confirmed that even a structured 12-week transition to minimalist shoes significantly increases

peak Achilles tendon force and loading rates in habitual rearfoot strikers [27]. If the tissue capacity is not progressively increased, this mechanical overload leads to acute soft tissue failure. Clinical observations corroborate this mechanism, revealing a high incidence of Achilles tendinopathy, tendon tears, and acute calf pain in transitioning runners [23,25]. The distal musculotendinous units must be systematically conditioned to handle this redistributed mechanical work.

8.3. Clinical Contraindications

Minimalist footwear is not universally applicable. It relies strictly on uncompromised plantar sensory feedback and adequate articular mobility. Consequently, it is mechanically and clinically contraindicated for specific patient populations. Patients with profound peripheral neuropathy, such as those with diabetic neuropathy, lack the protective sensation necessary to respond to plantar feedback. Removing conventional protective footwear in this population severely increases the risk of plantar ulceration. Furthermore, patients with rigid, non-reducible structural deformities, such as end-stage hallux rigidus, lack the intrinsic joint mobility required to absorb impact safely. These populations require structural support and thicker soles to compensate for their mostly irreversible loss of function.

8.4 Fit of Minimalist Footwear

The human foot shape exhibits variations in more than one dimension. An analysis of 1.2 million foot scans [28] demonstrated significant, measurable differences in foot width, instep height, and heel width across populations, even when comparing feet of the exact same length. Athletic footwear requires a restrictive fit to minimize internal movement and friction during dynamic activity. Conversely, minimalist footwear utilizes a wide, anatomical toe box and flexible structure to allow all parts of the foot unrestricted structural momentary deformation. Footwear designs intended to imitate a natural foot shape encounter the challenge of matching different foot shapes with secure fit. Currently, the footwear industry relies on standardized sizing systems that assume a single foot shape for each given length.

9. Discussion

9.1. Paradigm Shift in Treatment Strategies

The biomechanical mechanisms of minimalist footwear challenge conventional podiatric paradigms. Traditional treatments of foot conditions rely heavily on passive structural support, utilizing specially shaped orthoses and relieving cushioning. While passive support is effective for acute tissue offloading, it contributes to long-term intrinsic muscle atrophy and sensory attenuation. In contrast, the minimalist model operates on active adaptation. It prioritizes strengthening tissues through natural mechanical loading and improving the foot's sensory feedback and motor control. This approach shifts the primary clinical objective. Rather than accommodating structural deficits with external support, it seeks to reverse the underlying functional degradation through continuous physical conditioning.

9.2. The Transition Paradox

Minimalist footwear presents a distinct biomechanical paradox. Safe utilization requires substantial pre-existing intrinsic foot strength and Achilles tendon load capacity. However, locomotion in these shoes is the primary intervention used to develop those exact physical traits. Consequently, minimalist shoes act as a direct mechanical stimulus, not standard apparel. They must be implemented gradually. Wear time and load intensity must be progressively increased over a structured timeline. This gradual transition allows cortical bone remodeling and soft tissue adaptation to keep pace with the elevated mechanical demands, mitigating the risk of structural failure.

9.3. Limitations of Current Evidence

A critical evaluation of the existing literature reveals a certain number of methodological limitations. Current kinetic and kinematic models are robust. In most cases, laboratory data accurately quantifies the immediate mechanical shifts, joint load redistributions, and peak

forces associated with minimalist footwear. However, the literature lacks long-term, high-quality randomized controlled trials. Exemplifying this trend, biomechanical data proves that minimalist shoes reduce patellofemoral stress or osteoarthritis pain acutely, but evidence is insufficient to claim they permanently halt the progression of knee joint degeneration. Foundational evidence relies heavily on cross-sectional analyses assessing habitually barefoot populations or short-term intervention windows. Establishing definitive clinical efficacy requires longitudinal studies tracking pathological resolution over multiple years.

10. Conclusions

Current evidence provides multiple indications that minimalist footwear benefits the structural health of the foot and proximal parts of the body via the kinetic chain. Across the majority of reviewed studies, minimalist designs consistently outperform conventional footwear in terms of gait and dynamic movement biomechanics and musculoskeletal health implications.

Accounting for transition risks and utilizing adaptation protocols, minimalist shoes can be safely introduced to most athletes and healthy casual users. Application in individuals with pre-existing lower limb or systemic conditions requires strict clinical caution. However, current research suggests their viability as an active treatment for several specific pathologies, including hallux valgus, pes planus, plantar fasciitis, patellofemoral pain syndrome, and knee osteoarthritis.

The topic of minimalist footwear remains a promising field for future scientific research. Broader and more longitudinal studies have high potential for confirming current theses, providing new observations, and setting new standards for footwear design for both athletic and casual use. Additionally, these findings will presumably enhance public debate in the area of foot health and drive future innovations in commercial footwear development.

Disclosure:

Supplementary Material: There are no supplementary data connected with this article.

Author Contributions:

Conceptualization: BB

Methodology: BB, PT, NS, MS

Formal analysis: BB

Investigation: BB, JF, MS, KZ, WP, KRa, KRo, RW

Resources: BB, JF, MS, KZ, WP, KRa, KRo, RW

Data curation: JF, MS, KZ, WP, KRa, KRo, RW

Writing –original draft: BB

Writing –review and editing: JF, MS, KZ, WP, KRa, KRo, RW

Supervision: PT, NS

All authors have read and agreed with the published version of the manuscript.

Funding Statement: Study did not receive any funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors declare no acknowledgements.

Conflict of Interest Statement: There is no conflict of interest.

Declaration of the use of generative AI and AI-assisted technologies in the writing process:

The preparation of this work involved the use of AI as an assistive tool to support academic writing quality, including improvements to clarity and readability, text organization, formatting, and bibliographic consistency. All content generated with AI assistance was subsequently reviewed, revised, and approved by the authors, who bear full responsibility for the scientific integrity and accuracy of the published work.

References

1. Lieberman, D. E., Venkadesan, M., Werbel, W. A., Daoud, A. I., D'Andrea, S., Davis, I. S., Mang'eni, R. O., & Pitsiladis, Y. (2010). Foot strike patterns and collision forces in habitually barefoot versus shod runners. *Nature*, 463(7280), 531–535. <https://doi.org/10.1038/nature08723>
2. D'Août, K., Elnaggar, O., Mason, L., Rowlatt, A., & Willems, C. (2025). Footwear Choice and Locomotor Health Throughout the Life Course: A Critical Review. *Healthcare (Basel, Switzerland)*, 13(5), 527. <https://doi.org/10.3390/healthcare13050527>
3. Esculier, Jean-Francois & Dubois, Blaise & Dionne, Clermont & Leblond, Jean & Roy, Jean-Sébastien. (2015). A consensus definition and rating scale for minimalist shoes. *Journal of Foot and Ankle Research*. 8. 1-9. <https://doi.org/10.1186/s13047-015-0094-5>
4. Svoboda, Z., Janura, M., Kutilek, P., & Janurova, E. (2016). Relationships between movements of the lower limb joints and the pelvis in open and closed kinematic chains during a gait cycle. *Journal of human kinetics*, 51, 37–43. <https://doi.org/10.1515/hukin-2015-0168>
5. Xiao X, Lian A, Li Z and Fan Y (2025) Trends and hotspots in running shoe research: a bibliometric study from 2005 to 2024. *Front. Sports Act. Living* 7:1609141. <https://doi.org/10.3389/fspor.2025.1609141>

6. McKeon, P. O., Hertel, J., Bramble, D., & Davis, I. (2015). The foot core system: a new paradigm for understanding intrinsic foot muscle function. *British journal of sports medicine*, 49(5), 290. <https://doi.org/10.1136/bjsports-2013-092690>
7. Kelly, L. A., Cresswell, A. G., Racinais, S., Whiteley, R., & Lichtwark, G. (2014). Intrinsic foot muscles have the capacity to control deformation of the longitudinal arch. *Journal of the Royal Society, Interface*, 11(93), 20131188. <https://doi.org/10.1098/rsif.2013.1188>
8. Hollander, K., de Villiers, J. E., Sehner, S., Wegscheider, K., Braumann, K. M., Venter, R., & Zech, A. (2017). Growing-up (habitually) barefoot influences the development of foot and arch morphology in children and adolescents. *Scientific reports*, 7(1), 8079. <https://doi.org/10.1038/s41598-017-07868-4>
9. Holowka, N.B., Wallace, I.J. & Lieberman, D.E. Foot strength and stiffness are related to footwear use in a comparison of minimally- vs. conventionally-shod populations. *Sci Rep* 8, 3679 (2018). <https://doi.org/10.1038/s41598-018-21916-7>
10. Mei, Q., Fernandez, J., Fu, W., Feng, N., & Gu, Y. (2015). A comparative biomechanical analysis of habitually unshod and shod runners based on a foot morphological difference. *Human movement science*, 42, 38–53. <https://doi.org/10.1016/j.humov.2015.04.007>
11. Curtis, R., Willems, C., Paoletti, P., & D'Août, K. (2021). Daily activity in minimal footwear increases foot strength. *Scientific reports*, 11(1), 18648. <https://doi.org/10.1038/s41598-021-98070-0>
12. Kim, M. H., Yi, C. H., Weon, J. H., Cynn, H. S., Jung, D. Y., & Kwon, O. Y. (2015). Effect of toe-spread-out exercise on hallux valgus angle and cross-sectional area of abductor hallucis muscle in subjects with hallux valgus. *Journal of physical therapy science*, 27(4), 1019–1022. <https://doi.org/10.1589/jpts.27.1019>
13. Ribeiro, A. P., & João, S. M. A. (2022). The Effect of Short and Long-Term Therapeutic Treatment with Insoles and Shoes on Pain, Function, and Plantar Load Parameters of Women with Plantar Fasciitis: A Randomized Controlled Trial. *Medicina (Kaunas, Lithuania)*, 58(11), 1546. <https://doi.org/10.3390/medicina58111546>
14. MacGabhann, S., Kearney, D., Perrem, N., & Francis, P. (2022). Barefoot Running on Grass as a Potential Treatment for Plantar Fasciitis: A Prospective Case Series. *International journal of environmental research and public health*, 19(23), 15466. <https://doi.org/10.3390/ijerph192315466>
15. Shakoor, N., Sengupta, M., Foucher, K. C., Wimmer, M. A., Fogg, L. F., & Block, J. A. (2010). Effects of common footwear on joint loading in osteoarthritis of the knee. *Arthritis care & research*, 62(7), 917–923. <https://doi.org/10.1002/acr.20165>
16. Sacco, I. C., Trombini-Souza, F., Butugan, M. K., Pássaro, A. C., Arnone, A. C., & Fuller, R. (2012). Joint loading decreased by inexpensive and minimalist footwear in elderly women with knee osteoarthritis during stair descent. *Arthritis care & research*, 64(3), 368–374. <https://doi.org/10.1002/acr.20690>
17. Wang, B., Yang, Y., Zhang, X., Wang, J., Deng, L., & Fu, W. (2020). Twelve-Week Gait Retraining Reduced Patellofemoral Joint Stress during Running in Male Recreational Runners. *BioMed research international*, 2020, 9723563. <https://doi.org/10.1155/2020/9723563>
18. Li, Y., Nie, Y., Zhang, X., & Gu, Y. (2025). Effects of footwear and foot strike patterns on patellofemoral joint and Achilles tendon loading in novice runners and experienced runners. *Frontiers in sports and active living*, 7, 1610514. <https://doi.org/10.3389/fspor.2025.1610514>

19. Betsch, M., Schnependahl, J., Dor, L., Jungbluth, P., Grassmann, J. P., Windolf, J., Thelen, S., Hakimi, M., Rapp, W., & Wild, M. (2011). Influence of foot positions on the spine and pelvis. *Arthritis care & research*, 63(12), 1758–1765. <https://doi.org/10.1002/acr.20601>
20. Xu, Y., Zhu, C., Sun, D., Jian, X., Xia, Z., Qian, Y., Shen, L., Song, Y., Cen, X., Sárosi, J., Bíró, I., & Gu, Y. (2026). Footwear and illumination modulate muscle cocontraction strategies and joint work redistribution during stair-to-ground transition. *Journal of applied physiology* (Bethesda, Md. : 1985), 140(4), 935–945. <https://doi.org/10.1152/jappphysiol.01230.2025>
21. Gabriel, A., Fuchs, K., Haller, B., Sulowska-Daszyk, I., Horstmann, T., & Konrad, A. (2024). A four-week minimalist shoe walking intervention influences foot posture and balance in young adults-a randomized controlled trial. *PloS one*, 19(6), e0304640. <https://doi.org/10.1371/journal.pone.0304640>
22. Cudejko, T., Gardiner, J., Akpan, A., & D'Août, K. (2020). Minimal shoes improve stability and mobility in persons with a history of falls. *Scientific reports*, 10(1), 21755. <https://doi.org/10.1038/s41598-020-78862-6>
23. Ryan, M., Elashi, M., Newsham-West, R., & Taunton, J. (2014). Examining injury risk and pain perception in runners using minimalist footwear. *British journal of sports medicine*, 48(16), 1257–1262. <https://doi.org/10.1136/bjsports-2012-092061>
24. Firminger, C. R., Fung, A., Loundagin, L. L., & Edwards, W. B. (2017). Effects of footwear and stride length on metatarsal strains and failure in running. *Clinical biomechanics* (Bristol, Avon), 49, 8–15. <https://doi.org/10.1016/j.clinbiomech.2017.08.006>
25. Salzler, M. J., Kirwan, H. J., Scarborough, D. M., Walker, J. T., Guarino, A. J., & Berkson, E. M. (2016). Injuries observed in a prospective transition from traditional to minimalist footwear: correlation of high impact transient forces and lower injury severity. *The Physician and sportsmedicine*, 44(4), 373–379. <https://doi.org/10.1080/00913847.2016.1238282>
26. Knapik, J. J., Orr, R., Pope, R., & Grier, T. (2016). Injuries And Footwear (Part 2): Minimalist Running Shoes. *Journal of special operations medicine : a peer reviewed journal for SOF medical professionals*, 16(1), 89–96.
27. Zhang, X., Deng, L., Yang, Y., Xiao, S., Li, L., & Fu, W. (2021). Effects of 12-week transition training with minimalist shoes on Achilles tendon loading in habitual rearfoot strike runners. *Journal of biomechanics*, 128, 110807. <https://doi.org/10.1016/j.jbiomech.2021.110807>
28. Jurca, A., Žabkar, J., & Džeroski, S. (2019). Analysis of 1.2 million foot scans from North America, Europe and Asia. *Scientific reports*, 9(1), 19155. <https://doi.org/10.1038/s41598-019-55432-z>