WWW.IJRPR.COM

International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Comparison of Gait Biomechanics in Lower Limbs of Elderly Walking with Different Footwears: Systematic Review of Cross-Sectional Studies

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A B S T R A C T

Backgrounds: The function of footwear is to protect the plantar skin and keep the stability and efficiency of gait and the peripheral sensation of feet. For elder individuals, the effects of footwear on gait biomechanics are unclear due to the lack of evidence at a high level and should be systematically reviewed.

Objective: This systematic review of cross-sectional studies makes a comprehensive summary and analysis of the gait parameters and kinematic and dynamic statistics of lower limbs of elder individuals walking with different kinds of footwear.

Methods: A systematic review of cross-sectional studies were conducted by searching PubMed, Cochrane Library, and Web of Science with the eligibility criteria: (1) Participants over 60 years old and without musculoskeletal disabilities; (2) Comparing gait biomechanics when wearing different kinds of footwears; (3) Cross-sectional studies published in peer-reviews journals in English.

Results: The results showed that elder individuals wearing simplified footwear were inclined to have a longer gait cycle time and smaller minimum toe spacing variability, which indicated an increase the gait stability. Besides, unstable shoes seem to have less demand for power output from the musculoskeletal system and could reduce the minimum toe spacing that might increase the risk of falls. Moreover, cushion shoes will increase plantar pressure so the elderly with osteoarthrosis should choose this kind of footwear cautiously. This systematic review also found some limitations of current studies, there are large heterogeneities within the included studies because of the difference within their protocols and population of participants, suggesting that further studies should focus on the relationship and inner mechanism between the risk of falls and biomechanical parameters to help elder individuals to choose their footwears from an evidence-based perspective.

Keywords: elderly, footwear, biomechanics, gait, systematic review

Introduction

The definition of "Gait" is the pattern of movement of the limbs of animals, including humans, during locomotion over a solid substrate. When it comes to human beings, according to the analysis and classification of Milton Hildebrand, each lower limb in gait is partitioned into a stance phase, where the foot is in contact with the ground, and a swing phase, where the foot is lifted and moved forwards, each lower limb must complete a cycle in the same length of time (Hildebrand, 1989; Tasch et al., 2008). During the gait process, the body pushed its center of gravity forward with the lowest metabolic energy expenditure by moving each lower limb alternatively, and the individual difference in motor control, walking speed, force delivery, power cycling, and landing pattern make the biomechanical characteristic of human gait various.

During the process of aging, the function of humans' musculoskeletal system and central nervous system for motor control degenerate, changing the biomechanical characteristics of gait and increasing the risk of falls. For example, the acceleration of bone loss in the elderly induces bone mineral density decrease and secondary osteoporosis, which in turn affects the overall mechanical carrying capacity of the elderly musculoskeletal system. At the same time, the breakdown of muscle protein in the elderly, as well as the concomitant decrease in the number and recruitment ability of large motor units, also weaken the ability of posture control of the elderly. According to the survey results given out by the World Health Organization, 70% of falls in the elderly occur during walking (Organization, Ageing, & Unit, 2008). Considering that accidental falls are one of the largest risk factors for mortality in the elderly population worldwide, and the walking gait characteristics of the elderly and the changes in biomechanical parameters of their lower limbs are related to the risk of accidental falls, consequently, in recent years, the walking gait characteristics and the changes in biomechanical parameters of lower limbs in the elderly have gradually been paid more attention and deeper researched (Niederer, Engeroff, Fleckenstein, Vogel, & Vogt, 2021).

Footwear, as the garments worn on the feet, which have been in use since human history from the Chalcolithic, typically serves the purpose of protection against adversities of the environment such as wear from ground textures and temperature, and the purpose to ease locomotion and prevent injuries. Biologically, footwear, which is one of the external influence factors like walking environment and ground type, will affect human's gait together with internal influence factors such as the central nervous system and musculoskeletal system (Bruijn, Meijer, Beek, & van Dieen, 2013). Recently, thanks to the development of related science and technology, footwear and shoes have been given more functions, such as cushioning, stabilization, rebound, and motion control (Sun et al.). Therefore, nowadays, footwear can not only protect the feet, but also affect the peripheral nerve sensation of the user during walking, and then change the walking gait parameters, and even change the anthropometric and anatomical characteristics of the feet (Holowka et al., 2019). A previous study by Paterson's team that was published in 2021 demonstrated that, for the elderly, wearing functional shoes in daily activities can reduce the load on the lower limb joints and delay the progression of musculoskeletal degenerative diseases of the lower limbs (Kade L Paterson et al., 2021). In addition to providing cushion and stability, wearing footwear can also bring positive effects on balance by changing the friction in the plantar-shoe and shoe-ground interfaces, thereby reducing the risk of accidental falls in the daily life of the elderly (Hatton, Rome, Dixon, Martin, & McKeon, 2013; Hida, Fujimoto, Ooie, & Kobayashi, 2021).

To sum up, although many previous studies have identified that wearing footwear can change the gait biomechanical parameters of lower limbs in the elderly during walking, the relevant evidence is strong enough to provide convincible suggestions because of the heterogeneities within the protocols of studies such as the population, intervention, and study designs. It is necessary to synthesize as much evidence as possible systematically to explore the effect of different kinds of footwear on the biomechanical characteristics of walking gait in the elderly. The objective of this systematic review is to make a comprehensive summary and analysis of biomechanical parameters in the walking gait of the elderly when wearing different kinds of footwear.

Methods

Eligibility Criteria

The eligibility criteria of this systematic review are as follows:

Population: Studies that could be included in this systematic review should recruit individuals with an average age of more than 60 years old or clearly state that the participants were elderly (Kent, 2007). All the participants should have no musculoskeletal disabilities.

Intervention and Comparison: Walking with different kinds of footwear.

Outcomes: Gait biomechanical parameters include gait characteristics (Time and space parameters), kinematic parameters, and dynamic parameters.

Study design: Only cross-sectional studies will be included in this review, no matter the design is randomized or not.

Exclusion Criteria

Studies will be excluded if:

Participants had musculoskeletal diseases, or disabilities, or were clinically diagnosed with walking contraindications.

The average age of participants is younger than 60.

The study is not a cross-sectional study or just a published abstract without full text.

Outcome measures do not correspond with those in the eligibility criteria.

There are other gait interventions that exist in addition to footwear.

Lack of original data.

Information Sources

A comprehensive and reproducible search for peer-reviewed studies published in English was performed on the PubMed, Cochrane Library, and Web of Science databases from January 2000 to May 2022. Reference lists of studies and grey literature were also searched to identify potential studies. If the data were not provided in the published study, the authors would be contacted and asked for the missing data.

Search Strategy

In the search from Web of Science and Cochrane Library, the terms of Boolean logic searching were "((TS=(gait)) OR (TS=(walk))) AND ((TS=(footwear)) OR (TS=(shoe))) AND ((TS=(random)) AND ((TS=(elderly))) OR (TS=(older))) NOT (TI=(review))", while in PubMed, the terms of Boolean logic searching were "((gait) OR (walk)) AND ((shoe) OR (footwear)) AND (random) AND ((elderly) or (older)) NOT (review)".

Two independent authors (Shun Wang and Shudong Li) screened all the titles of the searched studies before the abstract screening. An independent librarian was invited to support the search strategies, checking other synonyms and entry terms to increase their sensitivity and specificity.

Selection Process

Studies searched from the databases were loaded into EndNote 20 Software (Thomson Reuters, Carlsbad, CA, USA) to further screen and remove duplicates. Two independent authors (Shun Wang and Shudong Li) performed further screening and any disagreement was resolved by a third independent reviewer.

Data Collection Process

The data were collected by two independent authors (Shun Wang and Shudong Li). An independent reviewer was invited to check all the collected data.

Data Items

The following data items were collected:

The characteristics of participants, such as their average age, and gender ratio.

Information about the kind of footwear and details of the intervention programs.

Outcome measure results, such as the sample size of each group, the protocol of gait assessment, and the main finding of the assessment.

Study Quality Assessment

The Agency for Healthcare Research and Quality (AHRQ) Cross-Sectional/Prevalence Study Quality Assessment Checklist (Rostom et al., 2004) was used to assess the quality of all included studies and identify the potential risk of bias. According to the Agency for Healthcare Research and Quality (AHRQ) Cross-Sectional/Prevalence Study Quality Assessment Checklist, the quality of a cross-sectional study was assessed by 11 items, each item had three answers (Yes/No/Unclear). Cohen's kappa value was used to present the agreement between authors. Two authors (Shun Wang and Shudong Li) assessed all the included studies independently and another independent arbitrator was invited when an agreement could not be met.

Results

Study Selection

The search yielded 790 titles and abstracts for screening. A total of 125 duplicated studies were removed, and 665 studies were included in the records screening. Then, 41 studies with ineligible type were excluded, and 624 studies were included for further screening. Among the 624 studies, 32 studies were excluded due to their ineligible participants, 563 studies were excluded because of their ineligible design, and 20 studies were excluded because of their ineligible interventions. Eventually, 9 studies were included in the systematic review (Buchecker, Lindinger, Pfusterschmied, & Müller, 2013; Hollander, Petersen, Zech, & Hamacher, 2021; Hurst, Branthwaite, Greenhalgh, & Chockalingam, 2017; Jordan et al., 2019; Kerrigan et al., 2005; Madden, Kean, Wrigley, Bennell, & Hinman, 2015; K. L. Paterson et al., 2017; Petersen, Zech, & Hamacher, 2020; van Tunen et al., 2018). The flow diagram is presented in Fig. 1.

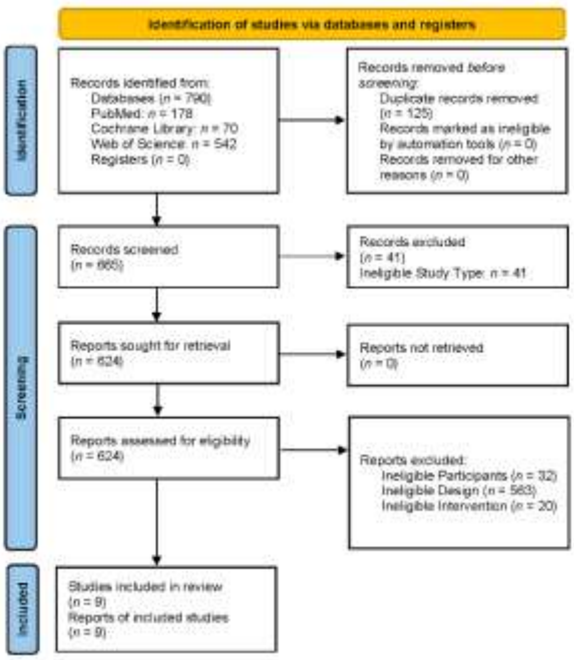

Fig. 1 – Flow diagram of the study selection and screening.

Study Characteristics and Mian Findings

According to the results of the study selection, 4 studies recruited healthy elderly as participants, 3 studies recruited elderly with knee osteoarthritis as participants, 1 study recruited elderly with plantar pain, and 1 study recruited elderly with claudication. For the outcome measures, 8 studies reported the change of gait characteristics (time and space parameters), 6 studies reported the change of kinematical parameters, and 7 studies reported the change of dynamic parameters. The detailed information and main findings of all the included studies was listed in Table 1.

Table 1 - The Agency for Healthcare Research and Quality (AHRQ) Cross-Sectional/Prevalence Study Quality Assessment Checklist

Study	Population	Sample Size	Gait Assessment	Types of Footwears	Assessment Tools	Outcome Measures and Main Findings
Buchecker 2013 (Buchecker et al., 2013)	Healthy elderly	11	1.5±0.1m/s Walking	● Masai Barefoot Technology shoes ● Conventional sport shoes	● VICON motion capture system ● The plantar pressure measurement system	● Gait characteristics: Stride frequency↔, Speed↔, Step length↔ ● Kinematics: Hip mobility↓, Peak hip flexion angle↓, Knee mobility↔, Peak knee extension in middle stance phase↓, Ankle flexion mobility↓, Ankle angle in later stance phase↓ ● Dynamics: Peak plantarflexion moment of the ankle↓, Peak dorsiflexion moment of the ankle↓, Peak power of eccentric contraction in ankle plantar flexors↓, Peak power of concentric contraction in ankle plantar flexors↓, Peak extension moment of the knee in middle stance phase↓, Peak adduction moment of the knee in middle stance phase↓, Peak flexion moment of the knee in early stance phase↓, Peak flexion moment of the knee in later stance phase↓, Concentric contraction power of knee extensors↓, Peak flexion moment of the hip in early stance phase↓, Concentric contraction power of hip extensors↓, Concentric contraction power of hip flexors in later stance phase↓
Hollander 2021 (Hollander et al., 2021)	Healthy elderly	42	Walking at a self-selected speed	● Cushion shoes ● Barefoot	● Inertial sensors	● Gait characteristics: Gait cycle time↑↑, Variance of gait cycle time↑, Speed↑↑, Step length↑, Minimum toes distance↑↑, Variance of minimum toes distance↑↑ ● Kinematics: Stabilities of kinematic parameters↔
Hurst 2017 (Hurst et al., 2017)	Elderly with plantar pain	30	Walking at a self-selected speed	● Medical-grade footwear ● Preferred shoes	● The in-shoeoe plantar pressure measurement system	● Kinematics: Mean ground-touching time of the 1st metatarsophalangeal↓, Mean ground-touching time of the 5th metatarsophalangeal↓, Mean ground-touching time of the 2nd to 4th metatarsophalangeals↔ ● Dynamics: Peak pressure of the 1st metatarsophalangeal↓, Peak pressure of the 5th metatarsophalangeal↓, Peak pressure of the 2nd to 4th metatarsophalangeals↔, Time to peak pressure of the 1st metatarsophalangeal↓, Time to peak pressure of the 5th metatarsophalangeal↓, Time to peak pressure of the 2nd to 4th metatarsophalangeals↔
Jordan 2019 (Jordan	Elderly with claudication	31	Walking at a self-selected speed	● Rocker-soled shoes	● QUALISYS motion capture system	● Gait characteristics: Stride frequency↔, Speed↔, Step length↔, Gait cycle time↔, Time of single limb support↔, Time of limb advancement↔

et al., 2019)				• Typical trainer shoes	• KISTLER force plates	• Kinematics: Hip angle in push-off and swing phases↔, Hip mobility↓, Knee angle in push-off and swing phases↓, Knee mobility↓↓, Peak angle of knee extension and flexion↓, Ankle angle in push-off and swing phases↔, Peak plantarflexion angle of the ankle↑, Ankle mobility↓↓ • Dynamics: Power output by hips↔, Power output by knees↔, Power output by ankles↓
Kerrigan 2005 (Kerrigan et al., 2005)	Healthy elderly	20	Walking at a self-selected speed	• Shoes with 1.5-inch heels • Control shoes without any additional heel	• VICON motion capture system • AMTI strain gauge force plates	• Gait characteristics: Speed↔ • Kinematics: Knee flexion angle in early stance phase↑, Peak angle of knee flexion in swing phase↓↓ • Dynamics: Peak knee varus moment in later stance phase↑↑, Peak knee varus moment in early stance phase↑, Peak knee flexion moment in early stance phase↑, Peak inner rotation moment of knee↑
Madden 2015 (Madden et al., 2015)	Elderly with knee osteoarthritis	30	Walking at a self-selected speed	• Rocker-soled shoes • Non–rocker-soled shoes • Barefoot	• Photoelectric timing gates • VICON motion capture system • AMTI strain gauge force plates	• Gait characteristics: Speed↔ • Dynamics: Peak adduction moment of the knee↓↓ (Rocker-soled shoes vs. Barefoot) ↑↑ (Rocker-soled shoes vs. Non-rocker-soled shoes) ↑↑ (Non-rocker-soled shoes vs. Barefoot), Peak adduction impulse of the knee↓↓ (Rocker-soled shoes vs. Barefoot) ↑↑ (Non-rocker-soled shoes vs. Barefoot), Knee flexion moment↔ (Rocker-soled shoes vs. Non-rocker-soled shoes vs. Barefoot)
Paterson 2017 (K. L. Paterson et al., 2017)	Elderly with knee osteoarthritis	28	Walking at a self-selected speed	• Flat flexible shoes • Stable supportive shoes • Barefoot	• VICON motion capture system • AMTI strain gauge force plates	• Gait characteristics: Speed↔ • Dynamics: Peak adduction moment of the knee↓↓ (Flat flexible shoes vs. Barefoot) ↑↑ (Flat flexible shoes vs. Stable supportive shoes) ↑↑ (Stable supportive shoes vs. Barefoot), Peak adduction impulse of the knee↓↓ (Flat flexible shoes vs. Barefoot) ↑↑ (Stable supportive shoes vs. Barefoot), Knee flexion moment↔ (Flat flexible shoes vs. Stable supportive shoes vs. Barefoot)
Petersen 2020 (Petersen et al., 2020)	Elderly with knee osteoarthritis	33	Walking at a self-selected speed	• Minimalist shoes • Barefoot	• MTW2 wireless inertial sensors	• Gait characteristics: Variance in step length↓↓, Variance in minimum toe distance↓, Variance in gait cycle time↔ • Kinematics: Stabilities of kinematic parameters↓
van Tunen 2018 (van Tunen et al., 2018)	Healthy elderly	21	Walking at a self-selected speed	• Knee unloading shoes • Conventional shoes	• Photoelectric timing gates • The in-shoeoe plantar pressure measurement system	• Gait characteristics: Speed↔ • Dynamics: Peak pressure in the lateral heel↑↑, Peak pressure in lateral forefoot↑↑, Peak pressure in medial heel and medial forefoot↓, Ratio of pressure in the lateral and median heel↓↓, Displacement of pressure center in frontal axis↑↑, Displacement of pressure center in sagittal axis↑

↑: increase significantly (p<0.05); ↑↑: increase very significantly (p <0.001); ↓: decrease significantly (p <0.05); ↓↓: decrease very significantly (p <0.001); ↔: unchanged or insignificantly changed (p >0.05).

Study Quality Assessment

The results of the study quality assessment were provided in Table 2. According to Table 2, all the included studies defined the source of information, listed inclusion and exclusion criteria for exposed and unexposed participants, described any assessments undertaken for quality assurance purposes as well as how confounding was assessed and/or controlled, and explain any patient exclusions from analysis and how missing data were handled in the analysis. However, no included studies indicated whether the participants were consecutive, summarized the response rates and completeness of data collection, or clarified what follow-up was expected and the percentage of participants for which incomplete data or follow-up was obtained.

Table 2 - The Agency for Healthcare Research and Quality (AHRQ) Cross-Sectional/Prevalence Study Quality Assessment Checklist

Items		Bucheck 2013 (Buchecker et al., 2013)	Hollander 2021 (Hollander et al., 2021)	Hurst 2017 (Hurst et al., 2017)	Jordan 2019 (Jordan et al., 2019)	Kerrigan 2005 (Kerrigan et al., 2005)	Madden 2015 (Madden et al., 2015)	Paterson 2017 (K. L. Paterson et al., 2017)	Petersen 2020 (Petersen et al., 2020)	Van Tunen 2018 (van Tunen et al., 2018)
1.	Define the source of information (survey, record review)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2.	List inclusion and exclusion criteria for exposed and unexposed subjects (cases and controls) or refer to previous publications	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3.	Indicate the period used for identifying patients	No	No	No	No	No	No	No	No	Yes
4.	Indicate whether or not subjects were consecutive if not population-based	No	No	No	No	No	No	No	No	No
5.	Indicate if evaluators of subjective components of the study were masked to other aspects of the status of the participants	Unclear	Unclear	No	Unclear	Unclear	Unclear	Yes	Unclear	Unclear
6.	Describe any assessments undertaken for quality assurance purposes (e.g., test/retest of primary outcome measurements)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
7.	Explain any patient exclusions from the analysis	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
8.	Describe how confounding was assessed and/or controlled	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
9.	If applicable, explain how missing data were handled in the analysis	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
10.	Summarize patient response rates and completeness of data collection	No	No	No	No	No	No	No	No	No

11.	Clarify what follow-up, if any, was expected and the percentage of patients for which incomplete data or follow-up was obtained	No	No	No	No	No	No	No	No	No

Discussion

Gait Characteristics (Time and space parameters)

According to the results of included studies, it could be inferred that walking with a different type of footwear will not change the gait time and space parameters of elder individuals, but the gait characteristics of walking with footwear were significantly different from those of walking with barefoot.

Only a few studies reported a significant difference between walking with different footwear. However, when compared with walking barefoot, wearing footwear could change the gait characteristics of elder individuals significantly. Considering the strong correlation between stride frequency and speed (Lindemann et al., 2021), the pooled evidence of the included studies showed that the stride frequency would keep unchanged when walking with unstable shoes (Rocker-soled shoes) or stable shoes (Non–rocker-soled shoes) (Buchecker et al., 2013). However, a study by Jordan's team published in 2019, which was a randomized cross-over design, demonstrated that, for the elderly with claudication, there was no difference in stride frequency between unpainful walking with rocker-soled shoes and non-rocker-soled shoes. But if the elderly had claudication because of plantar pain, the stride frequency would decrease significantly when walking with rocker-soled shoes (Jordan et al., 2019). This phenomenon indicated that the type of footwear might not affect the stride frequency of healthy elderly.

The speed of walking could represent the individual's coordination, strength, balance, and cardiovascular function (Holowka et al., 2019). Previous studies have demonstrated that the speed of walking and age are negatively correlated. After the age of 60, the comfortable walking speed decreases year by year, which negatively affects the quality of life and increases the fear of falling (Holowka et al., 2019). Therefore, elder individuals in unstable walking environments are inclined to adopt a relatively conservative gait pattern characterized by slower speeds and shorter step lengths, which are independent of the type of footwear (Buchecker et al., 2013; Jordan et al., 2019; Kerrigan et al., 2005; Madden et al., 2015; K. L. Paterson et al., 2017). Nevertheless, wearing footwear will increase the walking speed of elder individuals (Wang, Qiu, Chen, Chen, & Lv, 2019). A study by Hollander's team published in 2021 claimed that, when compared with walking barefoot, the speed of walking with footwear will increase significantly. This phenomenon correspondent with that in younger populations (Holowka et al., 2019). Therefore, it could be inferred that the decrease in speed when walking barefoot in the elderly might come from a more cautious gait pattern induced by the unfamiliarity with the barefoot condition.

Moreover, because the strong correlation between step length and walking speed, is similar to the results of walking speed, there was no difference in the step length between walking with different footwear (Jordan et al., 2019). However, previous studies have demonstrated that wearing footwear will also increase the step length of elder individuals. For example, in 2021, a study by Hollander's team identified that, when compared with walking barefoot, the step length of walking with cushion shoes was significantly larger (Hollander et al., 2021). The potential mechanism might be that the footwear increased the weight of lower extremities and then induced the "Enhanced Pendulum Effect". Besides, in 2020, a study conducted by Petersen's team found that the variance in step length in barefooted walking was bigger than that in walking with shoes. Moreover, Petersen's team also found that minimalist shoes might increase the stability of gait and decrease the risk of falls, cushion shoes might have a negative effect on elderly gait stability, whereas there was no positive effect on gait stability found during walking with walking shoes or slippers (Petersen et al., 2020).

When it comes to gait time parameters, this systematic review did not find any difference in the time length in the stance phase and swing phase within different footwear but found a significant increase in the variance of gait phases of walking barefoot than that of walking with footwear. This result is corresponding to that of Roca-Dols' study published in 2018, which claimed that there was no significant difference in the proportion of gait stance phase and swing phase between barefooted walking and wearing regular sneakers, minimalist shoes, slippers, and cushion shoes, and the potential mechanism might be related to the increased duration of heel contact time (Roca-Dols et al., 2018).

Lastly, for the gait space parameters, the result indicated that there might be no difference in step width within walking with different types of footwear for elder individuals. Previous studies have demonstrated that the variance in the minimum toe distance was related to the risk of falls in walking, the larger variance, the higher risk of falls (Barrett, Mills, & Begg, 2010). The result of this review showed that when being compared with barefooted walking, walking with cushion shoes would increase the variance in the minimum toe distance significantly, whereas walking with minimalist shoes could decrease the variance (Hollander et al., 2021; Petersen et al., 2020). Considering that the principle of minimalist shoe design is to make shoes restore bare feet as much as possible and provide as minimal protection as possible, it would be possible that walking with minimalist shoes could help to reduce the risk of falls for elder individuals, whereas cushion shoes could have the opposite effect.

Gait Kinematics

The included studies reported a significant decrease in hip, knee, and ankle mobility when walking with rocker-soled shoes. The decrease in joint mobilities means a lower activation of lower limb muscles and a lower level of physical fatigue in walking for elder individuals. However, the decrease in joint mobility will also induce a smaller minimum toe distance, which indicates a higher risk of falls during walking. Therefore, it should be cautious to select rocker-soled shoes for the elderly. Nevertheless, the evidence of previous studies has some contradiction. For example, a study by Jordan's team published in 2019 identified a decrease in hip mobility during walking with rocker-soled shoes but did not find any difference in the peak angle of hip flexion (Jordan et al., 2019). But a study by Buchecker's team published in 2013 claimed that walking with rocker-soled shoes would decrease hip mobility and peak flexion angle (Buchecker et al., 2013). The heterogeneity might come from the different assessment speeds and the population difference, waiting for identification by further studies.

Most of the included studies reported a difference in the kinematics of knee joints when walking with different footwear. According to the latest scientific research viewpoint, the changes in gait kinematic characteristics that occur with aging are mainly due to changes in the kinematics of hip and knee joints (Dewolf et al., 2022). Anatomically, the knee joint has a joint capsule, while the hip joint has a special bicondylar structure. Thus, differences in anatomy result in differences in biomechanical mechanisms (Zhou et al., 2021). This hypothesis has been supported by some previous studies. For example, some previous studies identified a decrease in the motion range of the knee when walking with rocker-soled shoes, especially the range of knee flexion. There might be two potential biomechanical mechanisms inducing this result. One is the decrease in the force of push-off, while the other might be the special design of rocker-soled shoes such as the "swing effect" in forefoot regions and the arch-shape heels (Buchecker et al., 2013; Jordan et al., 2019; Kerrigan et al., 2005). At the same time, in the swing phase of gait, a reduction in knee flexion angle is often accompanied by a reduction in minimum toe distance. Therefore, the design of footwear for the elderly should consider stabilizing the knee flexion angle during the swing phase of walking gait to maintain enough minimum toe distance for decreasing the risk of falls.

When it comes to the ankle joints. Included studies reported a decrease in the mobility of ankle plantarflexion and dorsiflexion during the middle of the stance phase. The potential mechanism might be the "windlass effect" of plantar, in which the extension of inner-plantar muscles limits the extension of triceps surae (Buchecker et al., 2013). This mechanism has been identified by a study published in 2019, which claimed that, during the push-off, the instability makes the dorsiflexion of the ankle joint increase passively, making the peak angle of ankle plantarflexion larger but the overall range of motion smaller (Jordan et al., 2019).

Kinematically, the stability, and disturbance of gait correlate with the risk of falls (Bruijn et al., 2013). The results of included studies reported that when compared with barefooted walking, walking with cushion shoes will not change the gait stability while walking with minimalist shoes will increase the gait stability. This phenomenon means that the positive acute effect of footwear on gait stability could compensate for the disturbance during walking for elder individuals.

Gait Dynamics

Only 2 included studies reported the change in the position of the plantar pressure center. A study published in 2021 compared the average migration velocity of the plantar pressure center when walking barefooted with walking in the footwear of different heel heights, finding that there was no significant difference in the average migration velocity of the plantar pressure center within these conditions neither any significant difference of gait dynamic parameters (Lindemann et al., 2021). Therefore, it could be indicated that the dynamic balance of elderly walking gait will not change when the heel height of their footwear is lower than a specific threshold. In 2018, a study conducted by van Tunen's team demonstrated that walking with cushion shoes will increase the lateral migration of the plantar pressure center, claiming that walking with cushion shoes could change the distribution of plantar pressure towards lateral plantar areas and then reduce the mechanical load of knee joints (van Tunen et al., 2018).

For the joint moment in lower limbs, the results of included studies showed that, when walking with rocker-soled shoes, the ankle joint moment of elder individuals will significantly decrease. The reasons might come to be that the special design of the rocker-soled shoes decreases the motion range of ankle plantarflexion and dorsiflexion during the gait stance phase and then limits the eccentric contraction of triceps surae as well as the force of push-off (Buchecker et al., 2013). Moreover, for maintaining stability and propulsion during walking, the dynamic of knee joints will change to compensate for the deficit of push-off moment. First, the peak moment in the knee and ankle increase when the heel height of shoes rises (Kerrigan et al., 2005). Second, the peak adductive moment in the knee will be lower when walking in flat shoes than when walking in stable shoes, indicating that walking in flat shoes can significantly reduce the mechanical load on the knee (K. L. Paterson et al., 2017). Additionally, an 8% reduction in peak knee flexion moment and a 22% reduction in peak knee extension moment when walking in rocker-soled shoes indicate a reduction in overall knee net moment when walking, especially for elder individuals. It can be inferred that the underlying mechanism of the results may be due to the different designs of the sole changing the joint mechanical loading pattern of the anterior knee. Considering that the peak knee adduction moment is positively correlated with the medial mechanical load of the knee but is not the only contributor to the medial mechanical load of the knee. Meanwhile, previous studies have shown that decreasing the peak knee adduction moment leads to an increase in knee flexion moment. Therefore, it can be inferred that walking in rocker-soled footwear may reduce contact stress on the medial side of the knee joint (Kade L Paterson et al., 2021). However, this inference is controversial, as some previous studies have found that while the peak knee adduction moment is lower when walking in rocker-soled shoes than when walking in flat shoes, the knee flexion moment will not significantly change (Chen, Yeh, Chen, Chuang, & Lin, 2022; Lin, Su, Chung, Hsia, & Chang, 2017a, 2017b). The heterogeneities within studies might be the different materials and designs of these shoes that make the sole density and shape radian various.

The results of hip joint dynamics showed that the peak hip flexion moment decreased with the extension of the hip joint in the early stance stage of walking gait in the elderly when wearing rocker-soled shoes, and the net power of extension in the lower limbs on the support side decreased by about 10%. The results indicated that walking in rocker-soled shoes has less demand on the mechanical work output of the musculoskeletal system. Previous studies have shown that the decrease in ankle mobility can lead to compensation in hip joints, which in turn increased hip stress and the risk of pain in the hip. Therefore, it indicated that walking in rocker-soled shoes will reduce the peak moment and net power output of the hip during the early and later stance phases of gait, and might reduce the pain caused by compensatory in the hip joint and the pain caused by osteoarthritis (Buchecker et al., 2013).

At last, the data on plantar pressure distribution showed that in elderly with subjective discomfort during walking, the proportion of plantar pressure in the forefoot area is often higher. Clinically, previous studies reported that the use of medically tailored orthotic shoes can significantly improve walking comfort in the elderly by reducing plantar pressure in specific areas of the foot, especially the medial and lateral foot, where plantar pain is most commonly reported. (Buchecker et al., 2013). However, some clinical studies on elderly with knee arthritis have found that the incidence of adverse stress response in foot and ankle joints increases when walking with shock cushion shoes, whose potential mechanism might be related to the increased proportion of plantar pressure distribution in the lateral heel and forefoot when walking with cushion shoes, leading to an increase in lower limb joints stress (van Tunen et al., 2018).

Limitations

The primary limitation of this systematic review is that there are not enough studies with high quality included. And another limitation of this review is the difference in the population of the included studies will induce extra heterogeneity within studies, creating a larger risk of bias. Moreover, although some footwear is classified into the same category, the details in the design of this footwear are still different, which could create potential heterogeneities within intervention protocols.

Conclusion

To sum up, for elder individuals, walking with minimalist shoes might be beneficial to gait stability. It should be cautious to select rocker-soled shoes for the elderly, since wearing rocker-soled shoes might have a positive effect on relieving joint pain, and reducing physical fatigue during walking, but also might increase the risk of falls. Lastly, the elderly should avoid wearing cushion shoes, and shoes with special functional might not be suitable for the elderly with knee arthritis.

Acknowledgements

Many people have offered the authors valuable help in this systematic review. Xin Li acted as the third review to check the studies searching, screening, and data collection. Yining Xu acted as the independent arbitrator when disagreement occurred in the process of study quality assessment.

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