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Review

Barefoot vs common footwear: A systematic review of the kinematic, kinetic and muscle activity differences during walking

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ABSTRACT

Habitual footwear use has been reported to influence foot structure with an acute exposure being shown to alter foot position and mechanics. The foot is highly specialised thus these changes in structure/position could influence functionality. This review aims to investigate the effect of footwear on gait, specifically focussing on studies that have assessed kinematics, kinetics and muscle activity between walking barefoot and in common footwear. In line with PRISMA and published guidelines, a literature search was completed across six databases comprising Medline, EMBASE, Scopus, AMED, Cochrane Library and Web of Science. Fifteen of 466 articles met the predetermined inclusion criteria and were included in the review. All articles were assessed for methodological quality using a modified assessment tool based on the STROBE statement for reporting observational studies and the CASP appraisal tool. Walking barefoot enables increased forefoot spreading under load and habitual barefoot walkers have anatomically wider feet. Spatial-temporal differences including, reduced step/stride length and increased cadence, are observed when barefoot. Flatter foot placement, increased knee flexion and a reduced peak vertical ground reaction force at initial contact are also reported. Habitual barefoot walkers exhibit lower peak plantar pressures and pressure impulses, whereas peak plantar pressures are increased in the habitually shod wearer walking barefoot. Footwear particularly affects the kinematics and kinetics of gait acutely and chronically. Little research has been completed in older age populations (50+ years) and thus further research is required to better understand the effect of footwear on walking across the lifespan.

1. Introduction

Humans are one of the few species who have mastered bipedal locomotion and their foot has evolved to be the basis for such a specialised gait. The human foot alone comprises 26 bones, 33 joints and 19 muscles [1]. The bones are arranged to form a medial longitudinal arch which makes it ideal for its function of supporting the weight of the body and spreading the forces experienced during gait [2]. Aside from the structure of the bones there is a complex array of muscles, both internal and external of the foot, which combine with the somesthetic system to control balance and movement [3]. Kennedy et al. [4] reported the presence of 104 cutaneous mechanoreceptors located in the foot sole. Furthermore receptor distribution was primarily where the foot is in contact with the ground, and when the foot was unloaded no background activity was found. In addition there are more fast adapting units than slow suggesting a high dynamic sensitivity [4]. Collectively these factors evidence the role of the human foot in balance and movement control but what is less clear is the impact of wearing shoes on the human foot and whether this may influence movement control and associated variables during walking gait.

Anthropological evidence suggests that footwear began to be worn approximately 40,000 years ago [5]. This is hypothesised based on the observations of a reduction in toe length at this time indicating a reduction in reliance on and loading of the lesser toes during locomotion [6]. Furthermore as footwear has evolved from simple open-toe sandals to more complex items of fashion, with their design being increasingly dependent on aesthetics, the potential impact on foot function has been overlooked. Pointed toe and closed toe shoes have become increasingly prominent in Western societies and the restriction of area within the toe box potentially contributes to, now deemed common, toe deformities such as hallux valgus, a valgus deformity on the first metatarso-phalangeal joint [7]. This is particularly a problem in advanced age with the over two thirds of the older population's feet being

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considerably wider than the footwear available [8]. Additionally research has reported that wearing high heels of 5 cm or higher over a minimum of a two-year period has significant effects to the muscle-tendon unit at the ankle [9,10]. Csapo and colleagues [9] found a significant reduction in the gastrocnemius medialis fascicle lengths and significantly greater Achilles' tendon stiffness in the high heels group, resulting in a more plantar flexed ankle position at rest and a reduced active range of motion. This demonstrates the modifiable nature of the foot-ankle complex and the importance of wearing appropriate footwear to maintain good foot health and function.

Research has also shown how certain footwear can directly influence function. A common feature of modern athletic footwear is that of increased sole thickness which is marketed as providing cushioning against harmful impacts. Recent research has demonstrated that wearing this type footwear evokes significantly increased activation in the Peroneus Longus suggesting greater interference to ankle stability [11]. Moreover, footwear has been shown to hinder the kinesthesia [12], with greater awareness of foot position observed in volunteers standing barefoot compared with wearing athletic footwear. Whilst these studies are limited to investigation in standing, the findings suggest the possibility that footwear could be interfering with the functional ability of the human foot and if this corresponds to changes in gait.

The aim of this review is to systematically review the research investigating kinematic, kinetic and muscle activity variables during walking barefoot and in normal footwear to help improve our understanding of how footwear influences gait pattern.

2. Methods

2.1. Study design and search strategy

Reporting in line with PRISMA guidelines (www.prisma-statement.org) and through consultation with subject specific and systematic review experts the literature review methodology was developed. The literature search was performed across a variety of databases (Medline, EMBASE, Web of Science, Cochrane Library, SCOPUS and AMED) encompassing publications within the years of 1980-January 2014. The search strategy employed across the electronic databases is presented below:

1. barefoot
2. walk*
3. exp Gait/
4. exp Locomotion
5. kinematic*
6. kinetic*
7. exp Electromyography
8. EMG
9. muscle activ*
10. 7 or 8 or 9
11. 5 or 6 or 10
12. 2 or 3 or 4
13. 1 and 12
14. 11 and 13

2.2. Study selection

One reviewer (SF), who had received training on database searching, completed all searches which were independently checked by a second author (LB). Differences of opinion were resolved through discussion or a third author. Citation checking and search of grey literature, including key conference proceedings within the last 3 years was also undertaken. Authors were subsequently contacted to determine if any relevant proceedings had since reached publication.

Inclusion criteria were determined a priori. Studies were required to assess gait characteristics between footwear in terms of spatial-temporal variables, kinematics, kinetics, and muscle activity and behaviour. Participants were to be healthy and able to ambulate independently such that their gait pattern was considered normal and would not influence comparisons between footwear conditions. They could be of any age group and either gender to observe any differences throughout age and include data from both males and females to draw comparisons from if possible. Overground walking and treadmill walking were both deemed acceptable in order to access all studies analysing barefoot walking gait characteristics. Studies of observational cross-sectional design were included to allow for review of the comparison between footwear conditions wear inclusive of socks, open-toe footwear such as sandals or flip-flops and slippers. Observational comparative studies were deemed suitable if they were comparing between habitually barefoot, who have grown up and continue to live without wearing shoes, and habitually shod, who wear shoes on a day-to-day basis, populations to determine changes which occur over long term use with or without shoes. Case-control studies were also included providing the control group fitted the participant criteria and data was available for conclusions to be drawn solely from this group with regard to footwear intervention. If both groups fitted the participant criteria, then providing that data was available these were included and comparisons were focussed on the separate group's response to the footwear intervention rather than the comparisons between groups.

Studies were excluded if the footwear included any interventions aside from the features included in the original footwear design such as separate insoles or orthotics. Any studies involving participants who required a walking aid to ambulate were also excluded along with participants who had a known previous or current gait disorder or condition that could influence their gait (unless the study also consists of a control group through which analysis can be drawn from). Studies were excluded if they used running, unless a walking test was also completed from which analysis could be solely focussed. Literature other than peer-reviewed journal articles and comparative studies were excluded from the review.

2.3. Data collection and items

Using a standardised form the lead reviewer independently extracted the data. Study characteristics included repeated measures designs between various footwear conditions and between subject comparisons in terms of habitual barefoot and habitual shod users. Included outcomes were any measures which assessed spatial-temporal, kinematic, kinetic or muscle activity/behaviour variables.

2.4. Risk of bias across studies

To assess the methodological quality a bespoke critical appraisal tool was developed based upon the STROBE Checklist [3] for reporting observational studies and the CASP appraisal tool [1]. All articles were assessed on these questions which determine if all the required steps for successful scientific reporting were taken and if the relevant information is presented clearly in the scientific paper. A score of 1 was given for each question if the article satisfied the question and a 0 given if it failed to do so. A total score out of 20 was then given for each paper. The quality assessment of the selected studies was carried out by one reviewer (SF) and then repeated independently by a second author (LB). Any issues were discussed to achieve consensus of opinion.