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Review

Impact attenuation during weight bearing activities in barefoot vs. shod conditions: A systematic review

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ABSTRACT

Although it could be perceived that there is extensive research on the impact attenuation characteristics of shoes, the approach and findings of researchers in this area are varied. This review aimed to clarify the effect of shoes on impact attenuation to the foot and lower leg and was limited to those studies that compared the shoe condition(s) with barefoot. A systematic search of the literature yielded 26 studies that investigated vertical ground reaction force, axial tibial acceleration, loading rate and local plantar pressures. Meta-analyses of the effect of shoes on each variable during walking and running were performed using the inverse variance technique. Variables were collected at their peak or at the impact transient, but when grouped together as previous comparisons have done, shoes reduced local plantar pressure and tibial acceleration, but did not affect vertical force or loading rate for walking. During running, shoes reduced tibial acceleration but did not affect loading rate or vertical force. Further meta-analyses were performed, isolating shoe type and when the measurements were collected. Athletic shoes reduced peak vertical force during walking, but increased vertical force at the impact transient and no change occurred for the other variables. During running, athletic shoes reduced loading rate but did not affect vertical force. The range of variables examined and variety of measurements used appears to be a reason for the discrepancies across the literature. The impact attenuating effect of shoes has potentially both adverse and beneficial effects depending on the variable and activity under investigation.

1. Introduction

With the large amount of research into shoe design, particularly athletic shoes, it could be expected that a substantial body of scientific evidence would be available regarding impact attenuation of shoes compared to barefoot. Weight-bearing activities have a risk of injury to the lower limb through repetitive impact and inadequate recovery [1]. There is an assumption that shoes can provide impact attenuation for the body, protecting the lower limb from repetitive loading during running and jumping through altering the vertical ground reaction force [2] and rate of loading to which the lower limb is exposed [3]. Indeed it has previously been stated that the primary objective of running shoes is to reduce the initial vertical ground reaction force impact transient [4], however the benefit of repetitive loading on the lower limbs for increasing bone mass cannot be ignored [5–7]. Despite systematic reviews being regarded as the highest level of evidence [8], a systematic review of the effect of shoes on impact attenuation has not previously been undertaken.

The concept that shoes reduce impact force has been implied in shoe advertising, but in the past decade there has been much debate on whether weight-bearing activities should be performed barefoot or shod. A recent trend has seen the appearance of minimalist footwear designs with thinner, flexible shoe soles for the everyday and competitive runner [9]. Altering the shoe design appears to alter shock attenuation, however there have been mixed results across the field.

Common variables used in the literature investigating impact attenuation are vertical ground reaction force, loading rate (rate of loading of vertical force over time), axial tibial acceleration (acceleration along the axis aligned through the shank) and plantar pressures, across the literature the nomenclature for the variables

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varies, therefore our definitions will be used in this review to provide consistency. Vertical ground reaction force can be collected at the impact transient or the peak value out of the whole stance phase can be used for analysis. The impact transient can be identified by 'the first vertical impact force peak' [10] which results from 'passive' [11] impact.

The standard method to measure the shock absorbing qualities of footwear is to mechanically compress the shoe at the rearfoot and forefoot sections using a durometer [12]. The shoe can be given a rating of hardness and resistance to compression using an appropriate hardness scale, most commonly the Shore A (used for normal rubber) or the Asker C (used for soft rubber and insoles of differing materials scales) with higher scores given to harder and more highly compression resistant footwear [13]. However, this fails to consider the human interaction with footwear. The studies by Robbins and colleagues examined the technique of landing on shoe midsole materials of different hardness properties [14,15]. When landing on unfamiliar or uneven surfaces the body will be cautious on the first exposure then adjusts accordingly on subsequent occasions [14–18]. The body can prepare the lower limbs for impact, adjusting joint stiffness in relation to the perceived hardness of the landing surface [14,15,19], but when wearing shoes plantar sensory feedback [18,20] and proprioception [21] are limited.

The vertical impact transient [22], which occurs just after initial ground contact, is claimed to be the crucial component of the gait cycle [3] as it has an association with repetitive strain injuries in the lower leg [23]. However, Shorten et al. [24] have suggested that previous studies, investigating force attenuation in shoes, are not explaining the differences in vertical ground reaction force adequately. Frequency analysis reveals footwear only contributes a small amount to the impact force at heel strike and load components from more proximal segments could influence the reduction in vertical ground reaction force [24]. While shoes are only one potential factor that could contribute to injury, shoes have the ability to modify biomechanical variables that may assist with reducing injury rates.

Although a previous systematic review found no studies investigating the effect of shoes on injury risk [25] due to strict inclusion criteria, studies have found an association between loading rate [26,27] and anterior tibial acceleration [28] and the development of musculoskeletal injuries. Proper footwear [29] and impact attenuating boot inserts [30] have been shown to prevent stress fractures through added force attenuation to protect the feet from impact forces. Also, changing footwear was found to be the greatest predictor of foot pain reduction [31]. Repetitive impact force and high loading rates are risk factors for stress fractures particularly if inadequate rest is given between bouts to allow for bone and soft tissue remodelling [32]. However, there is no scientific evidence to demonstrate a direct causal link between impact force and injury, also it is important not to disregard the beneficial properties of weight bearing activity and how repetitive impacts can improve bone mineral density [5–7] as long as dose and frequency are appropriate.

Many studies have examined shoes and their various effects, but in order to understand the absolute effect of shoes a comparison must be made with the barefoot condition. A systematic review of the current literature is needed to dispel the confusion surrounding the 'barefoot vs. shod' debate and discern the true impact attenuation characteristics of shoes compared to the barefoot condition during any weight bearing activity including walking, running and jumping. This review aims to clarify the effect of shoes on the most commonly used variables believed to be associated with impact attenuation to the foot and lower leg. Much of the literature is based on impact attenuation theory with the assumption that more compliant shoes will reduce vertical ground reaction force and delay the time at which the force peak occurs [24]. Hence, impact attenuation will be defined as the capacity to reduce the magnitude of vertical ground reaction force, loading rate, axial tibial acceleration and/or local peak plantar pressures.

2. Methods

2.1. Search strategy

A search for the literature was performed in the following databases: Cinahl (1982–September 2011), Cochrane Library (all years), Medline (1950–September 2011), PubMed (all years–September 2011), Scopus (all years–September 2011), SportDiscus (all years–September 2011), Embase (all years–September 2011), Eric (1966–September 2011), Web of Science (1899–September 2011), Ausport (all years–September 2011), AMED (all years–September 2011) and Google Scholar (all years–September 2011). There were no language restrictions. Search terms were: *[shock or impact or force or pressure] AND [(shoe* or shod or foot or feet or footwear or boot) AND (barefoot)]* OR *[viscoelastic or insert]*. The reference lists of the studies accepted for review were hand searched for any studies that were not picked up by the database search (Fig. 1). Leading authors in the field were contacted for any unpublished data to reduce publication bias [33].

Inclusion and exclusion criteria for the studies were determined a priori. Studies were included if the study was the full text version and compared shod conditions (whole shoe) with barefoot in healthy adults. Only studies examining a whole shoe, rather than shoe materials in the form of a mat were included because the lack of constraining heel cup and shoe upper could influence the results [34–38]. Case control, cohort and cross sectional studies were included while prospective studies and randomised controlled trials were included only if baseline data was provided. Only studies examining effects below the knee were included and the studies must have examined the effect of footwear or shoes on impact attenuation at the lower leg/shank, ankle and/or foot during dynamic weight bearing movement or activity. This encompasses attenuation of vertical ground reaction force, plantar pressures, loading rate or axial tibial acceleration.

Studies were excluded from review if they were: systematic reviews, reviews of the literature, did not clearly state the type of footwear used, did not examine footwear or the role of footwear in impact attenuation, or examined diseased or disabled populations (unless comparisons were made with non-diseased or disabled populations). Two independent reviewers eliminated the studies, first by title, then abstract, and finally the full text.

Data extraction was performed by the primary investigator and verified by a second investigator. Study authors were contacted for additional information, when required. The data extracted were the sample size and characteristics, the shoe conditions [39], activity performed during data collection and findings.

A modified version of the Quality Index was used to assess the scientific quality of the included studies [40]. This validated and reliable tool, designed to evaluate both randomised and non-randomised studies for health care intervention, was selected due to the lack of an equivalent tool to evaluate biomechanical studies. For the purposes of this review the shoe condition was considered the 'health intervention'. Of the 27 criteria, 14 applied to biomechanical investigations (Table 2) for a total score out of 14. Study quality was assessed by the primary investigator and corroborated by a second investigator; a third investigator resolved any differences.

Meta-analysis was undertaken for the effect of shoes on outcome variables during walking and running in Review Manager 5.0 (The Cochrane Collaboration, Copenhagen, Denmark). Sub-group analysis was performed for outcome variables with a