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Review article

Work boot design affects the way workers walk: A systematic review of the literature

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ABSTRACT

Safety boots are compulsory in many occupations to protect the feet of workers from undesirable external stimuli, particularly in harsh work environments. The unique environmental conditions and varying tasks performed in different occupations necessitate a variety of boot designs to match each worker's occupational safety and functional requirements. Unfortunately, safety boots are often designed more for occupational safety at the expense of functionality and comfort. In fact, there is a paucity of published research investigating the influence that specific variations in work boot design have on fundamental tasks common to many occupations, such as walking. This literature review aimed to collate and examine what is currently known about the influence of boot design on walking in order to identify gaps in the literature and develop evidence-based recommendations upon which to design future research studies investigating work boot design.

Contents

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1. Introduction

Safety boots provide an interface between the foot and the ground, protecting the foot from undesirable external stimuli, particularly in harsh work environments. Occupational environments and the tasks performed by workers vary widely among different industries, necessitating a variety of work boot designs to match unique workplace safety requirements. There is a reoccurring issue, however, as occupational footwear appears to be designed more for occupational safety at the expense of functionality and comfort.

Standards exist specifying the design, construction and classification of safety boots (e.g. Australian/New Zealand Standard, 2010). The design features focus on reducing injuries to the feet resulting from contact with objects, objects piercing the sole or upper, friction or pressure blistering, hazardous material contact and slipping (Australian/New Zealand Standard, 2010). Hence, some of the primary design features that differ among work boot styles include the materials from which boots are made, the need for waterproofing, the height of the shaft, whether a steel safety cap and/or closures are required and the stiffness and design of the sole (see Figs. 1 and 2). Even within a single occupation, such as the military, boots are often task and environment specific (e.g. a combat boot versus a jungle boot; Hamill and Bensel, 1996). Despite numerous design variations among work boots, there is a paucity of published research systematically investigating the influence these variations have on even fundamental tasks common to most occupations, such as walking.

Walking often constitutes a large component of the day-to-day activity in occupations that require safety work boots (Marr, 1999; Smith et al., 1999; Dobson et al., 2017). In such occupations it is imperative that an individual's work boots meet the demands placed on their lower limb while walking and when performing other working tasks. Otherwise, the risk of these workers incurring a lower limb injury is increased, whether it is an acute injury, such as a sprain/strain due to slipping/tripping, or a chronic injury, such as overuse due to prolonged walking (Böhm and Hösl, 2010; Smith et al., 1999; Hamill and Bensel, 1996; Marr, 1999; Marr and Quine, 1993). Lower limb injuries are prevalent in occupations that involve prolonged walking (WorkCover, 2010). In underground coal mining, an industry where workers spend an average of 8 h walking per shift (Dobson et al., 2017), 700 serious lower limb injuries were reported annually. Of these serious lower limb injuries, ankle injuries alone contributed to a median workers compensation cost of $5800 and 4.4 weeks off work (Safe Work Australia 2016, personal communication, 5 September).

It has been postulated that abnormal loading of the lower limb at the shoe-to-surface interface while walking can partly contribute to this high incidence of lower limb injuries (Böhm and Hösl, 2010; Hamill and Bensel, 1996). Boot design can alter the way the foot moves while walking, affecting the way the ground reaction forces are distributed throughout the lower limb (Redfern et al., 2001). If the lower limb is forced to move in a way that opposes its natural structural alignment, excess strain can be placed on the supporting anatomical structures, such as the ligaments, tendons and muscles, to maintain equilibrium (Böhm and Hösl, 2010; Hamill and Bensel, 1996; Neely, 1998). For example, when normal ankle range of motion is restricted, the knee is forced to compensate for loads that the ankle is unable to absorb, increasing the risk of sustaining knee strain injuries (Böhm and Hösl, 2010). Indeed, decreased eccentric loading at the ankle joint but increased eccentric loading at the knee joint was displayed when 15 healthy young men (mean age = 29 ± 5 years) walked over a coarse gravel surface while wearing a hiking boot that restricted their ankle range of motion (Böhm and Hösl, 2010). Even with this increased lower limb injury risk associated with changes to joint motion and loading caused by footwear, very little systematic research has investigated the effects of work boot design on lower limb motion or loading during walking.

Traditionally, studies that examined the effects of work boot design during walking predominantly focused on the boot-surface frictional properties in an attempt to minimise slip-related injuries (Ramsay and Senneck, 1972). Slip-related injuries alone only account for approximately 14% of all labourer and related worker injury claims annually (WorkCover, 2010). It is therefore necessary to systematically investigate other aspects of boot design in order to determine how they affect the way workers walk in their occupational environment and, in turn, the risk of lower limb injuries that are not slip-related.

Interactions among the supporting surface, shoe and human body create a three-part system whereby changes in footwear can influence walking (Frederick, 1986). Substantial research exists documenting how different non-work related footwear types influence biomechanical variables that characterise walking, such as kinematics (joint ranges of motion, segmental alignment and temporal-spatial patterns), kinetics (ground reaction forces, joint moments and plantar pressure distributions) and electromyography (muscle activity patterns). For example, numerous studies have identified differences in variables characterising walking between shod and barefoot conditions (Bishop et al., 2006; Bonacci et al., 2013; Shakoor and Block, 2006), shoes of varying sole hardness/texture (Demura and Demura, 2012; Hardin et al., 2004; Kersting et al., 2005; Nigg et al., 2003; Nurse et al., 2005; Wakeling et al., 2002), differences between standard and athletic shoes (Bourgit et al., 2008; Kong et al., 2009; Lee et al., 2011) and unstable footwear (Myers et al., 2006; Nigg et al., 2006; Scott et al., 2012). However, research quantifying how work boot design influences walking biomechanics is much more spare and lacking conclusive results. Hence, the purpose of this review article is to collate and examine the existing literature related to how boot design characteristics can influence walking. The results of this review will allow us to identify gaps in the literature and to provide evidence-based recommendations upon which to design future research studies investigating work boot design.