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Effect of work boot type on work footwear habits, lower limb pain and perceptions of work boot fit and comfort in underground coal miners

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Abstract

Lower limb injuries are highly prevalent in underground coal mining. Wearing gumboots with inadequate ankle support was thought to contribute to these injuries. Despite the uptake of leather lace-up boots, which provide more ankle support, no recent research could be found investigating the effect of this alternative work boot in underground coal mining. Consequently, this study aimed to determine whether boot type (gumboot, leather lace-up boot) influenced work footwear habits, foot problems, lower limb pain, lower back pain, or perceptions of work boot fit and comfort in underground coal miners. Chi-squared tests were applied to 358 surveys completed by underground coal miners to determine whether responses differed significantly ($p < 0.05$) according to boot-type. There were no significant between-boot differences in regards to the presence of foot problems, lower limb pain or lower back pain. However, the types of foot problems and locations of foot pain differed according to boot type. Gumboot wearers were also more likely to state that their work boot comfort was either uncomfortable or indifferent, their work boot fit was poor and their current boot did not provide enough support. The introduction of more structured leather lace-up boots appears to have positively influenced the support and fit provided by mining work boots, although foot problems, lower limb pain and lower back pain continue to be reported. Further investigation is recommended to identify which specific boot design features caused these observed differences in work boot fit, comfort and locations of foot pain and how these design features can be manipulated to create an underground coal mining work boot that is comfortable and reduces the high incidence of foot problems and lower limb pain suffered by underground coal miners.

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Running Head: Underground Coal Mining Boots

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ABSTRACT

Lower limb injuries are highly prevalent in underground coal mining. Wearing gumboots with inadequate ankle support was thought to contribute to these injuries. Despite the uptake of leather lace-up boots, which provide more ankle support, no recent research could be found investigating the effect of this alternative work boot in underground coal mining. Consequently, this study aimed to determine whether boot type (gumboot, leather lace-up boot) influenced work footwear habits, foot problems, lower limb pain, lower back pain, or perceptions of work boot fit and comfort in underground coal miners. Chi-squared tests were applied to 358 surveys completed by underground coal miners to determine whether responses differed significantly ($p < 0.05$) according to boot-type. There were no significant between-boot differences in regards to the presence of foot problems, lower limb pain or lower back pain. However, the types of foot problems and locations of foot pain differed according to boot type. Gumboot wearers were also more likely to state that their work boot comfort was either 'uncomfortable' or 'indifferent', their work boot fit was 'poor' and their current boot did not provide enough support. The introduction of more structured leather lace-up boots appears to have positively influenced the support and fit provided by mining work boots, although foot problems, lower limb pain and lower back pain continue to be reported. Further investigation is recommended to identify which specific boot design features caused these observed differences in work boot fit, comfort and locations of foot pain and how these design features can be manipulated to create an underground coal mining work boot that is comfortable and reduces the high incidence of foot problems and lower limb pain suffered by underground coal miners.

Keywords:

Boots, mining, fit, comfort, pain

1. Introduction

During a typical 8 hour shift, underground coal miners spend most of their time standing and walking on challenging surfaces that are uneven, wet and unstable (Dobson et al. 2016; Marr, 1999). As a result, lower limb injuries are highly prevalent with sprains and strains accounting for over half of all WorkCover claims annually (WorkCover New South Wales, 2010). Of these sprain/strain related lower limb injuries, 49.2% occur at the knee and 36.5% occur at the ankle (Smith et al., 1999). An unstructured gumboot that lacked ankle support and allowed too much foot movement within the boot was thought to explain this high lower limb injury incidence in the coal mining industry (Marr, 1999; Smith et al., 1999). Indeed, a report to the Joint Coal Board Health and Safety Trust (Smith et al., 1999) revealed that almost 40% of miners who sustained lower limb injuries identified their mining work boots as the main contributing factor to these injuries.

Underground coal miners (n = 400, aged 20-70 years) who habitually wore gumboots reported excessive foot movement within their work boot and a lack of ankle support (Marr, 1999). Of the miners surveyed, 41% reported their feet slid within their work boot, 46% stated that their ankle did not feel stable and 35.5% felt unstable when walking on uneven ground. Marr (1999) suggested the inability of gumboots to stabilise the foot within the boot also contributed to the high incidence of calluses (48%) and lower back stiffness (34%) reported by coal miners. These findings are consistent with the results of a survey of 589 miners in which insufficient ankle support (63.5%) and inadequate boot fit (52.1%) were cited as the two main reasons miners thought their gumboots contributed to their lower limb injuries (Smith et al., 1999). Consequently, 71.4% of the miners wanted their work boots changed (Smith et al., 1999).

Based on this previous research (Smith et al., 1999; Marr 1999), leather lace-up boots were introduced as a work boot option for underground coal miners, providing them with an

alternative that delivered a tighter fit and more ankle support than gumboots. Due to variations in the materials that a gumboot and leather lace-up boot are made out of, they substantially differ structurally, particularly in regards to shaft stiffness (upper part of the boot; see Figure 1 and Table 1). It was hypothesised that introducing a mining work boot with a stiffer shaft that provided a tighter fit and more support around the ankle/shank would improve the miners' perceptions of comfort and stability while minimising lost time at work due to injury (including lower back, hip, knee, ankle and foot injury; Marr, 1999). Previous research has shown that increased proprioception acuity and trends towards more active ankle stiffness have resulted when circumferential ankle pressure was applied to the ankle, although this was applied using a blood pressure cuff and it is unknown whether a boot shaft pressing against the shank would yield the same result (You et al., 2004). Nevertheless, differences in boot shaft design have been shown to limit lower limb motion and, consequently, lower limb pain (Böhm & Hösl, 2010; Jefferson, 2013; Dobson et al., 2015). The literature, however, is inconclusive and it is unknown whether a tighter fit due to a stiffer shaft is in fact beneficial in regards to reducing lower limb pain occurrence.

Manipulation of shaft stiffness in hiking boots (Böhm and Hösl, 2010; Cikajlo and Matjacić, 2007), military boots (Hamill and Bensel, 1996), work boots (Simeonov et al., 2008), basketball boots (Robinson et al., 1986), ski boots (Noé et al., 2009) and snowboarding boots (Delorme, 2004) has been found to significantly alter ankle range of motion. That is, a more flexible shaft has been shown to increase ankle range of motion during walking and a stiffer shaft can reduce it. The amount of ankle range of motion allowed by a boot shaft appears crucial to both efficient walking biomechanics, as well as reducing lower limb injury occurrence. Although adequate ankle range of motion is vital to efficient gait, excessive ankle motion is problematic because it causes the joint to rely on secondary anatomical structures, such as the muscles and ligaments, for support (Böhm and

Hösl, 2010; Hamill and Bensel, 1996), increasing the risk of lower limb sprain/strain injuries (Neely, 1998). Conversely, there is relatively strong evidence suggesting that restricted ankle joint motion during walking can have negative implications for the more proximal joints of the lower limb, such as the knee or hip (Böhm and Hösl, 2010; Horak and Nashner, 1986). For example, a lace-up hiking boot, with 50% less passive shaft stiffness, decreased eccentric energy absorption at the ankle joint while simultaneously increasing eccentric energy absorption at the knee joint, indicating that when the ankle joint's ability to absorb the ground reaction force is impaired, the knee joint has to compensate (Böhm and Hösl, 2010). Therefore, although the leather lace-up boot with its stiffer shaft might positively impact the ankle by providing more support, it could potentially have negative implications for the knee and more proximal joints by restricting normal ankle motion and causing compensations further up the lower limb chain.

Despite the introduction of a leather lace-up boot for coal miners over a decade ago, no research could be found investigating whether this more fitted and supportive work boot affected their lower limb pain or their perceptions of fit and comfort. Given the gap in the current literature, the aim of this study was to determine whether boot type (gumboot versus leather lace-up boot) influenced self-reported work footwear habits, lower limb pain, lower back pain, or perceptions of fit and comfort in underground coal miners. It was hypothesised that miners who wore leather lace-up boots would report more ankle support, fewer foot problems, less pain, and improved comfort and fit ratings when compared to gumboot wearers. However, due to restricted ankle motion, leather lace-up boot wearers would report more knee and hip pain compared to gumboot wearers.

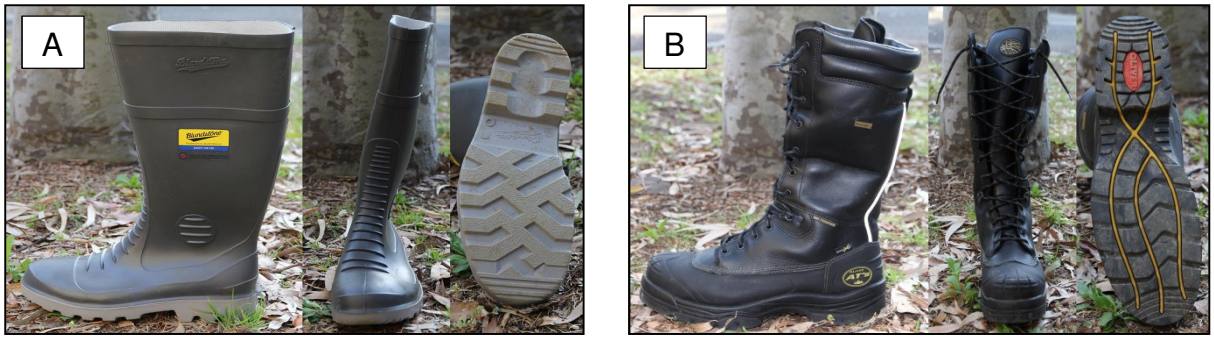

Figure 1: The two different underground coal mining work boots provided by Illawarra Coal (NSW, Australia) at the time of the study. A: Gumboot (Blundstone®, Australia) and B: Leather lace-up boot (Oliver, Australia).

Table 1: Characteristics of the gumboot (Style 015; Blundstone®, Australia) and leather lace-up boot (Style 65-691; Oliver, Australia).

Variable	Gumboot	Leather Lace-Up Boot
Mass (kg)*	2.7	3.1
Shaft Height (cm)*	37.5	35
Heel Height (cm)*	3.2	4.2
Materials	PVC/nitrile rubber (resistant to chemical, oil and acid)	Full grain (hide hasn't been sanded, buffed or snuffed) water resistant leather
Fastening Method	Nil: Slip-on	Laces
External Waterproofing	Waterproof	Water resistant
Internal Lining	Plush knitted mesh	SympaTex (SympaTex Technologies, GmbH) fabric (waterproof, windproof and breathable membrane)
Foot Bed	Soft polyurethane, covered with a full length cushion of foam polyurethane, topped with a mesh cover	Combination of cellular urethane and PORON® urethane
Sole	Combination of PVC/nitrile rubber and PORON®xRD™ material	Low density polyurethane
Toe Cap	Type 1 (heavy work environment) steel	High carbon steel with a latex cap liner
Sizes Available	AU 4-13 Wide fit to accommodate broad feet	AU 5-14, 6.5-10.5

**Averaged across the five most common boot sizes (8-12).*

2. Methods

2.1 Participants and Survey Implementation

Three hundred and fifty eight underground coal miners (n = 355 men and 3 women; age = 39.1 ± 10.7 years; height =1.78 ± 0.31 m; mass = 92.1 ± 13.7 kg) employed by Illawarra Coal at the Dendrobium and West Cliff sites (NSW, Australia) volunteered to complete a survey which collected job details, work boot habits, foot problems and lower limb pain history, boot likes/dislikes and ideal boot preferences. Underground coal mining remains a male dominated occupation with workers generally being middle aged (personal communication with industry, March 2016). Over half of the participants had worked underground (54.8%), and performed their current working role (52.6%), between 3 and 10 years. Nearly a fifth had worked underground for over 16 years (18.8%). The most common mining work boot sizes worn were sizes 8-12 with 90% of participants falling within this size range. Surveys were handed out to the participants at scheduled work health and safety meetings and training days or immediately prior to commencing a shift at the mines. The participants completed the survey under the guidance of the research team, who clarified any questions the participants had and ensured all questions were completed. All 358 participants who volunteered to fill out the survey completed it.

Participants were divided into two groups for analysis based on whether they chose to wear the employer-provided gumboot (n = 219 men and 3 women; age = 38 ± 9.8 years; height = 1.77 ± 0.67 m; mass = 91.6 ± 13.8 kg) or the other mandatory boot option of the leather lace-up boot (n = 109 men; age = 37.8 ± 10.1 years; height =1.78 ± 0.63 m; mass = 92.6 ± 14.9 kg; see Figure 1 and Table 1). Those who did not answer the question or selected wearing both boots were not included for analysis.

2.2 Survey Design and Development

The design of the survey was based on previously validated surveys that had investigated underground coal mining work boots (Marr and Quine 1993, Marr 1999, Smith et al., 1999), and modified after discussions with coal mining industry representatives. The survey was trialled by 15 participants (age = 18 - 40 years) to ensure questions were readily understood. The final survey instrument included 54 items (15 closed-ended and 39 open-ended items), divided into six sections that sought information pertaining to the underground coal miners' job details; work footwear habits; foot problems and lower limb pain history; low back pain; orthotic use; work footwear fit and comfort; and foot and footwear knowledge. The University of Wollongong Human Research Ethics Committee (HE11/198) provided approval of the survey content and administration procedures. The specific variables investigated in this study are discussed below.

2.3 Analytical Variables

2.3.1 Work Footwear Habits

To determine the participants' footwear preferences open-ended questions 'what is your current mining footwear' and 'what don't you like about your current work footwear', as well as a closed-ended question identifying preferred boot features were used.

2.3.2 Foot Problems, Lower Limb Pain, and Lower Back Pain History

Close-ended questions were used to determine current foot problems reported by the participants and whether a participant had foot, ankle and/or any other pain (lower back, knee, and hip). From a list, participants circled any problems/pain they had or circled 'no' if they did not have any current problems/pain. A five point Likert scale asked participants to elaborate on how often they experienced foot and/or ankle pain (1 'rarely' to 5 'always') and an image of the foot was provided for participants to mark specific pain locations. Finally, a close-ended question asked participants to circle 'yes' or 'no' in regards to whether they believed any foot pain they experienced was related to their work footwear.

2.3.3 Work Footwear Fit and Comfort

Overall work footwear fit (1 'very poor' to 5 'very good') and comfort (1 'very uncomfortable' to 5 'very comfortable') were determined via markings on a five point Likert scale. Participants then ranked 11 boot design features (1 being most important) they believed would enhance the comfort on an ideal work footwear. Two open-ended questions 'what is your everyday shoe size' and 'what is your current work footwear size', then recorded the participants' shoe sizes.

2.4 Survey Analysis

2.4.1 Descriptive Analysis

Descriptive statistics were calculated after coding and counting the close-ended item responses. Thematic analysis was used to calculate response frequencies to open-ended questions. Non-responses, multiple answer selection or when questions did not require an answer from all participants caused variations in the number of responses. Only data for participants who provided a response to that question were analysed.

2.4.2 Relationship Analysis

Chi-squared tests were applied to data related to work footwear habits, foot problems, lower limb pain, lower back pain history and work footwear fit and comfort. The purpose of this statistical design was to determine whether the participants' lower limb pain and perceptions of fit and comfort differed significantly ($p < 0.05$) based on boot type worn (gumboot, leather lace-up boot; SPSS Version 21, USA).

3. Results

3.1 Work Footwear Habits

Leather lace-up boot wearers were more likely to select fit - length ($\chi^2 = 23.75$, $p < 0.001$), fit - width ($\chi^2 = 12.87$, $p < 0.05$), ankle support ($\chi^2 = 128.12$, $p < 0.001$), comfortable ($\chi^2 = 100.08$, $p < 0.001$), flexible ($\chi^2 = 8.44$, $p < 0.05$), fastening method ($\chi^2 = 10.65$, $p < 0.05$), grip

($\chi^2 = 8.6$, $p < 0.05$) and breathable ($\chi^2 = 21.1$, $p < 0.001$) as preferred features of their current work boot (see Figure 2). Conversely, gumboot wearers were more likely to select waterproof ($\chi^2 = 7.07$, $p < 0.05$) and only option available ($\chi^2 = 29.8$, $p < 0.001$) as why they preferred their current work boot (see Figure 2).

In regards to what underground coal miners did not like about their current work boot, those who wore a leather lace-up boot were more likely to select boot gets wet ($\chi^2 = 14.95$, $p < 0.05$), shrinks ($\chi^2 = 27.2$, $p < 0.001$) and hard to get on/off ($\chi^2 = 9.4$, $p < 0.05$; see Figure 3). In contrast, gumboot wearers were more likely to select hot/sweaty ($\chi^2 = 10.8$, $p < 0.05$) and no support ($\chi^2 = 26.95$, $p < 0.001$) as what they did not like about their current work boot (see Figure 3).

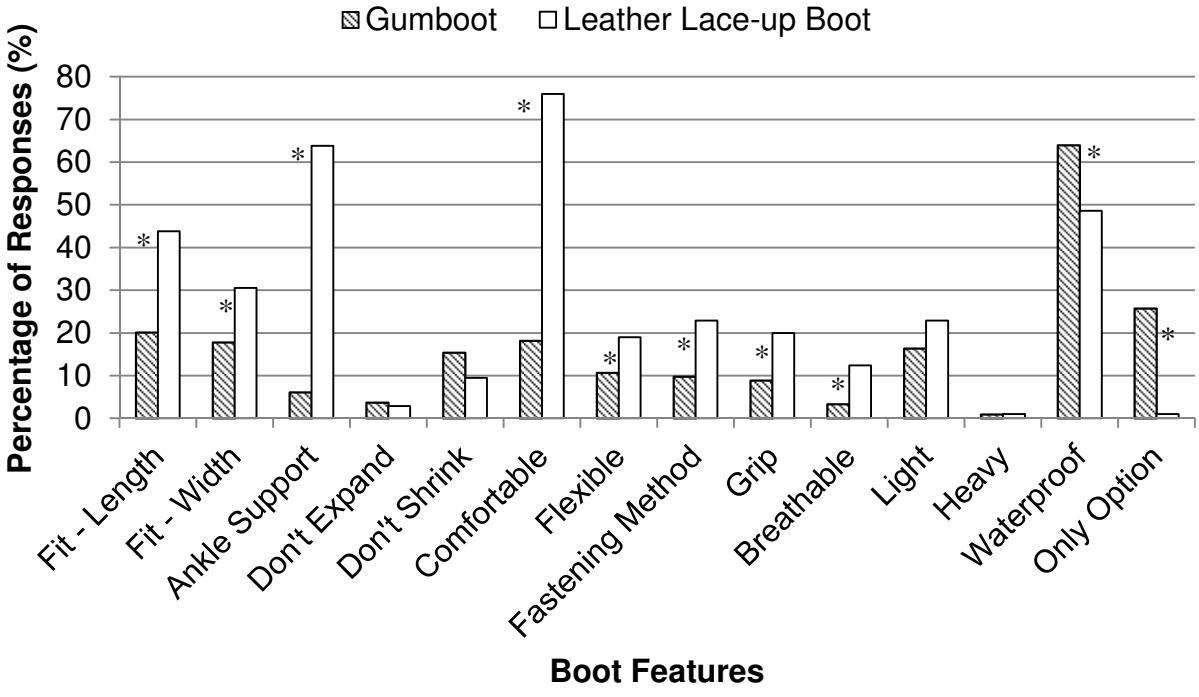

Figure 2: Factors participants preferred about their current mining work boots based on work boot worn (gumboot or leather lace-up boot; n = 323). * indicates a significant difference between boots ($p < 0.05$).

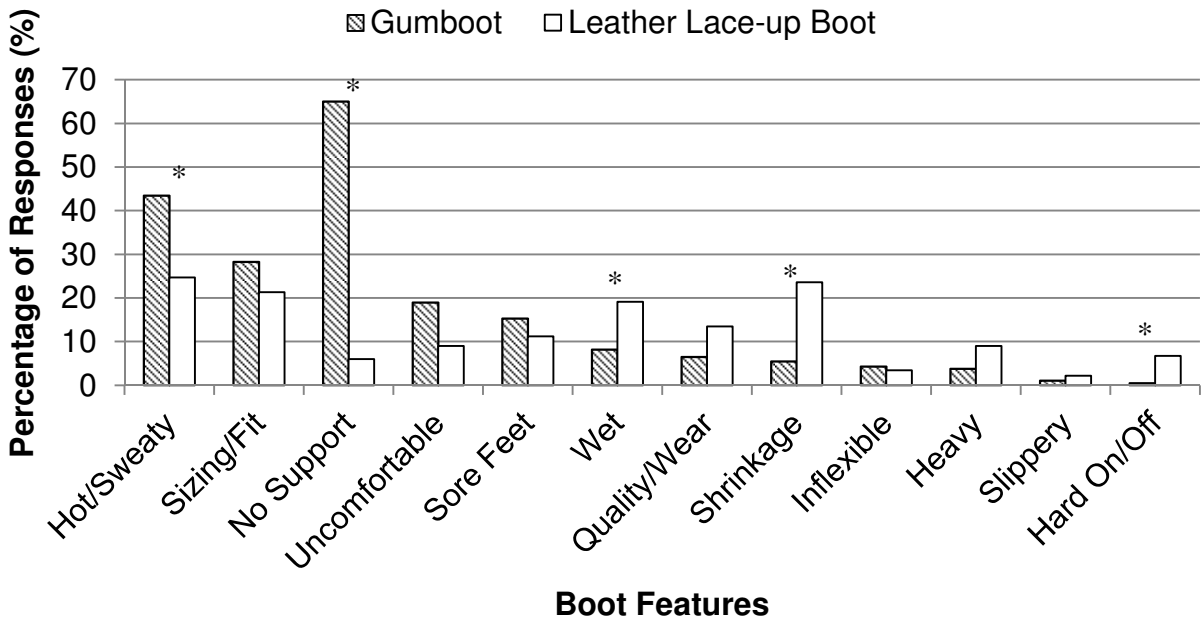

Figure 3: Factors participants did not like about their current mining work boots based on work boot worn (gumboot or leather lace-up boot; n = 276). * indicates a significant difference between boots ($p < 0.05$).

3.2 Foot Problems, Lower Limb Pain and Lower Back Pain History

There was no significant difference between the gumboot wearers compared to the leather lace-up boot wearers in regards to the reported presence of lower back pain ($\chi^2 = 2.76$, $p = 0.25$), hip pain ($\chi^2 = 0.62$, $p = 0.73$), knee pain ($\chi^2 = 1.15$, $p = 0.56$), ankle pain ($\chi^2 = 1.04$, $p = 0.60$) or foot pain ($\chi^2 = 1.9$, $p = 0.38$; see Figure 4). The existence of foot problems also did not differ significantly between wearers of the two boot types ($\chi^2 = 0.88$, $p = 0.65$). However, of those who reported having a foot problem and/or foot pain, there were significant differences between the gumboot and leather lace-up boot wearers in regards to the type and location of the foot problems and pain (see Figure 5). Furthermore, of those participants who reported having ankle pain, leather lace-up boot wearers were more likely to report it occurred 'rarely' (55.3% vs 24.7%) compared to gumboot wearers who were more likely to report their ankle pain as occurring occasionally (50.6% vs 21.3%; $\chi^2 = 15.64$, $p < 0.05$).

There was no significant difference between gumboot wearers and leather lace-up boot wearers in whether they experienced calluses ($\chi^2 = 3.12$, $p = 0.21$) or blisters ($\chi^2 = 3.12$, $p = 0.21$). Furthermore, there was no significant difference between gumboot wearers and leather lace-up boot wearers in whether they thought their work boots contributed to their foot pain ($\chi^2 = 2.30$, $p = 0.22$).

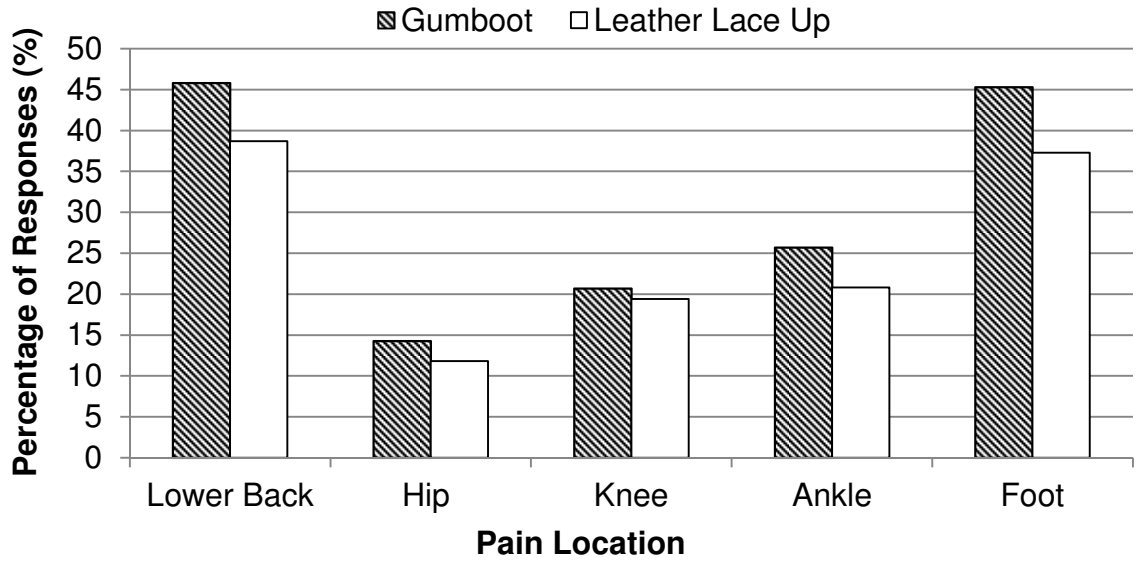

Figure 4: Reported pain incidence based on work boot worn (gumboot or leather lace-up boot; n = 319 foot and ankle pain, n = 263 lower back, hip and knee pain).

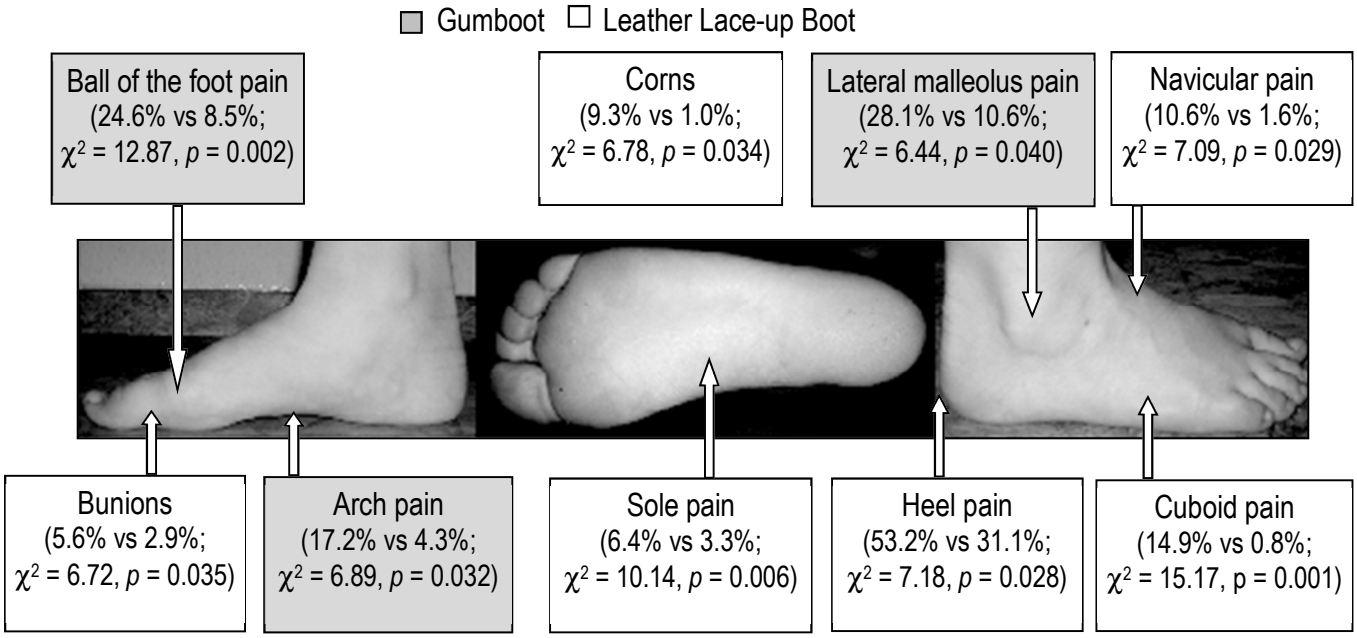

Figure 5: Specific pain locations and foot problems based on the work boots participants reported they were more likely to occur in (percentage of responses; Chi-squared result; n = 159 foot problems and n = 136 foot pain location).

3.3 Work Footwear Fit and Comfort

Comparing responses from participants who wore gumboots versus leather lace-up boots revealed significant differences in regards to ratings of mining work boot fit ($\chi^2 = 42.29$, $p < 0.001$; see Figure 6) and comfort ($\chi^2 = 57.72$, $p < 0.001$; see Figure 7). Participants who wore gumboots, compared to leather lace-up boots, stated the fit of their mining work boots was 'poor' (14.5 vs 3.6%; see Figure 6) and their mining work boot comfort was either 'uncomfortable' (24.9% vs 4.6%) or 'indifferent' (45.0% vs 25.7%; see Figure 7). Conversely, leather lace-up boot wearers were more likely to rate their mining work boot comfort as 'comfortable' when compared to gumboot wearers (59.6% vs 27.1%; see Figure 7).

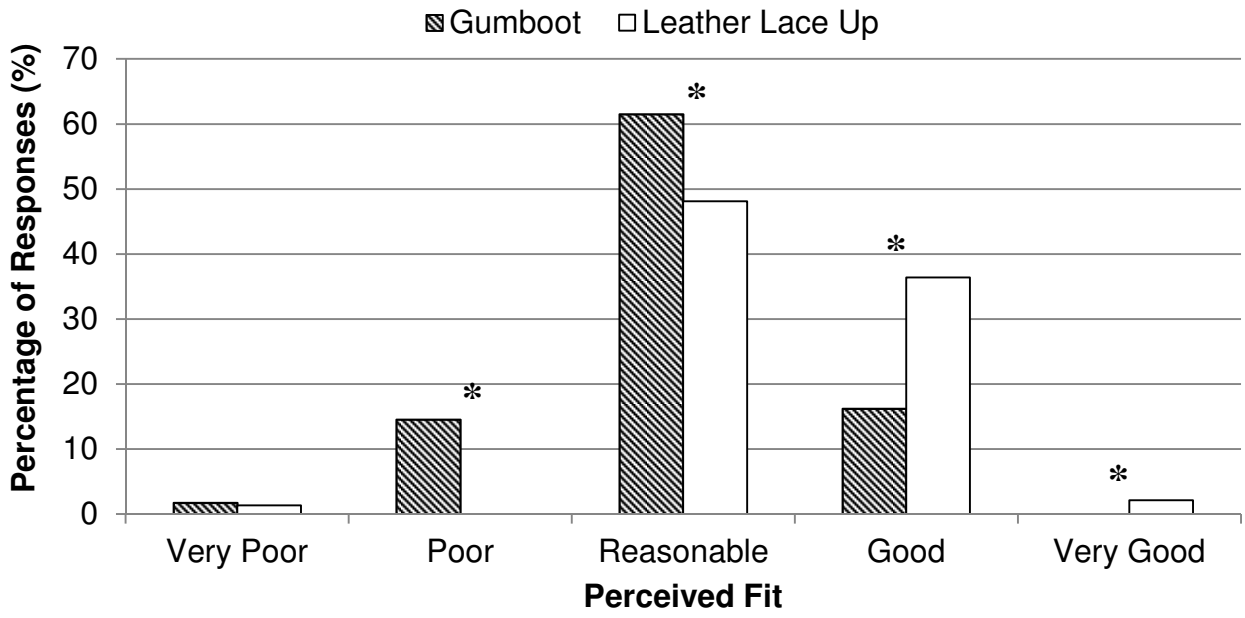

Figure 6: Mining work boot fit ratings based on work boot worn (gumboot or leather lace-up boot; n = 329). * indicates a significant difference between boots ($p < 0.001$).

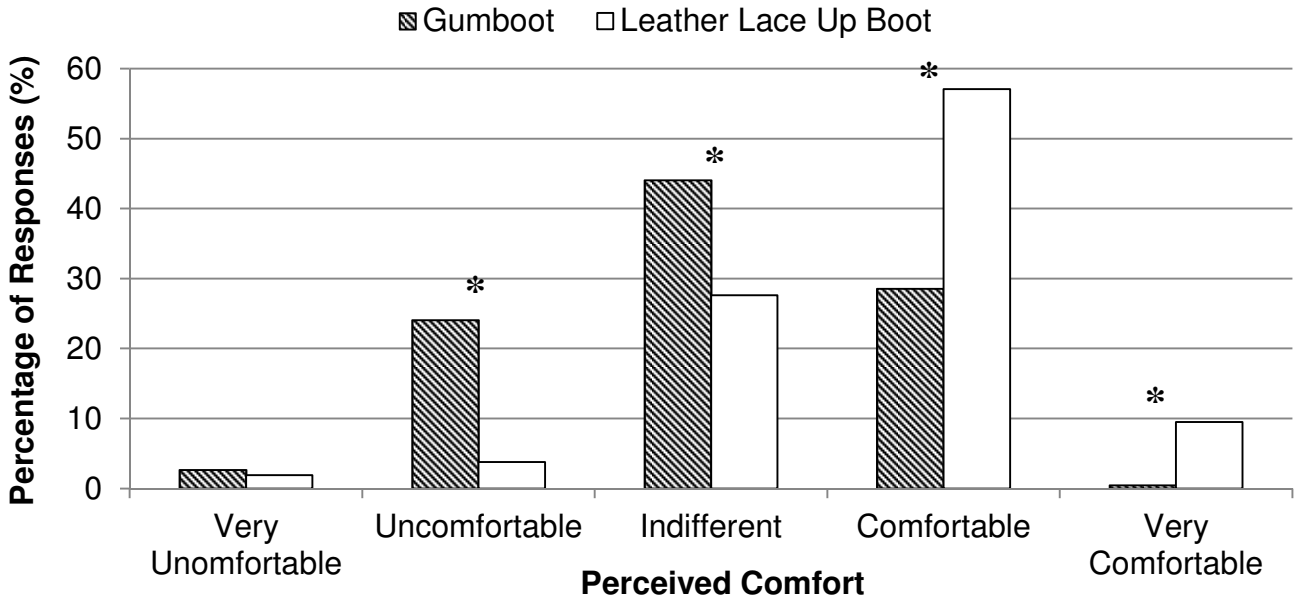

Figure 7: Mining work boot comfort ratings based on work boot worn (gumboot or leather lace-up boot; n = 329). * indicates a significant difference between boots ($p < 0.001$).

Leather lace-up boot wearers were more likely to select a work boot that was larger than their everyday shoe size (40.0% vs 27.1%; $\chi^2 = 17.21$, $p < 0.05$) compared to gumboot wearers, who were more likely to select a smaller sized work boot (29.4% vs 10.0%).

There was no significant difference between what gumboot wearers and leather lace-up boot wearers selected as their first ($\chi^2 = 20.36$, $p = 0.44$) or second ($\chi^2 = 10.98$, $p = 0.90$) choices in regards to what design features would make an ideal work boot more comfortable. Waterproofing was the most common first choice and ankle support the most common second choice across the responses from wearers of both boots type.

4. Discussion

Over a decade ago leather lace-up boots, which had greater ankle support than gumboots, were made available for underground coal miners in an attempt to reduce the high incidence of lower limb injuries. As no research could be found investigating whether this more fitted and supportive work boot affected coal miners' lower limb pain or perceptions of fit and comfort this study investigated whether boot type (gumboot versus leather lace-up boot) influenced self-reported work footwear habits, lower limb pain, lower back pain and perceptions of fit and comfort in underground coal miners. Results of the present study revealed that although leather lace-up boots positively influenced coal miners' perceptions of support and fit provided by their mining work boots, lower back pain, foot pain and calluses are still frequently report by underground coal miners, irrespective of boot type. The implications of these findings are discussed below.

Prior to the availability of leather lace-up boots, 46.3% of underground coal miners listed poor support as a limitation of their current mining work boots (Marr, 1999), with 65.3% specifically listing inadequate ankle support as the limitation (Smith et al., 1999). A work boot that does not provide adequate support to limit excessive inversion and rotation of the ankle is likely to increase the risk of ankle sprain (Barrett and Bilisko, 1995). In support

of our hypothesis, gumboot wearers were more likely to report their boots as providing inadequate support and leather lace-up boot wearers were more likely to list 'ankle support' as a feature they preferred about their current work boots. Leather lace-up boot wearers were also more satisfied with the comfort of their underground coal mining work boots when compared to gumboot wearers. Regardless of what boot underground coal miners wore, participants prioritised ankle support as a design feature required to make an ideal boot comfortable. It is therefore likely that ankle support substantially influenced the difference in comfort ratings between the two boots. However, further research is needed to confirm this theory as the underground coal miners in this current study were not directly asked to rate their perceived ankle support.

Differences in ventilation might also explain the variance in boot comfort ratings with leather lace-up boot wearers preferring the breathability provided by their boots and gumboot wearers disliking their boot because it was hot/sweaty. Differences in ventilation, however, appeared to be a trade-off in regards to waterproofing. Because waterproofing was the first design feature recommended to make an ideal comfortable boot, leather lace-up boot ratings of comfort could be improved by ensuring the boots are waterproof. Nevertheless, further research is required to determine what specific design features make the leather lace-up boot more comfortable than the gumboot and whether this is consistent across different surfaces and working tasks encountered by underground coal miners.

Leather lace-up boots, which are designed to provide more comfort, stability and support than a gumboot, were introduced as a means to reduce lower back pain in underground coal mining (Marr, 1999). Contrary to our hypothesis, there was no significant difference in the incidence of reported lower back pain between underground coal miners who wore leather lace up boots and those who wore gumboots. In fact, almost half (43%) of the miners, irrespective of work boot type, reported lower back pain, an increase compared to

the 34% who reported lower back stiffness in 1999 (Marr, 1999). It is plausible that the high incidence of lower back pain reported in both studies is due to the nature of the working tasks underground coal miners perform and/or the surfaces they work on rather than their work boots *per se*. For example, in a survey of 322 airline assembly workers who were required to operate machinery while standing on hard concrete floors, 69.3% of the workers reported having lower back pain within the last year (Jefferson, 2013). The authors were unsure whether the lower back pain was due to working on hard concrete floors, having to maintain a static posture to operate machinery, or a combination of the two (Jefferson, 2013). Machine operation was the most common working role reported by underground coal miners in the present survey, with 36.3% of the miners reporting that they stand between 4-8 hours each shift (Dobson et al. 2016). Therefore, the high incidence of lower back pain reported by underground coal miners may be related more to the working task and/or environment rather than design differences between leather lace-up boots and gumboots.

Ankle, knee and hip pain incidence also did not differ significantly when comparing gumboot wearers to leather lace-up boot wearers. In fact, the frequency of these pains was similar to the stiffness and injury rates reported by Marr (1999) and Smith et al. (1999) over a decade ago. The current study indicated the increased ankle support provided by the leather lace-up boot did not reduce lower limb pain. Ankle joint motion, however, did appear to have some influence on lower limb pain frequency. That is, of those participants who reported ankle pain, leather lace-up boot wearers were more likely to report the pain occurred 'rarely' whereas gumboot wearers were more likely to report their ankle pain occurred 'occasionally'. Previous research has highlighted that when healthy male participants (29 years of age) wore a lace-up hiking boot with a 50% reduction in passive shaft stiffness, eccentric energy absorption at the ankle joint was decreased (Böhm and Hösl, 2010). Therefore, it is possible that the tighter leather lace-up boot provided more protection to the

ankle than the gumboot via restricting ankle joint motion. If ankle joint restriction was the mechanism via which this result occurred, it did not have any effect on knee pain incidence, which is in contrast to previous findings (Böhm and Hösl, 2010). This result could be due to the unique surfaces and working tasks encountered by underground coal miners. Indeed, the influence of boot shaft alterations on ankle motion can vary depending on the surface and task performed. For example, when male construction workers walked on a level surface, boots with varying shank support provided different levels of ankle stability compared to when they walked on an elevated, tilted surface (Simeonov et al., 2008). The authors speculated that this unexpected result was caused by an interaction between the higher boot shaft and ankle joint when the construction workers walked on the tilted surface, resulting in additional moments and lateral forces being generated. It was suggested that more flex in the boot shaft might dampened the generation of additional moments and lateral forces when the boot was tilted at an angle, i.e. when walking on a sloped surface, so that it would not have such a direct impact on ankle joint motion (Simeonov et al., 2008). Therefore, a better understanding of how much ankle support is required to allow pain free lower limb motion when walking on specific underground coal mining surfaces while performing working tasks is vital when designing comfortable and functional work boots for miners. Because the link between ankle joint motion and lower limb pain incidence is purely speculative, further research is needed to investigate boot design features that influence ankle motion, such as shaft stiffness, and how this affects both comfort and function.

In contrast to our hypothesis, underground coal miners still reported that their work boots contributed to their foot pain while working, despite the option to wear a more supportive leather lace-up boot. Over half (61.2%) of participants who reported foot pain believed this pain was related to their mining work boots, an increase since 1999 in which 53.4% of injured workers previously believed their boots contributed to their lower limb

injuries (Smith et al., 1999). It is interesting to note, in the current study, of those participants who reported having foot pain, the locations of foot pain differed depending on boot type worn. The design differences between the gumboot and leather lace-up boot appear to be uniquely influencing foot motion and, consequently, locations of foot pain.

Underground coal miners are required to remain on their feet, either standing or walking, throughout most of their work shift (Dobson et al. 2016). If a work boot does not support the longitudinal arch of a miner's foot, this continued loading could lead to arch pain (de Castro et al., 2010). Furthermore, excessive foot movement inside a work boot can increase loading of mediolateral foot structures, such as the lateral malleolus, due to mediolateral movements that occur when walking on uneven surfaces (Thies et al., 2007). Excessive foot movement within a shoe can also cause significantly higher pressure-time integrals under the hallux and toes 2-5 that, over time, are likely to lead to foot pain and discomfort (Fiedler et al., 2011). Therefore, the looser fitting nature of gumboots, the tendency to allow more foot movement inside the boot and a lack of support (Marr, 1999; Smith et al., 1999) could explain why gumboot wearers were more likely to have pain in the arch, lateral malleolus and ball of the foot compared to their counterparts who wore the more structured leather lace-up boots.

Repetitive loading experienced during prolonged walking is a risk factor for cuboid and navicular pain in the foot (Gross and Nunley, 2015; Patterson, 2006). The finding that leather lace-up boot wearers were more likely to have pain around the navicular, cuboid, sole of the foot and heel indicates that the leather lace-up boot might not be providing sufficient cushioning to the plantar surface of the foot (Marr, 1999). This notion is supported by leather lace-up boot wearers being more likely to have corns and bunions, which result from increased pressure at concentrated locations on the foot (Grouios, 2004). Therefore, although introducing leather lace-up boots did not change the incidence of foot pain, the finding that

underground coal miners have different locations of foot pain depending on the type of boot they wear indicates work boot design features have the potential to influence foot pain incidence. A better understanding of the influence different boot design features have on foot motion when miners perform common working tasks, such as walking and standing, is therefore needed. Such research could help explain why different boot design features are associated with specific locations of foot pain and how pain in these locations can be prevented.

Over half (52.1%) of underground coal miners in previous studies reported their gumboots did not fit properly and 41.3% said their feet slid inside their boots (Marr, 1999; Smith et al., 1999). The adjustability of the leather lace-up boot, accommodating individual fit preferences, most likely explains the observed improvement in ratings of mining work boot fit in the present study. Indeed, leather lace-up boot wearers were more likely to select 'fastening method' as something they preferred about their current work boots. A more supportive fit provided by laces, however, appears to have hindered the ability to get the boots on/off. Future research into underground coal mining work boot design needs to investigate whether other fastening designs, apart from laces, can be used to maintain a firm fit but still enable the boots to be easy to get on/off.

Improved perceptions of fit in the current study most likely accounted for the decrease in reported calluses (33.1%) compared to previous research (48.5%; Marr, 1999). However, no significant difference was found in the reported occurrence of calluses and blisters between the two boot types. A possible explanation is that leather lace-up boot wearers wore a work boot that was a size bigger than their everyday shoe size and gumboot wearers wore a size smaller than their everyday shoe size. When a boot is either too small or too broad the foot is unable to stabilise within the boot, leading to a high risk of calluses (Marr, 1999). With the gumboot being a wider style design and the leather lace-up boot a narrower style

design, it appears that the wearers of each boot type are being forced to compensate boot length to achieve the desired boot width. In order to create a boot that fits comfortably and reduces the high incidence of calluses, further studies are needed to investigate the shape of miners' feet relative to the shape of their underground coal mining work boots to identify possible mismatches. These mismatches can then be used to provide evidence of mining work boot design features that require modification to enable the boots to better fit the feet of underground coal miners. It is acknowledged, however, that given the large variation in the size and shape of the feet of underground coal miners (unpublished research, Dobson et al.) it is unlikely to be feasible to create a generic work boot that would suit the feet of all underground coal miners. However, it is important that future boot designs are based on the foot dimensions of coal miners and include design features which allow the miners to perform their work tasks in their unique work environment.

Regardless of which boot an underground coal miner wore, the participants reported the same top two design features that they considered would make an ideal work boot more comfortable: waterproofing and adequate ankle support. These results were also consistent irrespective of whether an underground coal miner worked in a wet or dry mine (Dobson et al., 2016). Adequate boot ventilation was also deemed an important boot design feature, although achieving both increased ventilation and waterproofing is challenging. It is therefore recommended that boot manufacturers investigate new materials other than the traditional rubber and leather in order to design work boots that are waterproof, and provide adequate ankle support and ventilation.

4.1 Limitations

The following limitations of the current study are acknowledged. Due to the cross-sectional and retrospective nature of the survey questions, boot design cannot be concluded as the sole contributing factor to the observed results. Also no mechanical testing was performed on the

boots and differences in their structures were not systematically controlled. Therefore, although it was assumed structural design differences between the two underground coal mining work boots caused the observed results, further research with a prospective design should investigate the influence of boot design on lower limb function and comfort when coal miners perform working tasks. The accuracy of self-reported measures, presence of the research team, errors due to non-responses and validity differences between open and closed questions are also acknowledged as possible limitations of the survey. Given this study was compared to previous survey results reported by underground coal miners from the same demographics under similar conditions, we believe the impact of these limitations is minimal.

5. Conclusions

The introduction of a more structured leather lace-up boot as a work boot option has positively influenced perceptions of ankle support, fit and comfort reported by underground coal miners. The frequency of foot problems, lower limb pain and lower back pain reported by these miners, however, are still high, irrespective of the work boot type their wear. Although boot type did not alter the incidence of foot pain, underground coal miners reported different locations of foot pain depending on boot type, indicating differences in work boot design have the potential to influence foot pain. Further investigation is therefore recommended to identify which specific boot design features caused these observed differences in work boot fit, comfort and locations of foot pain and how these design features can be manipulated to create an underground coal mining work boot that is comfortable and reduces the high incidence of foot problems and lower limb pain suffered by underground coal mining.

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Conflict of interest

None.

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