A narrative review of musculoskeletal problems of the lower extremity and back associated with the interface between occupational tasks, feet, footwear and flooring.

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Abstract:

At least 50% of workers are exposed to the risk of musculoskeletal disorders (MSD) due to spending prolonged hours standing at work. There is a lack of information regarding issues with the feet, solutions to the problem and links between MSD, feet, footwear and flooring. This paper provides a narrative review of the research in this area based on 31 papers. Workers who stand for large proportions of the working day had a level of MSD considerably greater than a normal population. Muscle co-activation, blood pooling, muscle fatigue and individual characteristics are all associated with MSD. Altering flooring provided mixed results, whilst footwear appears to have the potential to impact MSD but the dearth of literature limits the conclusions that can be drawn. Despite their inextricable link, literature regarding the relationship between occupational tasks, MSDs, footwear and flooring remains limited and future studies will benefit from rigorously designed protocols.

Keywords: shoe, biomechanics, prolonged standing, work, discomfort

Introduction

Standing is a requirement of some occupations but may be chosen by a worker if it increases versatility and mobility (Halim and Omar, 2011). Prolonged occupational standing involves spending over 50% of time at work on the feet (Tomei *et al.*, 1999) and is associated with a range of maladaptive responses: chronic venous insufficiency; preterm birth; carotid atherosclerosis; and musculoskeletal disorders (MSD) (Halim and Omar, 2011). MSD include any symptoms such as pain and discomfort as well as damage to any body structure (Bernal *et al.,* 2015). The lower back, lower extremity and feet are particularly susceptible to MSD (Halim and Omar, 2011). The financial impact can be significant, with lower limb disorders exacerbated by standing responsible for a large proportion of sick days (O’Neill, 2005). Prolonged standing has also been associated with reduced work performance as discomfort and injuries can decrease the efficiency with which workers perform tasks (Halim and Omar, 2011).

With at least half the working population experiencing prolonged standing at work (O’Neill, 2005; Parent-Tirion *et al.,* 2012), it is imperative to understand how this posture relates to the risk of injury and investigate strategies to reduce this risk (O’Neill, 2005). Halim and Omar (2011) elude to the benefits of appropriate flooring and footwear but we must first understand the interaction between prolonged standing, footwear and flooring. Therefore the aim of this review is to investigate the interplay between these components with consideration to lower limb biomechanics and foot structure.

Method

Table 1 details search parameters and inclusion criteria. All papers focused on the effect of prolonged standing in relation to lower back, lower limb or feet occupational MSD, the effects of flooring or the effects of footwear.

[Table 1 near here]

Results

31 papers met the criteria (Tables 2- 7) and results organised into 6 themes.

The association between prolonged standing and lower back MSD

The lower back was the most frequently investigated area associated with prolonged standing (Table 2).

[Table 2 near here]

In 430 dentists, 46% reported low back pain with 25% of these cases lasting over a month (Alexopoulus *et al*., 2004). In perioperative nurses and technicians, over half noted symptoms in the lower back occurring in the previous seven days and this increased to 84% over the previous year (Sheikhzadeh *et al.,* 2009). The same study found that nearly a quarter of these nurses and technicians had visited a physician and a third had taken time off work. By comparison, in a study of 6000 generic UK inhabitants recruited randomly from GP surgeries-, the prevalence of back pain was far lower, at 12% in women and 7% in men aged 16-44 (Urwin *et al.*, 1998), suggesting job demands have a dramatic impact on risk of lower back MSD.

In a two-year prospective study of various occupations that included administration, nursing, industrial work, kitchen, cleaning and technical staff, standing for >30 minutes in every hour of work was associated with a 1.9 (CI = 1.2-3.0) fold increase in risk of low back pain (Andersen *et al.,* 2007). A similar 3-year prospective study in Norway reported standing for three quarters of the working day increased risk of lower back pain by 1.48 (CI = 1.20-1.83) to 1.74 (CI = 1.46-2.07) dependent on other occupational risk factors (Sterud & Tynes, 2013).

The impact of prolonged standing is also evident after shorter periods (2 hours) (Antle and Côte, 2013; Gregory and Callaghan, 2008; Marshall *et al.*, 2011; Nelson-Wong *et al.*, 2008; Nelson-Wong and Callaghan, 2010). These studies of simulated occupational settings used a visual analogue scale (VAS) to assess pain or discomfort. Despite all lasting 2 hours and using similar participants, the outcomes varied between studies. In one study, 40% of 43 asymptomatic participants developed low back pain (Nelson Wong and Callaghan, 2010) whereas Gregory and Callaghan (2008) reported 81% of 16 participants developed lower back discomfort. Other studies suggest prevalence rates of 65% (Nelson-Wong *et al.*, 2008) and 71% (Marshall *et al.*, 2011). The prevalence differences are in part due to variances in the dependent variable, with prevalence of pain (40-65%) (Gregory and Callaghan, 2008; Nelson-Wong and Callaghan, 2010) lower than discomfort (71-81%) (Marshall *et al.*, 2011; Nelson-Wong *et al.*, 2008). This is expected since discomfort precedes pain (Goonetileke and Luximon, 2001). Differences could also occur due to the characteristics of participants, such as the initial standing posture (Gregory and Callaghan, 2008).

One advantage of laboratory based studies is that they enable biomechanical variables to be measured. One factor critical to the development of low back pain is co-activation of muscles. Nelson-Wong *et al.*, (2008) found the presence or absence of gluteus medius co-activation predicted whether lower back pain would develop in 76% of subjects. As the co-activation was recorded prior to pain onset, the authors speculated that the co-activation was a causative factor and not an adaptive response. Nelson-Wong and Callaghan (2010) also reported co-activation of the gluteus medius muscles to be a causative factor of low back pain. A later study used gluteus medius co-activation to predict the development of low back pain in 80% of participants but suggested there were additional causative factors as the remaining 20% were false-negatives (Marshall *et al.*, 2011). Antle and Côte (2013) found only trends towards muscle co-activation in gluteus medius muscles and the trunk flexor-extensors although, the authors concede that differences in protocol and calculating co-activation could contribute to the lack of effect. Furthermore, Antle and Côte (2013) allowed participants to shift weight from foot to foot thus altering the biomechanics of the task.

The association between prolonged standing and lower extremity MSD

Eight studies have investigated the effect that prolonged standing at work has on the lower extremity (Table 3).

[Table 3 near here]

A questionnaire survey of factory workers who stand, showed 68% of 407 self-reported lower extremity fatigue by the end of a working day, with 34% stating it affected activities outside of work (Gell *et al.,* 2011). Furthermore, a fifth of workers were already undergoing treatment for lower extremity problems. In perioperative staff, knee pain was reported in 45% of 50 participants in the last 7 days and in 58% over the last year (Sheikhzadeh *et al.,* 2009). This compares to 7% of a general population aged 16-44 (Urwin *et al.,* 1998). In the ankle and foot, 59% had suffered pain in the last 7 days, 74% over the last year (Sheikhzadeh *et al.,* 2009) resulting in 25% taking time off. Increased hip pain is also associated with standing for long periods, both at work and in leisure activities (Pope *et al.,* 2003).

A prospective 2-year study (Andersen *et al.*, 2007) demonstrated that standing for 30 minutes or more of every hour at work, elevated the odds ratio for pain in the hip, knee or foot to 1.7 (CI = 1.0-2.9). Messing *et al*. (2006) reported a high odds ratio for calf or leg pain (3.69, CI = 2.19-6.23) and an increased odds ratio for ankle/foot pain (3.89, CI = 2.53-5.99) associated with standing compared to sitting with the freedom to move around.

Two short term studies used a VAS to assess lower limb and foot pain/ discomfort during a simulated prolonged standing work-based task. Antle and Côte (2013) found 15 of 18 participants (83%) reported discomfort, reaching a mean of 3.47/10 in just 34 minutes. In a comparison of static standing (only small adjustments to posture permitted) to dynamic standing (including walking between different tasks) over 1-hour, static standing induced higher levels of discomfort, with leg and overall comfort approximately 25% lower (Balasubramanian *et al.*, 2009). This suggests that self-reported indicators of MSD occur rapidly with static tasks having a greater effect.

The literature (Antle and Côte, 2013; Antle *et al.*, 2013; Halim *et al.* 2012; Balasubramanian *et al.* 2009) suggests two main biomechanical variables are related to lower extremity MSD: vascular blood pooling and muscular fatigue. Blood pooling is thought to occur due to venous reflux associated with standing. It occurs quickly, as demonstrated by Antle *et al.* (2013) in 32 minutes. In this short time, increased cutaneous blood flow in the foot and soleus correlated highly (>0.75) with lower extremity discomfort. Similarly, within a 34 minute protocol, lower limb blood pressure was increased (an early sign of blood pooling) in 85% of participants, though the correlation with discomfort was weaker ($r=0.35$, $p<0.05$) (Antle and Côte, 2013). The relationship between blood pooling and discomfort occurs as a result of a build-up of metabolites that accelerate the onset of pain and fatigue (Edwards, 1988). King (2002) reported that these metabolites activate afferent nociceptors that can lead to hypersensitivity of the muscles (Djupsjobacka *et al.*, 1994; Djupsjobacka *et al.*, 1995).

Muscle fatigue is also thought to be a key factor in the development of MSD (Phinyomark *et al.*, 2012), although the exact mechanistic link is unknown. Balasubramanian *et al.* (2009) investigated fatigue in static standing in comparison to dynamic standing over 1-hour. In the gastrocnemius muscles there was a decrease in the mean power frequency and an increase in the root mean square regression slope, indicating fatigue. This corresponded with an increase in discomfort. The relationship between self-reported fatigue and muscular fatigue evaluated using EMG was investigated by Halim *et al.* (2012) who reported prolonged standing caused psychological fatigue and muscular fatigue in the gastrocnemius, tibialis anterior and erector spinae muscles. This was assessed through the mean power frequency and the time to fatigue. Conversely, Antle and Côte (2013) recorded significant decreases in the muscle activation of the tibialis anterior (19%) and the gastrocnemius (13%), occurring in the first 8 minutes (then becoming stable for the remaining time). However, as this effect occurred early, it could have been caused by initial adjustments made by participants.

The effects of prolonged standing on musculoskeletal disorders of the feet

Only three studies were identified that investigated the foot as a separate entity (Table 4).

[Table 4 near here]

Riddle *et al.* (2003) found a relationship between prolonged standing and the development of plantar fasciitis. In agreement, Nealy *et al.* (2012) found 167 of 502 nurses suffered from plantar fasciitis, despite only 12 having the problem prior to becoming a nurse. However, 74% were aged >40 and over half were overweight or obese, all confounding factors in plantar fasciitis (Riddle et al., 2003; Nealy *et al.*, 2012). Furthermore, the results are based on self-diagnosis.

Nealy *et al.* (2012) found that approximately 50% of the nurses reported problems in their feet (metatarsalgia, heel bursitis, bone spur, Morton’s neuroma, Achilles tendonitis, bunions and hammer toes), compared to 17.4% of a general population (Hill *et al.,* 2008). The process of questionnaire development did not follow a rigorous approach as defined by Oppenheim, (1992) and reflects the need for more validated workplace questionnaire surveys.

Focussing on sales and kitchen workers, Messing and Kilbom (2001) reported that 35% of workers time was spent walking, 62% was spent standing, and static standing only lasted up to 7 seconds. Furthermore, the minimum pressure needed to induce foot pain was lowered by 23% in individuals who spent the day on their feet, compared to only 5% in a control group (who sat for 95% of the day). Those that experienced foot pain throughout the day demonstrated a lower pain pressure threshold. This provides key information into the patterns of movement in these work environments as well as identifying the pain-pressure threshold as another variable affected by prolonged standing.

From these studies we learn that discomfort and foot related MSD are caused by prolonged standing in the work place. However, very little is known about the prevalence of foot MSD at work and the relationship it has with prolonged standing. The alteration of the pain-pressure threshold over a working day emphasises the importance of study duration. Future studies that focus on specific work places and tasks would provide a better insight into the current prevalence.

The effect of flooring on lower limb /back MSD during prolonged standing

Flooring offers an opportunity for employers to alter the relationship between the body, foot and surface. This review identified 11 studies that considered the impact flooring has on prolonged standing (Table 5).

[Table 5 near here]

Whilst the mechanism of action is not clear, anti-fatigue mats claim to decrease fatigue (Zander *et al.*, 2004) by permitting deformation of the floor in response to postural deviations and thus increase centre of mass sway. In order to maintain balance, contractions of lower limb muscles are required and this increases venous return, opposing blood pooling and thus likely delaying discomfort (Antle and Côte, 2013).

Lin *et al.* (2012) compared a hard surface to a 12.5 mm mat and the former significantly increased discomfort and corresponded to a significant increase in thigh and shank circumferences. They also considered the effect of flooring on supermarket workers who stood all day. Over four hours, the hard floor increased thigh and shank circumference by 1.7 cm and 0.8 cm respectively, significantly more than the anti-fatigue mat (0.8cm and 0.5cm respectively). Similarly, over a 2-hour period in which ‘feeling of unpleasantness’ was the dependent variable, mean unpleasantness was 71% higher (p=0.004) for a hard surface compared to a polyurethane anti-fatigue mat (Madelaine *et al.*, 1998). Unfortunately none of these studies provide a quantitative measure of floor hardness.

Three studies (King, 2002; Orlando and King, 2004; Brownie and Martin, 2015) found anti-fatigue mats to reduce self-reported fatigue. King (2002) reported a 5/8 inch thick polyurethane 'Ergomat®' reduced fatigue levels (mean leg fatigue = 2.68) compared to a wooden floor (mean leg fatigue = 3.93) over a week. The second study compared a 3/4 inch thick polyurethane 'Ergomat®' over an 8-hour working day to a wooden floor in a factory, reporting decreased leg fatigue (-0.7, via 5-point Likert scale) (Orlando and King, 2004). Brownie and Martin (2015) reported a positive effect on feet with a ¾ inch rubber anti-fatigue mat, with no effect in the legs, knees, buttocks or lower back. Again, these studies failed to provide measures of floor hardness.

In contrast to these results, in a 2-hour standing protocol Hansen *et al.* (1998) suggest no benefit in lower limb discomfort using a 10 mm polyurethane mat with 5 mm bumps (compared to a concrete floor).The authors claimed any impact on blood pooling (shank volume) was 'marginal' compared to the effect of time. Likewise, in the first two hours of testing, Cham and Redfern (2001) found no significant difference in discomfort between a steel floor and six mats (7.1-16.9 mm of various stiffness). However, in the third and fourth hours, significant differences in discomfort were apparent with the hardest and softest floors receiving the worst ratings. This suggests there is an optimum hardness within this range. The discomfort on the highly deformable floor result from the material 'bottoming out' and becoming hard (Wiggerman, 2011). There were no significant differences in lower leg volume between the seven floorings Cham and Redfern (2001) demonstrated the need for investigations to be of sufficient duration to establish differences between the conditions. They suggest a minimum duration of 4-hours. The disparity of results emphasises the need for more consistent protocols that utilise the same measure for blood pooling and report objective measures of floor hardness (and other properties).

Over an 8-hour factory shift, Zander *et al.* (2004) also failed to find alterations in calf circumference when comparing a wooden floor to anti-fatigue mats. However, diversity between subjects in terms of footwear and movements made meant flooring was not the only independent variable. Similarly in a work place questionnaire sent to plant workers, anti-fatigue mats were not found to be protective against self-reported fatigue (Gell *et al.*, 2011). However, every 10% of time spent on carpet as opposed to a hard surface reduced the risk of fatigue by 34%.

Wahlström *et al.* (2012) considered the long-term effect (2 years) of a change in flooring in a nursing home on MSD in nursing assistants. The addition of a 2.5 mm foam to the floor significantly reduced foot and low back pain intensity compared to a control group. Furthermore, this effect remained after 2 years. However, slight differences in the psychosocial environment and work tasks between establishments could have impacted results.

Centre of pressure (COP) displacement is thought to provide an objective measure of discomfort or fatigue when standing on different surfaces and has been associated with leg fatigue (Wiggerman, 2011; Vuillerme *et al.*, 2002). An increase in COP displacement is suggested as a protective mechanism, as it results from increased lower limb muscle action. This could have a positive impact on venous return and thus blood pooling (Antle and Côte, 2013). Cham and Redfern (2001) reported a positive correlation between higher levels of COP displacement and whole leg fatigue (r=0.45), leg discomfort (r=0.86), ankle discomfort (r = 0.80) and foot discomfort (r=0.70). The authors suggested that lateral shifting of the COP was a mechanism employed to reduce fatigue and discomfort. This is supported by a 15%

increase in lateral COP shift (0.537 m to 0.615 m) occurring after muscle pain was induced with a hypertonic saline (Madelaine *et al.*, 1998).

Studies investigating the ability of mats or flooring to expel muscular fatigue measured through EMG is inconclusive. Cham and Redfern (2001) found no effect of either time or flooring condition on the mean power frequency in a 4-hour standing protocol for the lower back or leg despite using a range of different flooring. Brownie and Martin (2015) used a muscle twitch force technique in which the gastrocnemius muscles were stimulated. Over five hours, a continuous decrease in the muscle twitch force was observed, but no differences arose between surfaces. In contrast, using the root mean square and mean power frequency for the tibialis anterior and soleus over two hours, Madelaine *et al.* (1998) ascertained an increase of muscle activity in the tibialis anterior on the soft surface in comparison to the hard surface, with the opposite true of the soleus. Kim *et al.* (1994) found no delay in calf muscle fatigue when on the mat but did find the erector spinae fatigue was reduced. The different muscles used and the EMG analysis techniques limits the ability to accurately compare studies. Currently, there is inconclusive evidence to support the use of anti-fatigue mats for reducing muscular fatigue, although this warrants further investigation.

Overall, numerous studies report alterations in matting or flooring to have a positive impact on MSD when standing (King, 2002; Orlando and King, 2004; Brownie and Martin, 2015; Wahlström *et al.*, 2012; Lin *et al.* 2012; Madelaine *et al.*, 1998). However, different methodologies have created disparities between studies and the lack of information regarding the exact properties of the flooring or mats used make it impossible to draw practical recommendations. The impact of flooring on muscle activation is not well supported and the study numbers are limited.

The effect of footwear on factors related to musculoskeletal disorders in the workplace.

The feet are the only body surface that interacts with the ground when standing or walking. Therefore, they have the ability to cause alterations in standing posture as well as how forces and movements occur. Footwear provides an interface between the feet and the floor, creating an opportunity to modify this relationship. Despite this, there is limited research in this area, particularly in regards to standing (Table 6).

[Table 6 near here]

Lin *et al.* (2012) found sports shoes, in comparison to barefoot, decreased subjective discomfort by approximately 1.5 on a 7-point Likert scale. However, no difference between conditions in shank circumference were observed over the 4-hours. Hansen *et al.* (1998) reported no impact on self-reported discomfort ratings between a hard wooden clog and a sports shoe, but did find the sports shoe significantly reduced blood pooling and thus oedema formation from 3.2% to 2.8%, when flooring was kept constant. As these were the only two studies investigating this variable, future work should consider the impact of altering footwear on blood pooling in the lower limb, due to its association with discomfort (Antle and Côte, 2013). It is possible that these discrepancies arose as a result of the reliance on subjective measures.

Participants subjective measures of footwear relating to discomfort and fatigue were recorded in multiple studies (Gell et al., 2011; King, 2002; Orlando and King, 2004; Lin et al., 2007; Chiu and Wang, 2007). Gell *et al.* (2011) reported harder footwear (those with a type C durometer reading over 32) increased the risk for lower extremity self-reported fatigue by 2.6 (CI = 1.3-5.3) times in comparison to footwear with a low hardness level (those with a type C durometer reading below 18). King (2002) found viscoelastic insoles and floor mats provided statistically similar reductions in both general fatigue (mean floor = 3.95; mean with insoles = 2.84) and leg fatigue (mean on floor = 3.93; mean with insoles = 2.68) in comparison to a hard floor over an entire working week. However, they were unable to control for the footwear worn. In factory workers over an eight hour shift, adding an insole to a shoe decreased the firmness rating from 4.1 to 2.55, the general fatigue from 3.20 to 2.45 and the leg fatigue from 3.4 to 2.18 based on a 5-point Likert scale (Orlando and King, 2004). The mean fatigue reductions were larger than that reported when using an anti-fatigue mat (Orlando and King, 2004). Lin *et al.*, (2007) tested clean room boots (shoes made of an outsole and upper covering the entire shank) that differed only in the sole elasticity and shock absorption. Over 1-hour, low values of elasticity and shock absorption were related to discomfort. Chiu and Wang (2007) reported a thin sole in nursing shoes increased the number of discomfort complaints in the back, thigh, knee and shin (Chiu and Wang, 2007). Furthermore, a positive relationship was reported between the discomfort ratings and plantar pressure measurement. The only exception to this was in the arch area, in which the authors suggested an ill-fitting arch increased the level of discomfort.

In-shoe plantar pressure is an important biomechanical measure as areas of high pressure can build into areas of pain and cause corns, calluses and blisters as well as exacerbate and increase the risk of more serious MSD (Springett and Johnson, 2002). Testing 3 pairs of nursing shoes, Chiu and Wang (2007) found significant differences in all seven areas of the foot (the toe, 2^{nd}-5^{th} phalanges, 1^{st} metatarsal, 2^{nd}-3^{rd} metatarsal, 4^{th}-5^{th} metatarsal, arch and heel). They reported that the width of footwear impacted on the pressure distribution in the toes and an arch support increased the area of the foot in contact with the shoe, reducing peak pressures. It was also suggested that the outsole thickness and material have the ability to alter the pressures on the plantar surface. Kersting *et al.* (2005) also collected in-shoe plantar pressure measurements, dividing the foot into 8 regions for analysis. The variable ‘shoe’ had the greatest impact on plantar pressure, and concurring with Chiu and Wang (2007), they reported that an increased arch support reduced the pressure in other areas such as the lateral forefoot and heel. The lack of cushioning in some shoes was also suggested to be a contributor to high peak pressures. However, the large number of structural variations prevents specific conclusions being drawn. Furthermore, it must be noted that this occurred during tasks that were mostly dynamic in nature and no study was identified that considered the effect of footwear in static standing on plantar pressures.

Muscle activation was tested in two occupational footwear studies (Chiu and Wang, 2007; Kersting *et al.*, 2005), although these primarily focused on walking tasks. Chiu and Wang (2007) reported EMG, normalised to maximum voluntary contraction, remained unaltered across 3 pairs of nursing footwear for all muscles apart from the medial gastrocnemius in which a significant decrease in muscle activation was recorded in two of the shoes. This was attributed to increased arch support, although the diverse structural differences between them makes it impossible to firmly attribute a specific footwear feature to the changes. In catering staff, three shoes varying in midsole stiffness, arch support, grip, material and heel counters were tested (Kersting *et al.*, 2005). Higher EMG values of the peroneus longus and gastrocnemius muscles were found in the footwear with the stiffest midsole and no arch support in comparison to that with the soft insole, high grip and increased foot support. The authors directly attributed this to the grip differences, but it is equally feasible that the stiff midsole could have instigated higher muscle activation to permit pronation. Alternatively, this could have been caused by the alterations in arch support (Chiu and Wang, 2007). Erector spinae muscle activation was also altered between shoes, with greater EMG displayed in the stiff midsole shoe again, but this time in comparison to the shoe with the flexible midsole with no support. It is impossible to ascribe these changes to a specific feature.

Contributing factors to occupational musculoskeletal disorders

A number of variables that can impact the reported MSD at work must also be considered (Table 7).

[Table 7 near here]

The most obvious contributing factor to the development of MSD is age. In a general population, Hill *et al.* (2008) found foot pain to significantly increase ($P<0.001$) with every ten years of age added, from 25 years to over 75 years. The odds ratio increased to 2.4 (CI = 1.79-3.22) in ages 45-54 and to 2.78 (CI = 2.04-3.77) in ages 55-64. Conversely, Alexopoulus *et al.* (2004) found no change in the odds ratio for increasing age in terms of MSD in the lower back.

Further to age, the body mass index (BMI) also impacts on the prevalence of MSD in the workplace. Andersen *et al.* (2007) report a higher BMI to increase the odds of any regional pain from 1.1-1.4 and for hip, knee and foot pain from 1.4-2.3, dependent on BMI category. Gell *et al.* (2011) reported that for every increase of 5 on the BMI scale the odds of reporting fatigue increased 28%. A BMI of 25 – 30 and over 30 increased the odds of developing plantar fasciitis by 2 (CI = 1.28-3.08) and 5.6 (1.9-16.6), respectively. The greater levels of discomfort and pain could be caused by the larger amount of blood pooling that has been shown to occur in individuals with a greater mass (Zander *et al.*, 2004). Irving *et al.* (2007) report a significantly increased risk (odds ratio = 2.9, CI = 1.4-6.1) of developing plantar heel pain when BMI was over 30. The authors also reported that a pronated foot type increased these odds, which raises the question of the impact of foot posture on developing MSD in the work place, which has not yet been explored.

In addition to physical factors, psychosocial factors including high job demand and low job control influence the level of self-reported MSD. A 3-year prospective study identified attributable risks with these two factors of 11.6% and 4.9% respectively (Sterud and Tynes, 2013). Over 2-years, and after multivariate adjustments were made, low social support from colleagues, low job satisfaction and fear avoidance were attributable risks for MSD, with odds ratios from 1.3 to 2.1 (Andersen *et al.*, 2007). Job dissatisfaction was also shown to increase the risk for lower extremity fatigue in plant workers with an odds ratio of 1.3 although supervisor support was shown to be a protective factor (Gell *et al.,* 2011). A systematic review and meta-analysis of 24 studies (Bernal *et al.,* 2015) found that high psychosocial demands and low job control were associated with an increase in the incidence of low back pain by 1.56 (CI = 1.22-1.99), knee pain by 2.21 (CI= 1.07-4.54) and of pain in any site by 1.38 (CI =1.09-1.75). Associations were also found between low social support and the prevalence of back pain (1.38, CI = 1.43-2.32) and between MSD prevalence in any area and an imbalance between effort and reward (6.13, CI = 5.32-7.07). This suggests that workplace MSD cannot be addressed by physical solutions alone and it is actually a multifaceted problem that requires psychosocial workplace assessment as well.

Discussion

This narrative review provides the first comprehensive review on the effect of prolonged standing on the lower back, lower limb and foot. It has clearly identified that prolonged occupational standing is having a negative impact on the body, with a high prevalence of MSD in working populations. Furthermore, it has been identified that there are multiple factors contributing to this including: muscle co-activation (Nelson-Wong *et al.,* 2008; Marshall *et al.,* 2011; Antle and Côte, 2013), vascular blood pooling (Antle *et al.,* 2013; Antle and Côte, 2013; Lin *et al.,* 2012) and muscular fatigue (Balasubramanian *et al.* 2009; Halim *et al.,* 2012). Other impacting factors include: age, a high BMI and psychosocial factors (Hill et al., 2008; Andersen et al., 2007; Bernal et al., 2015). Potential solutions include alterations in footwear and flooring, which are associated with changes in: subjective ratings, blood pooling, muscle activation, kinematics and plantar pressures (Kersting *et al.,* 2005; Chiu and Wang, 2007; Kim et al., 1998; Cham and Redfern, 20001; Hansen et al., 1998), although time standing remains a key influence on outcome (Cham and Redfern, 2001). Understanding the mechanisms that increase the risk of developing MSD is essential for the development of more effective preventative solutions, or treatments where issues already exist.

There are clear limitations to current studies. The lack of methodological standardisation, particularly in studies looking at solutions (i.e. flooring and footwear) is contributing to conflicting results between studies. This is due to both a lack of detail in some methods and the range of techniques used to measure the same dependent variables. An objective measure of the hardness of both flooring and footwear midsoles including thickness and material would enhance understanding and enable flooring and footwear to be adjusted more purposefully than is currently possible.

In laboratory based studies, the nature of the standing task must be specified more thoroughly and be based on observation of a target work place task (such as that by Messing and Kilbom (2001)) as these currently differ between studies. Some permit shifting of weight between feet (e.g. Antle *et al*., 2013), some allow arms to rest on a surface (e.g. Gregory and Callaghan, 2008), and others provide a confined area within which movement is permitted (e.g. Marshall *et al.,* 2011; Nelson-Wong *et al.,* 2008). Others also include breaks of varying lengths (e.g. Brownie and Martin, 2015). Understanding this will enable more effective transfer of knowledge to specific work environments. A common method for assessing self-reported measures would also improve the comparability of studies. Finally, the varying duration of studies is a critical issue. If an insufficient time is allowed the full extent of any effect on the body may be underestimated. It has been demonstrated that alterations in biomechanical variables do not always occur in a few hours (Hansen *et al.,* 1998; Cham and Redfern, 2001), but instead it is recommended that studies last 4-5 hours in order to observe the full effect of an intervention.

In terms of current suggestions for translating information from this review to the work place, it is recommended that employees create an environment that permits a range of postures. Workers should be encouraged to break periods of prolonged standing with walking due to the positive implications it has (Balasubramanian *et al.,* 2009). Flooring alterations or mats should be considered in environments where the floor is especially hard as this can reduce MSD in the long term (Wahlström *et al.,* 2012) and reduce perceived fatigue (King, 2002; Orlando and King, 2004; Brownie and Martin, 2015). In terms of current solutions not reviewed here, both compression socks and rocker shoes have been shown to decrease the effect of blood pooling and decrease discomfort (Chiu and Wang, 2007; Bringard *et al.,* 2006; Karimi *et al.* 2016). However, it must be noted that these are not appropriate for all environments (e.g. rocker shoes would not be suitable in jobs requiring precise dexterity tasks, e.g. surgery). Time should also be put into ensuring future research developments are translated to both work places and manufacturers. By following guidelines to reduce occupational MSD, it can be expected that reductions in performance caused by prolonged standing (Halim and Omar, 2011) and time off due to MSD would both be reduced. Therefore, implementing changes could benefit both the employee and the employer.

There are a number of areas that require future research. Focus on understanding the implications of methodological variations is essential, including the influence of using pain versus discomfort ratings, the most appropriate EMG methods of analysis and the most accurate and reliable way to measure venous blood pooling in the lower limb. For back pain, investigating risk factors other than muscle co-activation is important, since muscle co-activation fails to predict the development of 20-25% low back pain cases (Nelson-Wong *et al.,* 2008; Marshall *et al.,* 2011). The ability to predict the variables responsible for causing pain or discomfort in the lower limb and foot would also enhance the ability to create effective solutions. Lastly, the impact of interventions on muscle activation must be explored with rigorous methodology to gain a greater insight into the effect they are having.

Quantifying the current prevalence and nature of foot MSD is vital as very few studies have considered the foot as a separate entity. Furthermore, national surveys of specific work environments and MSD would enhance the current knowledge. This should include information into the current footwear worn, individual foot types and the activities in each specific environment in order to enhance future footwear development. Finally, the combined effects of individual flooring and footwear parameters alongside anthropometric variations must be considered, as it is highly likely they are interrelated. For instance, the optimal footwear condition may depend on the flooring used (and vice versa), which may in turn depend on foot posture. The implications of more research in this area could result in the creation of new work place legislation (e.g. certain flooring specifications), that would protect workers.

The exact impact of interventions (flooring and footwear) on prolonged standing is not clearly understood. It is crucial to understand this relationship in order for manufacturers to be able to develop suitable products to reduce the risk of MSD. Current footwear intervention studies use different pairs of shoes with many different design features making it impossible to distinguish which footwear design feature is causing the alterations in the dependent variables. Furthermore, although it appears there is a link between subjective measures of discomfort and blood pooling, similar associations have not been identified for other objective measures (muscle activation, kinematics, pressure and force measurements). To develop products that will be used, it is necessary for the user to be comfortable with the product as well as it being scientifically sound. Therefore studies should use a blend of device, biomechanical, physiological and user testing to not only understand the effects on individual parameters but also any associations between them.

The role of individual characteristics such as age, BMI, other health issues and psychosocial factors is clearly a relevant issue in terms of MSD at work but is not yet entirely understood. Establishing which variables effect MSD caused by prolonged standing at work could provide key information to individuals and employers on how to decrease the associated risk factors. For example, with more information, employers could promote healthier psychosocial environments in the work place. Understanding the impact of these individual characteristics could also lead to the development of cohort specific interventions, for example older individuals may be more suited to different floorings in comparison to younger people and people with a high BMI may require different footwear.

In conclusion, this narrative review has highlighted the impact of prolonged standing on the lower back, lower extremity and foot MSD, which affects a large proportion of the working population. There is a dearth of literature, particularly in relation to solutions such as footwear. However, it is important to emphasise that flooring, footwear and the body are inextricably linked and thus the impact of all three factors must be considered at the same time to establish solutions that will improve the daily lives of workers as well as manage the financial burden on employers and the health care system.

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Table 1: Summary of search criteria for papers.

Table 2 – Summary of studies looking at the effects of prolonged standing on lower back pain (VAS = visual analogue scale, G= gastrocnemius, S = soleus, TA = tibialis anterior, GM = gluteus medius, RA = rectus abdominus, EO = external oblique, IO = internal oblique, ES = erector spinae).

Table 3 – Summary of studies looking at the effect of prolonged standing on lower extremity pain and discomfort. (VAS = visual analogue scale, JCQ = job content questionnaire, G= gastrocnemius, S = soleus, TA = tibialis anterior, GM = gluteus medius, RA = rectus abdominus, EO = external oblique, IO = internal oblique, ES = erector spinae, T = trapezius).

Table 4 – Summary of studies looking at the effect of prolonged standing on the feet.

Table 5 – Summary of studies looking at the effect of flooring on various parameters. (COP = centre of pressure, G= gastrocnemius, S = soleus, TA = tibialis anterior, ES = erector spinae)

Table 6 – Summary of studies looking at the effect of footwear on various parameters. (G= gastrocnemius, TA = tibialis anterior, PL = peroneus longus, RF = rectus femoris, BF = biceps femoris ES = erector spinae, COP = centre of pressure)

Table 7 – Summary of studies investigating the confounding factors that contribute to musculoskeletal disorders. (JCQ = job content questionnaire, BMI = body mass index)

Table 1: Summary of search criteria for papers.

Sources of papers	**Years searched**	**Search terms**	**Search term connectors**	**Languages**
Solar Science Direct Web of Science Google Scholar	1994-2015 (last 21.5 years)	‘biomechanical’ ‘blood pooling’, ‘co-activation’ ‘discomfort’ ‘fatigue’, ‘feet’, ‘flooring’ ‘footwear’ ‘lower back’ ‘lower extremity/ leg’ ‘muscular fatigue’ ‘musculoskeletal disorders’, ‘occupation’ ‘musculoskeletal problems’, ‘pain’ ‘prolonged standing’ ‘shoe’ ‘work place’	‘and’ ‘effect’ ‘of’ ‘on’	English

Table 2 – Summary of studies looking at the effects of prolonged standing on lower back pain. (VAS = visual analogue scale, G= gastrocnemius, S = soleus, TA = tibialis anterior, GM = gluteus medius, RA = rectus abdominus, EO = external oblique, IO = internal oblique, ES = erector spinae).

Authors	**Participant**	**Time assessed**	**Outcomes/ measured variables**				
			MSD	**EMG**	**Psycho-social**	**VAS**	**Other**
Alexopoulus *et al.* (2004)	430 dentists	One-off question-naire	In last 12 months	-	-		-
Andersen *et al*. (2007)	5604 workers	2 years	In last 12 months	-	Copen-hagen		Physical risk factors
Antle and Côte (2013)	18 healthy participants	34 minutes	-	TA, S, G, GM, RA, EO, ES	-	Back	Blood flow Blood pressure
Gregory and Callaghan (2008)	16 healthy participants	2 hours	-	ES, RA, EO, GM	-	Low back	Spine kinematics
Marshall *et al.* (2011)	24 healthy participants	2 hours	-	GM	-	Low back	-
Nelson-Wong *et al.* (2008)	23 healthy participants	2 hours	-	ES, RA, EO, GM	-	Low back	-
Sheikhzadeh *et al.* (2009)	50 nurses/ technicians	One-off question-naire	In the last 12 months	-	Own questions	-	-
Sterud and Tynes (2013)	12 550 workers	3 years	In the last month	-	Own questions	-	Mechanical exposure
Nelson-Wong and Callaghan (2010)	43 healthy participants	2 hours	-	ES, RA, IO, EO, GM	Pain attitude and beliefs	Low back	Activity scale Physio tests

Table 3 – Summary of studies looking at the effect of prolonged standing on lower extremity pain and discomfort. (VAS = visual analogue scale, JCQ = job content questionnaire, G= gastrocnemius, S = soleus, TA = tibialis anterior, GM = gluteus medius, RA = rectus abdominus, EO = external oblique, IO = internal oblique, ES = erector spinae, T = trapezius).

Authors	**Participants**	**Time assessed**	**Outcomes/ measured variables**				
			MSD	**EMG**	**Psycho-social**	**VAS**	**Other**
Andersen *et al.* (2007)	5604 workers	2 years	In last 12 months	-	Copen-hagen	-	Physical risk factors
Antle *et al.* (2013)	10 healthy female participants	32 minutes	-	ES, RA	-	Feet Knees	Blood flow Blood pressure
Balasubramanian *et al.* (2009)	9 healthy male participants	60 minutes	-	G, T, ES	-	Leg Back Overall	-
Gell *et al.* (2011)	407 plant workers	One-off questionnaire	In the last year and Fatigue levels	-	JCQ	-	Physical examination Shoe hardness
Halim *et al.* (2012)	20 male production workers	5 hours 45 minutes	Fatigue of legs/ lower back	ES, TA, G	-	-	-
Messing *et al.*, (2006)	7770 workers	One-off questionnaire	Nordic questionnaire	-	JCQ	-	-
Pope *et al.* (2003)	3847 adults from 2 GP surgeries	One-off questionnaire	Hip pain in last month	-	-	-	Occupational/ leisure demands
Sheikhzadeh *et al.* (2009)	50 nurses/ technicians	One-off questionnaire	In the last 12 months	-	Own questions	-	-

Table 4 – Summary of studies looking at the effect of prolonged standing on the feet.

Authors	Participants	Time assessed	Outcomes/ measured variables	
			MSD	Other
Riddle *et al.* (2003)	50 with plantar fasciitis, 129 controls	One off measurements	-	Time on feet Plantar fasciitis risk factors
Nealy *et al.* (2012)	351 nurses	One off questionnaire	Foot pain. Foot problems.	-
Messing and Kilbom (2001)	10 members of staff	2-20 hours each.	-	Observation Pain pressure threshold

Table 5 – Summary of studies looking at the effect of flooring on various parameters. (COP = centre of pressure, G= gastrocnemius, S = soleus, TA = tibialis anterior, ES = erector spinae)

Authors	**Participant**	**Time assessed**	**Mat/flooring Intervention**	**Outcomes/ measured variables**				
				MSD	**EMG**	**Psycho-social**	**Blood pooling**	**Other**
Brownie and Martin (2015)	10 young, 6 older adults	5 hours	Nitrile rubber mat	-	G	-	-	-
Cham and Redfern (2001)	10 healthy participants	4 hours	6 different floor mats + hard floor	-	TA, S, ES	-	-	COP
Gell *et al.* (2011)	407 plant workers	One-off question naire	Anti-fatigue mat Hard surface Carpet	In the last year	-	JCQ	-	Physical factors
Hansen *et al.* (1998)	8 healthy females	2 hours	Polyurethane profiled mat (10mm)	Comfort (VAS)	ES	-	Foot volume	Skin temp.
Kim *et al.* (1994)	5 healthy participants	2 hours	8 mm mat 22 mm mat (compression: 6.9%; 2.2%)	-	G, TA, ES	-	-	-
King (2002)	27 factory workers	1 week	Mat	Fatigue Discom-fort	-	-	-	Perceived firmness
Lin *et al.*, (2012)	24 subjects	4 hours	Anti-fatigue mat (12.5 mm)	Discom-fort	-	-	Shank/ thigh circum-ference	COP
Madelaine *et al.* (1998)	13 healthy males	2 hours	Polyurethane mat	Muscle pain Unpleas -antness	TA	-	Shank circum-ference	Force platform Skin temp.
Orlando and King (2004)	16 factory workers	8 hours	Polyurethane mat	Fatigue Discomf ort	-	-	-	Perceived firmness
Wahlström *et al.* (2012)	Nurses (interventio n: 91 control:62)	2 years	4 mm vinyl floor (with 2.5 mm foam)	Pain	-	-	-	Pain related disability Perceived exertion
Zander *et al.* (2004)	13 factory workers	8 hours	Anti-fatigue mat	-	-	-	Shank circum-ference	-

Table 6 – Summary of studies looking at the effect of footwear on various parameters. (G= gastrocnemius, TA = tibialis anterior, PL = peroneus longus, RF = rectus femoris, BF = biceps femoris ES = erector spinae, COP = centre of pressure)

Authors	**Participant**	**Time assessed**	**Mat/flooring /Shoe**	**Outcomes/ measured variables**				
				MSD	**EMG**	**Plantar pressure**	**Blood pooling**	**Other**
Chiu and Wang (2007)	12 healthy participants	80 minutes	3 pairs of nursing shoes	-	RF, TA, BF, G	Yes	-	Motion capture GRF
Gell *et al.* (2011)	407 plant workers	One-off question naire	Shoe hardness (durometer)	In the last year	-	-	-	Physical factors
Hansen *et al.* (1998)	8 healthy females	2 hours	Wooden clog Sports shoe	Comfort (VAS)	ES	-	Foot volume	Skin temp.
Kersting *et al.*, (2005)	16 waiters	-	3 shoes: casual, neutral, functional	-	TA, G, PL	Yes	-	Rearfoot motion
King (2002)	27 factory workers	1 week	Viscoelastic insole	Fatigue Discom-fort	-	-	-	Perceived firmness
Lin *et al.*, (2007)	12 healthy females	1 hour	Outsole material (clean room boots)	-	ES, RF, BF, TA, G	-	-	Motion capture GRF
Lin *et al.*, (2012)	24 subjects	4 hours	Barefoot, Sports shoe	Discom-fort	-	-	Shank/ thigh circum-ference	COP
Orlando and King (2004)	16 factory workers	8 hours	Viscoelastic insole	Fatigue Discom-fort	-	-	-	Perceived firmness

Table 7 – Summary of studies investigating the confounding factors that contribute to musculoskeletal disorders. (JCQ = job content questionnaire, BMI = body mass index)

Authors	**Participant**	**Time assessed**	**MSD**	**Confounding factors**	
				Psychosocial	**Anthropometric**
Alexopoulus *et al.* (2004)	430 dentists	One-off questionnaire	In last 12 months	JCQ	-
Andersen *et al*. (2007)	5604 workers	2 years	In last 12 months	Copenhagen questionnaire	BMI
Bernal et al. (2015)	Review	-	-	Multiple	-
Gell *et al.* (2011)	407 plant workers	One-off questionnaire	In the last year and fatigue	JCQ	BMI, age, Physical examination, Foot posture
Hill et al. (2008)	4060 people	2 years	Foot pain	-	Age, BMI, waist: hip ratio, sex,
Irving et al. (2007)	80 patients, 80 controls	One-off measurements	Plantar heel pain	-	BMI, Foot posture Ankle dorsiflexion
Sterud and Tynes (2013)	12 550 workers	3 years	In the last month	QPS Nordic and own questions	-