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

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

32

33 **Abstract:**

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

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

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## 56 **Introduction**

57 Standing is a requirement of some occupations but may be chosen by a worker if it increases  
58 versatility and mobility (Halim and Omar, 2011). Prolonged occupational standing involves  
59 spending over 50% of time at work on the feet (Tomei *et al.*, 1999) and is associated with a  
60 range of maladaptive responses: chronic venous insufficiency; preterm birth; carotid  
61 atherosclerosis; and musculoskeletal disorders (MSD) (Halim and Omar, 2011). MSD include  
62 any symptoms such as pain and discomfort as well as damage to any body structure (Bernal *et*  
63 *al.*, 2015). The lower back, lower extremity and feet are particularly susceptible to MSD  
64 (Halim and Omar, 2011). The financial impact can be significant, with lower limb disorders  
65 exacerbated by standing responsible for a large proportion of sick days (O'Neill, 2005).  
66 Prolonged standing has also been associated with reduced work performance as discomfort  
67 and injuries can decrease the efficiency with which workers perform tasks (Halim and Omar,  
68 2011).

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

76

## 77 **Method**

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

81 [Table 1 near here]

82

### 83 **Results**

84 31 papers met the criteria (Tables 2- 7) and results organised into 6 themes.

#### 85 *The association between prolonged standing and lower back MSD*

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

88 [Table 2 near here]

89 In 430 dentists, 46% reported low back pain with 25% of these cases lasting over a  
90 month (Alexopoulos *et al.*, 2004). In perioperative nurses and technicians, over half noted  
91 symptoms in the lower back occurring in the previous seven days and this increased to 84%  
92 over the previous year (Sheikhzadeh *et al.*, 2009). The same study found that nearly a quarter  
93 of these nurses and technicians had visited a physician and a third had taken time off work.  
94 By comparison, in a study of 6000 generic UK inhabitants recruited randomly from GP  
95 surgeries-, the prevalence of back pain was far lower, at 12% in women and 7% in men aged  
96 16-44 (Urwin *et al.*, 1998), suggesting job demands have a dramatic impact on risk of lower  
97 back MSD.

98 In a two-year prospective study of various occupations that included administration,  
99 nursing, industrial work, kitchen, cleaning and technical staff, standing for >30 minutes in  
100 every hour of work was associated with a 1.9 (CI = 1.2-3.0) fold increase in risk of low back  
101 pain (Andersen *et al.*, 2007). A similar 3-year prospective study in Norway reported standing  
102 for three quarters of the working day increased risk of lower back pain by 1.48 (CI = 1.20-  
103 1.83) to 1.74 (CI = 1.46-2.07) dependent on other occupational risk factors (Sterud & Tynes,  
104 2013).

105           The impact of prolonged standing is also evident after shorter periods (2 hours) (Antle  
106 and Côte, 2013; Gregory and Callaghan, 2008; Marshall *et al.*, 2011; Nelson-Wong *et al.*,  
107 2008; Nelson-Wong and Callaghan, 2010). These studies of simulated occupational settings  
108 used a visual analogue scale (VAS) to assess pain or discomfort. Despite all lasting 2 hours  
109 and using similar participants, the outcomes varied between studies. In one study, 40% of 43  
110 asymptomatic participants developed low back pain (Nelson Wong and Callaghan, 2010)  
111 whereas Gregory and Callaghan (2008) reported 81% of 16 participants developed lower back  
112 discomfort. Other studies suggest prevalence rates of 65% (Nelson-Wong *et al.*, 2008) and  
113 71% (Marshall *et al.*, 2011). The prevalence differences are in part due to variances in the  
114 dependent variable, with prevalence of pain (40-65%) (Gregory and Callaghan, 2008; Nelson-  
115 Wong and Callaghan, 2010) lower than discomfort (71-81%) (Marshall *et al.*, 2011; Nelson-  
116 Wong *et al.*, 2008). This is expected since discomfort precedes pain (Goonetilleke and  
117 Luximon, 2001). Differences could also occur due to the characteristics of participants, such  
118 as the initial standing posture (Gregory and Callaghan, 2008).

119           One advantage of laboratory based studies is that they enable biomechanical variables  
120 to be measured. One factor critical to the development of low back pain is co-activation of  
121 muscles. Nelson-Wong *et al.*, (2008) found the presence or absence of gluteus medius co-  
122 activation predicted whether lower back pain would develop in 76% of subjects. As the co-  
123 activation was recorded prior to pain onset, the authors speculated that the co-activation was a  
124 causative factor and not an adaptive response. Nelson-Wong and Callaghan (2010) also  
125 reported co-activation of the gluteus medius muscles to be a causative factor of low back pain.  
126 A later study used gluteus medius co-activation to predict the development of low back pain  
127 in 80% of participants but suggested there were additional causative factors as the remaining  
128 20% were false-negatives (Marshall *et al.*, 2011). Antle and Côte (2013) found only trends  
129 towards muscle co-activation in gluteus medius muscles and the trunk flexor-extensors

130 although, the authors concede that differences in protocol and calculating co-activation could  
131 contribute to the lack of effect. Furthermore, Antle and Côte (2013) allowed participants to  
132 shift weight from foot to foot thus altering the biomechanics of the task.

### 133 ***The association between prolonged standing and lower extremity MSD***

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

#### 136 **[Table 3 near here]**

137 A questionnaire survey of factory workers who stand, showed 68% of 407 self-  
138 reported lower extremity fatigue by the end of a working day, with 34% stating it affected  
139 activities outside of work (Gell *et al.*, 2011). Furthermore, a fifth of workers were already  
140 undergoing treatment for lower extremity problems. In perioperative staff, knee pain was  
141 reported in 45% of 50 participants in the last 7 days and in 58% over the last year  
142 (Sheikhzadeh *et al.*, 2009). This compares to 7% of a general population aged 16-44 (Urwin  
143 *et al.*, 1998). In the ankle and foot, 59% had suffered pain in the last 7 days, 74% over the last  
144 year (Sheikhzadeh *et al.*, 2009) resulting in 25% taking time off. Increased hip pain is also  
145 associated with standing for long periods, both at work and in leisure activities (Pope *et al.*,  
146 2003).

147 A prospective 2-year study (Andersen *et al.*, 2007) demonstrated that standing for 30  
148 minutes or more of every hour at work, elevated the odds ratio for pain in the hip, knee or foot  
149 to 1.7 (CI = 1.0-2.9). Messing *et al.* (2006) reported a high odds ratio for calf or leg pain  
150 (3.69, CI = 2.19-6.23) and an increased odds ratio for ankle/foot pain (3.89, CI = 2.53-5.99)  
151 associated with standing compared to sitting with the freedom to move around.

152 Two short term studies used a VAS to assess lower limb and foot pain/ discomfort  
153 during a simulated prolonged standing work-based task. Antle and Côte (2013) found 15 of  
154 18 participants (83%) reported discomfort, reaching a mean of 3.47/10 in just 34 minutes. In a

155 comparison of static standing (only small adjustments to posture permitted) to dynamic  
156 standing (including walking between different tasks) over 1-hour, static standing induced  
157 higher levels of discomfort, with leg and overall comfort approximately 25% lower  
158 (Balasubramanian *et al.*, 2009). This suggests that self-reported indicators of MSD occur  
159 rapidly with static tasks having a greater effect.

160         The literature (Antle and Côte, 2013; Antle *et al.*, 2013; Halim *et al.* 2012;  
161 Balasubramanian *et al.* 2009) suggests two main biomechanical variables are related to lower  
162 extremity MSD: vascular blood pooling and muscular fatigue. Blood pooling is thought to  
163 occur due to venous reflux associated with standing. It occurs quickly, as demonstrated by  
164 Antle *et al.* (2013) in 32 minutes. In this short time, increased cutaneous blood flow in the  
165 foot and soleus correlated highly ( $>0.75$ ) with lower extremity discomfort. Similarly, within a  
166 34 minute protocol, lower limb blood pressure was increased (an early sign of blood pooling)  
167 in 85% of participants, though the correlation with discomfort was weaker ( $r=0.35$ ,  $p<0.05$ )  
168 (Antle and Côte, 2013). The relationship between blood pooling and discomfort occurs as a  
169 result of a build-up of metabolites that accelerate the onset of pain and fatigue (Edwards,  
170 1988). King (2002) reported that these metabolites activate afferent nociceptors that can lead  
171 to hypersensitivity of the muscles (Djupsjobacka *et al.*, 1994; Djupsjobacka *et al.*, 1995).

172         Muscle fatigue is also thought to be a key factor in the development of MSD  
173 (Phinyomark *et al.*, 2012), although the exact mechanistic link is unknown. Balasubramanian  
174 *et al.* (2009) investigated fatigue in static standing in comparison to dynamic standing over 1-  
175 hour. In the gastrocnemius muscles there was a decrease in the mean power frequency and an  
176 increase in the root mean square regression slope, indicating fatigue. This corresponded with  
177 an increase in discomfort. The relationship between self-reported fatigue and muscular fatigue  
178 evaluated using EMG was investigated by Halim *et al.* (2012) who reported prolonged  
179 standing caused psychological fatigue and muscular fatigue in the gastrocnemius, tibialis



180 anterior and erector spinae muscles. This was assessed through the mean power frequency and  
181 the time to fatigue. Conversely, Antle and Côte (2013) recorded significant decreases in the  
182 muscle activation of the tibialis anterior (19%) and the gastrocnemius (13%), occurring in the  
183 first 8 minutes (then becoming stable for the remaining time). However, as this effect  
184 occurred early, it could have been caused by initial adjustments made by participants.

### 185 *The effects of prolonged standing on musculoskeletal disorders of the feet*

186 Only three studies were identified that investigated the foot as a separate entity (Table  
187 4).

#### 188 [Table 4 near here]

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

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

200 Focussing on sales and kitchen workers, Messing and Kilbom (2001) reported that  
201 35% of workers time was spent walking, 62% was spent standing, and static standing only  
202 lasted up to 7 seconds. Furthermore, the minimum pressure needed to induce foot pain was  
203 lowered by 23% in individuals who spent the day on their feet, compared to only 5% in a  
204 control group (who sat for 95% of the day). Those that experienced foot pain throughout the

205 day demonstrated a lower pain pressure threshold. This provides key information into the  
206 patterns of movement in these work environments as well as identifying the pain-pressure  
207 threshold as another variable affected by prolonged standing.

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

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

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

218 **[Table 5 near here]**

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

224 Lin *et al.* (2012) compared a hard surface to a 12.5 mm mat and the former  
225 significantly increased discomfort and corresponded to a significant increase in thigh and  
226 shank circumferences. They also considered the effect of flooring on supermarket workers  
227 who stood all day. Over four hours, the hard floor increased thigh and shank circumference by  
228 1.7 cm and 0.8 cm respectively, significantly more than the anti-fatigue mat (0.8cm and  
229 0.5cm respectively). Similarly, over a 2-hour period in which ‘feeling of unpleasantness’ was

230 the dependent variable, mean unpleasantness was 71% higher ( $p=0.004$ ) for a hard surface  
231 compared to a polyurethane anti-fatigue mat (Madelaine *et al.*, 1998). Unfortunately none of  
232 these studies provide a quantitative measure of floor hardness.

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

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

255 more consistent protocols that utilise the same measure for blood pooling and report objective  
256 measures of floor hardness (and other properties).

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

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

270 Centre of pressure (COP) displacement is thought to provide an objective measure of  
271 discomfort or fatigue when standing on different surfaces and has been associated with leg  
272 fatigue (Wiggerman, 2011; Vuillerme *et al.*, 2002). An increase in COP displacement is  
273 suggested as a protective mechanism, as it results from increased lower limb muscle action.  
274 This could have a positive impact on venous return and thus blood pooling (Antle and Côte,  
275 2013). Cham and Redfern (2001) reported a positive correlation between higher levels of  
276 COP displacement and whole leg fatigue ( $r=0.45$ ), leg discomfort ( $r=0.86$ ), ankle discomfort  
277 ( $r = 0.80$ ) and foot discomfort ( $r=0.70$ ). The authors suggested that lateral shifting of the COP  
278 was a mechanism employed to reduce fatigue and discomfort. This is supported by a 15%

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

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

295         Overall, numerous studies report alterations in matting or flooring to have a positive  
296 impact on MSD when standing (King, 2002; Orlando and King, 2004; Brownie and Martin,  
297 2015; Wahlström *et al.*, 2012; Lin *et al.* 2012; Madelaine *et al.*, 1998). However, different  
298 methodologies have created disparities between studies and the lack of information regarding  
299 the exact properties of the flooring or mats used make it impossible to draw practical  
300 recommendations. The impact of flooring on muscle activation is not well supported and the  
301 study numbers are limited.

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

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

308 **[Table 6 near here]**

309           Lin *et al.* (2012) found sports shoes, in comparison to barefoot, decreased subjective  
310 discomfort by approximately 1.5 on a 7-point Likert scale. However, no difference between  
311 conditions in shank circumference were observed over the 4-hours. Hansen *et al.* (1998)  
312 reported no impact on self-reported discomfort ratings between a hard wooden clog and a  
313 sports shoe, but did find the sports shoe significantly reduced blood pooling and thus oedema  
314 formation from 3.2% to 2.8%, when flooring was kept constant. As these were the only two  
315 studies investigating this variable, future work should consider the impact of altering footwear  
316 on blood pooling in the lower limb, due to its association with discomfort (Antle and Côte,  
317 2013). It is possible that these discrepancies arose as a result of the reliance on subjective  
318 measures.

319           Participants subjective measures of footwear relating to discomfort and fatigue were  
320 recorded in multiple studies (Gell *et al.*, 2011; King, 2002; Orlando and King, 2004; Lin *et al.*,  
321 2007; Chiu and Wang, 2007). Gell *et al.* (2011) reported harder footwear (those with a type C  
322 durometer reading over 32) increased the risk for lower extremity self-reported fatigue by 2.6  
323 (CI = 1.3-5.3) times in comparison to footwear with a low hardness level (those with a type C  
324 durometer reading below 18). King (2002) found viscoelastic insoles and floor mats provided  
325 statistically similar reductions in both general fatigue (mean floor = 3.95; mean with insoles =  
326 2.84) and leg fatigue (mean on floor = 3.93; mean with insoles = 2.68) in comparison to a  
327 hard floor over an entire working week. However, they were unable to control for the

328 footwear worn. In factory workers over an eight hour shift, adding an insole to a shoe  
329 decreased the firmness rating from 4.1 to 2.55, the general fatigue from 3.20 to 2.45 and the  
330 leg fatigue from 3.4 to 2.18 based on a 5-point Likert scale (Orlando and King, 2004). The  
331 mean fatigue reductions were larger than that reported when using an anti-fatigue mat  
332 (Orlando and King, 2004). Lin *et al.*, (2007) tested clean room boots (shoes made of an  
333 outsole and upper covering the entire shank) that differed only in the sole elasticity and shock  
334 absorption. Over 1-hour, low values of elasticity and shock absorption were related to  
335 discomfort. Chiu and Wang (2007) reported a thin sole in nursing shoes increased the number  
336 of discomfort complaints in the back, thigh, knee and shin (Chiu and Wang, 2007).  
337 Furthermore, a positive relationship was reported between the discomfort ratings and plantar  
338 pressure measurement. The only exception to this was in the arch area, in which the authors  
339 suggested an ill-fitting arch increased the level of discomfort.

340 In-shoe plantar pressure is an important biomechanical measure as areas of high  
341 pressure can build into areas of pain and cause corns, calluses and blisters as well as  
342 exacerbate and increase the risk of more serious MSD (Springett and Johnson, 2002). Testing  
343 3 pairs of nursing shoes, Chiu and Wang (2007) found significant differences in all seven  
344 areas of the foot (the toe, 2<sup>nd</sup>-5<sup>th</sup> phalanges, 1<sup>st</sup> metatarsal, 2<sup>nd</sup>-3<sup>rd</sup> metatarsal, 4<sup>th</sup>-5<sup>th</sup> metatarsal,  
345 arch and heel). They reported that the width of footwear impacted on the pressure distribution  
346 in the toes and an arch support increased the area of the foot in contact with the shoe,  
347 reducing peak pressures. It was also suggested that the outsole thickness and material have the  
348 ability to alter the pressures on the plantar surface. Kersting *et al.* (2005) also collected in-  
349 shoe plantar pressure measurements, dividing the foot into 8 regions for analysis. The variable  
350 'shoe' had the greatest impact on plantar pressure, and concurring with Chiu and Wang  
351 (2007), they reported that an increased arch support reduced the pressure in other areas such  
352 as the lateral forefoot and heel. The lack of cushioning in some shoes was also suggested to be

353 a contributor to high peak pressures. However, the large number of structural variations  
354 prevents specific conclusions being drawn. Furthermore, it must be noted that this occurred  
355 during tasks that were mostly dynamic in nature and no study was identified that considered  
356 the effect of footwear in static standing on plantar pressures.

357         Muscle activation was tested in two occupational footwear studies (Chiu and Wang,  
358 2007; Kersting *et al.*, 2005), although these primarily focused on walking tasks. Chiu and  
359 Wang (2007) reported EMG, normalised to maximum voluntary contraction, remained  
360 unaltered across 3 pairs of nursing footwear for all muscles apart from the medial  
361 gastrocnemius in which a significant decrease in muscle activation was recorded in two of the  
362 shoes. This was attributed to increased arch support, although the diverse structural  
363 differences between them makes it impossible to firmly attribute a specific footwear feature to  
364 the changes. In catering staff, three shoes varying in midsole stiffness, arch support, grip,  
365 material and heel counters were tested (Kersting *et al.*, 2005). Higher EMG values of the  
366 peroneus longus and gastrocnemius muscles were found in the footwear with the stiffest  
367 midsole and no arch support in comparison to that with the soft insole, high grip and  
368 increased foot support. The authors directly attributed this to the grip differences, but it is  
369 equally feasible that the stiff midsole could have instigated higher muscle activation to permit  
370 pronation. Alternatively, this could have been caused by the alterations in arch support (Chiu  
371 and Wang, 2007). Erector spinae muscle activation was also altered between shoes, with  
372 greater EMG displayed in the stiff midsole shoe again, but this time in comparison to the shoe  
373 with the flexible midsole with no support. It is impossible to ascribe these changes to a  
374 specific feature.

### 375 ***Contributing factors to occupational musculoskeletal disorders***

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



378 **[Table 7 near here]**

379           The most obvious contributing factor to the development of MSD is age. In a general  
380 population, Hill *et al.* (2008) found foot pain to significantly increase ( $P < 0.001$ ) with every  
381 ten years of age added, from 25 years to over 75 years. The odds ratio increased to 2.4 (CI =  
382 1.79-3.22) in ages 45-54 and to 2.78 (CI = 2.04-3.77) in ages 55-64. Conversely, Alexopoulos  
383 *et al.* (2004) found no change in the odds ratio for increasing age in terms of MSD in the  
384 lower back.

385           Further to age, the body mass index (BMI) also impacts on the prevalence of MSD in  
386 the workplace. Andersen *et al.* (2007) report a higher BMI to increase the odds of any  
387 regional pain from 1.1-1.4 and for hip, knee and foot pain from 1.4-2.3, dependent on BMI  
388 category. Gell *et al.* (2011) reported that for every increase of 5 on the BMI scale the odds of  
389 reporting fatigue increased 28%. A BMI of 25 – 30 and over 30 increased the odds of  
390 developing plantar fasciitis by 2 (CI = 1.28-3.08) and 5.6 (1.9-16.6), respectively. The greater  
391 levels of discomfort and pain could be caused by the larger amount of blood pooling that has  
392 been shown to occur in individuals with a greater mass (Zander *et al.*, 2004). Irving *et al.*  
393 (2007) report a significantly increased risk (odds ratio = 2.9, CI = 1.4-6.1) of developing  
394 plantar heel pain when BMI was over 30. The authors also reported that a pronated foot type  
395 increased these odds, which raises the question of the impact of foot posture on developing  
396 MSD in the work place, which has not yet been explored.

397           In addition to physical factors, psychosocial factors including high job demand and  
398 low job control influence the level of self-reported MSD. A 3-year prospective study  
399 identified attributable risks with these two factors of 11.6% and 4.9% respectively (Sterud and  
400 Tynes, 2013). Over 2-years, and after multivariate adjustments were made, low social support  
401 from colleagues, low job satisfaction and fear avoidance were attributable risks for MSD,  
402 with odds ratios from 1.3 to 2.1 (Andersen *et al.*, 2007). Job dissatisfaction was also shown to

403 increase the risk for lower extremity fatigue in plant workers with an odds ratio of 1.3  
404 although supervisor support was shown to be a protective factor (Gell *et al.*, 2011). A  
405 systematic review and meta-analysis of 24 studies (Bernal *et al.*, 2015) found that high  
406 psychosocial demands and low job control were associated with an increase in the incidence  
407 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  
408 any site by 1.38 (CI =1.09-1.75). Associations were also found between low social support  
409 and the prevalence of back pain (1.38, CI = 1.43-2.32) and between MSD prevalence in any  
410 area and an imbalance between effort and reward (6.13, CI = 5.32-7.07). This suggests that  
411 workplace MSD cannot be addressed by physical solutions alone and it is actually a  
412 multifaceted problem that requires psychosocial workplace assessment as well.

413

## 414 **Discussion**

415 This narrative review provides the first comprehensive review on the effect of  
416 prolonged standing on the lower back, lower limb and foot. It has clearly identified that  
417 prolonged occupational standing is having a negative impact on the body, with a high  
418 prevalence of MSD in working populations. Furthermore, it has been identified that there are  
419 multiple factors contributing to this including: muscle co-activation (Nelson-Wong *et al.*,  
420 2008; Marshall *et al.*, 2011; Antle and Côte, 2013), vascular blood pooling (Antle *et al.*, 2013;  
421 Antle and Côte, 2013; Lin *et al.*, 2012) and muscular fatigue (Balasubramanian *et al.* 2009;  
422 Halim *et al.*, 2012). Other impacting factors include: age, a high BMI and psychosocial  
423 factors (Hill *et al.*, 2008; Andersen *et al.*, 2007; Bernal *et al.*, 2015). Potential solutions  
424 include alterations in footwear and flooring, which are associated with changes in: subjective  
425 ratings, blood pooling, muscle activation, kinematics and plantar pressures (Kersting *et al.*,  
426 2005; Chiu and Wang, 2007; Kim *et al.*, 1998; Cham and Redfern, 20001; Hansen *et al.*,  
427 1998), although time standing remains a key influence on outcome (Cham and Redfern,

428 2001). Understanding the mechanisms that increase the risk of developing MSD is essential  
429 for the development of more effective preventative solutions, or treatments where issues  
430 already exist.

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

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

452           In terms of current suggestions for translating information from this review to the  
453 work place, it is recommended that employees create an environment that permits a range of  
454 postures. Workers should be encouraged to break periods of prolonged standing with walking  
455 due to the positive implications it has (Balasubramanian *et al.*, 2009). Flooring alterations or  
456 mats should be considered in environments where the floor is especially hard as this can  
457 reduce MSD in the long term (Wahlström *et al.*, 2012) and reduce perceived fatigue (King,  
458 2002; Orlando and King, 2004; Brownie and Martin, 2015). In terms of current solutions not  
459 reviewed here, both compression socks and rocker shoes have been shown to decrease the  
460 effect of blood pooling and decrease discomfort (Chiu and Wang, 2007; Bringard *et al.*, 2006;  
461 Karimi *et al.* 2016). However, it must be noted that these are not appropriate for all  
462 environments (e.g. rocker shoes would not be suitable in jobs requiring precise dexterity  
463 tasks, e.g. surgery). Time should also be put into ensuring future research developments are  
464 translated to both work places and manufacturers. By following guidelines to reduce  
465 occupational MSD, it can be expected that reductions in performance caused by prolonged  
466 standing (Halim and Omar, 2011) and time off due to MSD would both be reduced.  
467 Therefore, implementing changes could benefit both the employee and the employer.

468           There are a number of areas that require future research. Focus on understanding the  
469 implications of methodological variations is essential, including the influence of using pain  
470 versus discomfort ratings, the most appropriate EMG methods of analysis and the most  
471 accurate and reliable way to measure venous blood pooling in the lower limb. For back pain,  
472 investigating risk factors other than muscle co-activation is important, since muscle co-  
473 activation fails to predict the development of 20-25% low back pain cases (Nelson-Wong *et*  
474 *al.*, 2008; Marshall *et al.*, 2011). The ability to predict the variables responsible for causing  
475 pain or discomfort in the lower limb and foot would also enhance the ability to create

476 effective solutions. Lastly, the impact of interventions on muscle activation must be explored  
477 with rigorous methodology to gain a greater insight into the effect they are having.

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

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

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

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

517

518 **Word count: 6029**

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690 **Table 1:** Summary of search criteria for papers.

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

696

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

701

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

703

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

706

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

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

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720 **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

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751 **Table 2** – Summary of studies looking at the effects of prolonged standing on lower back  
 752 pain. (VAS = visual analogue scale, G= gastrocnemius, S = soleus, TA = tibialis anterior, GM  
 753 = gluteus medius, RA = rectus abdominus, EO = external oblique, IO = internal oblique, ES =  
 754 erector spinae).  
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Authors	Participant	Time assessed	Outcomes/ measured variables				
			MSD	EMG	Psycho-social	VAS	Other
<b>Alexopoulos et al. (2004)</b>	430 dentists	One-off questionnaire	In last 12 months	-	-	-	-
<b>Andersen et al. (2007)</b>	5604 workers	2 years	In last 12 months	-	Copenhagen	-	Physical risk factors
<b>Antle and Côte (2013)</b>	18 healthy participants	34 minutes	-	TA, S, G, GM, RA, EO, ES	-	Back	Blood flow Blood pressure
<b>Gregory and Callaghan (2008)</b>	16 healthy participants	2 hours	-	ES, RA, EO, GM	-	Low back	Spine kinematics
<b>Marshall et al. (2011)</b>	24 healthy participants	2 hours	-	GM	-	Low back	-
<b>Nelson-Wong et al. (2008)</b>	23 healthy participants	2 hours	-	ES, RA, EO, GM	-	Low back	-
<b>Sheikhzadeh et al. (2009)</b>	50 nurses/ technicians	One-off questionnaire	In the last 12 months	-	Own questions	-	-
<b>Sterud and Tynes (2013)</b>	12 550 workers	3 years	In the last month	-	Own questions	-	Mechanical exposure
<b>Nelson-Wong and Callaghan (2010)</b>	43 healthy participants	2 hours	-	ES, RA, IO, EO, GM	Pain attitude and beliefs	Low back	Activity scale Physio tests

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768 **Table 3** – Summary of studies looking at the effect of prolonged standing on lower extremity  
769 pain and discomfort. (VAS = visual analogue scale, JCQ = job content questionnaire, G=  
770 gastrocnemius, S = soleus, TA = tibialis anterior, GM = gluteus medius, RA = rectus  
771 abdominus, EO = external oblique, IO = internal oblique, ES = erector spinae, T = trapezius).  
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Authors	Participants	Time assessed	Outcomes/ measured variables				
			MSD	EMG	Psycho-social	VAS	Other
<b>Andersen et al. (2007)</b>	5604 workers	2 years	In last 12 months	-	Copenhagen	-	Physical risk factors
<b>Antle et al. (2013)</b>	10 healthy female participants	32 minutes	-	ES, RA	-	Feet Knees	Blood flow Blood pressure
<b>Balasubramanian et al. (2009)</b>	9 healthy male participants	60 minutes	-	G, T, ES	-	Leg Back Overall	-
<b>Gell et al. (2011)</b>	407 plant workers	One-off questionnaire	In the last year and Fatigue levels	-	JCQ	-	Physical examination Shoe hardness
<b>Halim et al. (2012)</b>	20 male production workers	5 hours 45 minutes	Fatigue of legs/ lower back	ES, TA, G	-	-	-
<b>Messing et al., (2006)</b>	7770 workers	One-off questionnaire	Nordic questionnaire	-	JCQ	-	-
<b>Pope et al. (2003)</b>	3847 adults from 2 GP surgeries	One-off questionnaire	Hip pain in last month	-	-	-	Occupational/ leisure demands
<b>Sheikhzadeh et al. (2009)</b>	50 nurses/ technicians	One-off questionnaire	In the last 12 months	-	Own questions	-	-

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

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

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811 **Table 5** – Summary of studies looking at the effect of flooring on various parameters. (COP =  
812 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
<b>Brownie and Martin (2015)</b>	10 young, 6 older adults	5 hours	Nitrile rubber mat	-	G	-	-	-
<b>Cham and Redfern (2001)</b>	10 healthy participants	4 hours	6 different floor mats + hard floor	-	TA, S, ES	-	-	COP
<b>Gell et al. (2011)</b>	407 plant workers	One-off questionnaire	Anti-fatigue mat Hard surface Carpet	In the last year	-	JCQ	-	Physical factors
<b>Hansen et al. (1998)</b>	8 healthy females	2 hours	Polyurethane profiled mat (10mm)	Comfort (VAS)	ES	-	Foot volume	Skin temp.
<b>Kim et al. (1994)</b>	5 healthy participants	2 hours	8 mm mat 22 mm mat (compression: 6.9%; 2.2%)	-	G, TA, ES	-	-	-
<b>King (2002)</b>	27 factory workers	1 week	Mat	Fatigue Discomfort	-	-	-	Perceived firmness
<b>Lin et al., (2012)</b>	24 subjects	4 hours	Anti-fatigue mat (12.5 mm)	Discomfort	-	-	Shank/thigh circumference	COP
<b>Madelaine et al. (1998)</b>	13 healthy males	2 hours	Polyurethane mat	Muscle pain Unpleasantness	TA	-	Shank circumference	Force platform Skin temp.
<b>Orlando and King (2004)</b>	16 factory workers	8 hours	Polyurethane mat	Fatigue Discomfort	-	-	-	Perceived firmness
<b>Wahlström et al. (2012)</b>	Nurses (intervention: 91 control:62)	2 years	4 mm vinyl floor (with 2.5 mm foam)	Pain	-	-	-	Pain related disability Perceived exertion
<b>Zander et al. (2004)</b>	13 factory workers	8 hours	Anti-fatigue mat	-	-	-	Shank circumference	-

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817 **Table 6** – Summary of studies looking at the effect of footwear on various parameters. (G=  
818 gastrocnemius, TA = tibialis anterior, PL = peroneus longus, RF = rectus femoris, BF =  
819 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
<b>Chiu and Wang (2007)</b>	12 healthy participants	80 minutes	3 pairs of nursing shoes	-	RF, TA, BF, G	Yes	-	Motion capture GRF
<b>Gell et al. (2011)</b>	407 plant workers	One-off question naire	Shoe hardness (durometer)	In the last year	-	-	-	Physical factors
<b>Hansen et al. (1998)</b>	8 healthy females	2 hours	Wooden clog Sports shoe	Comfort (VAS)	ES	-	Foot volume	Skin temp.
<b>Kersting et al., (2005)</b>	16 waiters	-	3 shoes: casual, neutral, functional	-	TA, G, PL	Yes	-	Rearfoot motion
<b>King (2002)</b>	27 factory workers	1 week	Viscoelastic insole	Fatigue Discom- fort	-	-	-	Perceived firmness
<b>Lin et al., (2007)</b>	12 healthy females	1 hour	Outsole material (clean room boots)	-	ES, RF, BF, TA, G	-	-	Motion capture GRF
<b>Lin et al., (2012)</b>	24 subjects	4 hours	Barefoot, Sports shoe	Discom- fort	-	-	Shank/ thigh circum- ference	COP
<b>Orlando and King (2004)</b>	16 factory workers	8 hours	Viscoelastic insole	Fatigue Discom- fort	-	-	-	Perceived firmness

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

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