Prolonged standing in the workplace – a mixed methods approach to exploring, developing and evaluating footwear solutions

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Statement of Own Contribution

As a PhD by published works, six papers are presented that have been published in peer-reviewed journals. These papers have been written in collaboration with co-authors, for which the contribution from each can be seen in the below table. The verification for this table has been provided by all key authors, available in the appendix at the end of these works (Appendix 1).

***Table 0.1** Authors and individual contribution for each paper in this thesis*

Paper Number	Authors	Independent Contribution	Joint Contribution	Reference
1	Jennifer Anderson, Anita E Williams Christopher J Nester	Literature search Initial paper draft	Study conception and design Paper writing and editing	(Anderson *et al.*, 2017a)
2	Jennifer Anderson, Malcolm H. Granat, Anita E. Williams Christopher Nester	Recruitment Data Collection Data Analysis Initial paper draft	Study conception Study and analysis design Data Interpretation Paper writing and editing	(Anderson et al., 2019)
3	Jennifer Anderson, Anita E Williams Christopher J Nester	Recruitment Data collection Data analysis Initial paper draft	Study conception and design Questionnaire design Data Interpretation Paper writing and editing	(Anderson *et al.*, 2021)
4	Jennifer Anderson, Anita E Williams Christopher J Nester	Recruitment Data Collection Primary Data Analysis Initial paper draft	Study conception and design Secondary data analysis Data Interpretation Paper writing and editing	(Anderson *et al.*, 2017b)
5	Jennifer Anderson, Anita E Williams Christopher J Nester	Laboratory set up Recruitment Data Collection Data Analysis Initial paper draft	Study conception and design Technical research design Data Interpretation Paper writing and editing	(Anderson *et al.*, 2018)
6	Jennifer Anderson, Anita E Williams Christopher J Nester	Recruitment Data Collection Data Analysis Initial paper draft	Study conception and design Insole design Technical research design Data Interpretation Paper writing and editing	(Anderson *et al.*, 2020)

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Abstract

Prolonged standing at work, or prolonged periods maintaining an upright posture is required in 58-72% of working populations and is associated with the development of work-related musculoskeletal disorders in the lower back, legs and feet. This can result in the loss of workforce and a reduced quality of life for workers and has financial implications at a government level, for the individuals and for the employers.

This thesis is comprised of 6 peer-reviewed journal papers as a focussed body of work and a critical analysis of these papers and how they relate to the work of others in the field. It is presented in two parts. The first *explores* the demands of prolonged standing, considering the previous literature, definitions of workplace activity and the prevalence of musculoskeletal disorders. The second part *develops* and *evaluates* a footwear solution for prolonged standing workers through: interviews with end-users; studying biomechanical changes over time and assessing footwear comfort.

The adopted mixed methods approach enables footwear development based on quantitative biomechanical outcomes and qualitative consumer data, demonstrating a novel approach to the problem of prolonged standing at work. The impact of the published works is considered in the critical analysis chapter that also critiques the key methodological strengths and limitations, provides documentation of a research-based footwear development process and develops suggestions for future research.

Overall, this thesis identifies that workers spending prolonged periods of time standing demonstrate a high prevalence of musculoskeletal disorders, recognises the need to redefine standing into multiple activities and develops a range of insoles for footwear that optimise comfort for the individual based on the identification that a one-shoe-fits-all approach is not adequate. The footwear solution comprised a range of insoles varying in hardness under the medial arch alongside an exploration of factors related to insole preference and comfort. However, perhaps the most important conclusion that can be drawn from these works relate to the need for future research, and specifically the relationships between time, standing, foot health and footwear.

Chapter 1 : Introduction

This introduction will define the context of the research, introduce the topic of prolonged work-based standing and identify the approach taken to the research.

1.1 The research in context

This body of work had two overarching aims. As part of a Knowledge Transfer Partnership (KTP), a joint project with a business and an academic partner (in this instance the University of Salford), the work had to meet the expectations of the commercial partner but also create novel academic papers. The commercial project's aim was to "embed an applied research function into product development resulting in the partner company leading in world class footwear for demanding environments". From an academic perspective it was expected to develop knowledge surrounding the demands faced by prolonged standing workers and the impact standing had on foot health and footwear, a topic for which there is a dearth of information. In the context of the KTP, the research questions were thus derived to fit the needs of the company in a way that would produce commercially viable solutions while addressing the current gaps in the literature.

The partner company specialised predominantly in footwear for health service surgical staff working in operating theatres. Prior to the KTP, the company did not have a research led product development strategy or knowledge about the function of the lower limb and foot. As a small company, the KTP project was expected to have a direct impact on all areas of the business, from marketing and sales to product development. Therefore, research surrounding health at work was also important for the company to establish themselves as knowledge leaders within their market.

From a personal perspective, my motivation for this project came from the opportunity to complete novel research with a real-world impact. The link with a commercial partner meant that the research would be directed towards the development of a final product, rather than solely the publication of papers. Furthermore, it created the opportunity for me to learn about how a business operates and how product development and research could work together.

Overall, this body of work provides a real-world example of how the development of knowledge can lead to a footwear solution. It also documents the impact that academic research can have on a company's direction and tells the story of how the two evolved together.

1.2 Prolonged standing at work

1.2.1 What is prolonged standing?

There is no single accepted definition of prolonged standing in the workplace. Perhaps the most frequently cited definition is 'roles in which standing is required for 50% or more of the total time at work', i.e. one in which the primary activity in the workplace is standing. The studies that this is derived from investigated the risk of venous disorders in working populations, and found those standing for over 50% of their time were at a greater risk of suffering from such problems (Abramson *et al.*, 1981; Tomei *et al.*, 1999). However, other studies have used different lengths of time. For example, a study considering adverse pregnancy outcomes defined prolonged standing as 'more than 3 hours per day or the predominant occupational posture' (Mozurkewich *et al.*, 2000). Another study looking at hospitalisation due to varicose veins defined it as 'standing or walking' at least 75% of time (Tüchsen *et al.*, 2005). These definitions appear to be fairly arbitrary rather than objectively chosen and rely solely on the overall duration of an activity.

Based on the range of jobs identified and the associated variations in work activity, prolonged standing would perhaps be better considered on a scale of risk, rather than a single cut off point. This idea underpins the work by Halim and Omar (2012), whose 'Prolonged Standing Strain Index' quantifies the risks of individual standing jobs. It consists of an equation that rates standing duration but also includes other risk factors such as working posture and muscle activity (Figure 1.1). Multipliers were applied to each value dependent on the risk rating it was given. With respect to standing these were as follows:

- Low risk = <u>below</u> 1 hour of continuous standing <u>and</u> less than 4 hours of total standing
- Moderate risk = <u>over</u> 1 hour of continuous standing <u>or</u> over 4 hours of total standing
- High risk = <u>over</u> 1 hour of continuous standing <u>and</u> over 4 hours of total standing.

PSSI = WP x MA x SD x HT x WBV x IAQ

PSSI = prolonged standing strain index
WP=working posture
MA= muscle activity
SD = standing duration
HT = holding time
WBV = whole body vibration
IAQ indoor air quality

Figure 1.1 *Equation defining prolonged standing strain index (Halim and Omar, 2012)*

The need to include the duration of single standing bouts alongside the total duration of standing, as suggested by Halim and Omar (2012) is reinforced by the results of a systematic review of laboratory based standing studies that identifies a safe limit of 40 minutes of continuous standing, after which individuals start to develop lower back pain (Coenen *et al.*, 2017). Similarly the Association for Perioperative Registered Nurses recommends not standing for more than 30% of the work day or for more than 2 hours at a time (Hughes *et al.*, 2011). Thus, when considering problems associated with prolonged standing, it appears important to consider not only its total duration but also the length of continuous standing periods.

1.2.2 Who is affected by prolonged standing?

The broad range of jobs that demand periods of prolonged standing include factory workers, those in the food industry, teachers, hairdressers, a range of health care workers, retail workers and security guards to name a few. As a result, estimations of those undertaking prolonged standing are typically large proportions of the working population, although the exact number is clearly dependent on the definition used for standing. In Australia, 62% of a sample of the general population reported work that included periods of standing (Safe Work Australia, 2011), comparable to that reported in Quebec, Canada, in which 58% of workers reported their usual working position as standing (Tissot *et al.*, 2005). In a European Survey, it was estimated that 72% of men and 66% of women of workers undertook prolonged standing for at least a quarter of their working time (Parent-Thirion *et al.*, 2012). Although estimations, all of these figures indicate that the majority of the working population are spending prolonged periods of their work time standing and consequently the findings of the research within this thesis are likely to be relevant to a large proportion of our population.

1.2.3 What are the effects of prolonged standing?

There are several risks associated with prolonged standing. These have been previously listed as chronic venous insufficiency, pre term birth (in pregnant women) and musculoskeletal disorders of the lower back, legs and feet (McCulloch, 2002), the latter of which will be the focus of this body of work.

Musculoskeletal disorder is a non-specific term that encompasses pain caused by a variety of factors that include damage to muscles, tendons, ligaments, peripheral nerves, joints, bones, cartilage or supporting blood vessels (Stack *et al.*, 2016). Work related musculoskeletal disorders (WMSD) refer to those that are caused or worsened by working conditions (Stack *et al.*, 2016). Both physical workload and personal factors contribute to the development of work-related musculoskeletal disorders.

There are varying levels of musculoskeletal disorders that have been defined, ranging from aches and pains to irreversible damage (Table 1.1). The Canadian Centre for Occupational Health and

Safety (2019) describes an initial ache or pain during the working day that over time progresses to pain and weakness at rest that impacts daily life. A second model also starts with aches and pains that do not impact performance that eventually become persistent symptoms that impact even the lightest tasks (Stack *et al.*, 2016). This highlights the necessity of identifying and finding solution to the initial aches and pains to prevent them from worsening into life limiting conditions or disabilities.

Table 1.1 *Stages of work-related musculoskeletal disorders (WMSD)*

	Canadian Centre for Occupational Health and Safety, (2019)	**Stack, Ostrom and Wilhelmsen (2016), p361**
Stage 1	Aching and tiredness of the affected limb occur during the work shift but disappear at night and during days off work. No reduction of work performance.	Usually shows aches and fatigue during the working hours but with rest at night and days off work these aches seem to settle. • Shows no drop in performance. • May persist for weeks or months. • Can be reversed.
Stage 2	Aching and tiredness occur early in the work shift but disappear at night and during days off work.	Same symptoms occur early in the work shift and sleep does not settle the pain. In fact, sleep may be disturbed. • Shows performance of the task is reduced • Usually persist over months • Can be reversed
Stage 3	Aching, fatigue and weakness persist at rest. Inability to sleep and to perform light duties.	Symptoms persist while resting. Pain occurs while performing nonrepetitive movements • The person is unable to perform even light tasks • May last for months or years • Usually not reversible

1.2.4 Prevalence of musculoskeletal disorders

Musculoskeletal prevalence is most often assessed using the above defined Stage 1 of their development, i.e. through the identification of specific regions that suffer from pain while at work. It is most commonly assessed with the Standardised Nordic questionnaire, that assess pain in each region of the body (Kuorinka *et al.*, 1987). All questions in the assessment are binary (yes/no) or multiple choice and aim to screen for musculoskeletal disorders in an ergonomic context. It considers individual body regions although it unfortunately groups the ankle and feet as a single component (figure 1.2), limiting our understanding of these regions independently.

When considering the regions in Figure 2, studies have assessed the prevalence of musculoskeletal disorders in a range of professions from nurses and dentists to retail and food workers (Table 1.2). On average, 58% reported lower back pain, 23% pain in the hip/thigh, 38% in the knee, 18% in the lower leg and 35% in the ankles/feet. In the general adult population it has been identified that 24% suffered from back pain, 12% from hip/thigh pain and 24% knee pain (Urwin *et al.*, 1998). In the feet, it has been reported that 17% of the general Australian population and 22% of the UK population suffered from foot pain (Garrow *et al.*, 2004; Hill *et al.*, 2008). However, it must be noted that the three general population studies asked participants about pain in the past 1 month compared to the 12 months in the Nordic Questionnaire, for which no general population data was available.

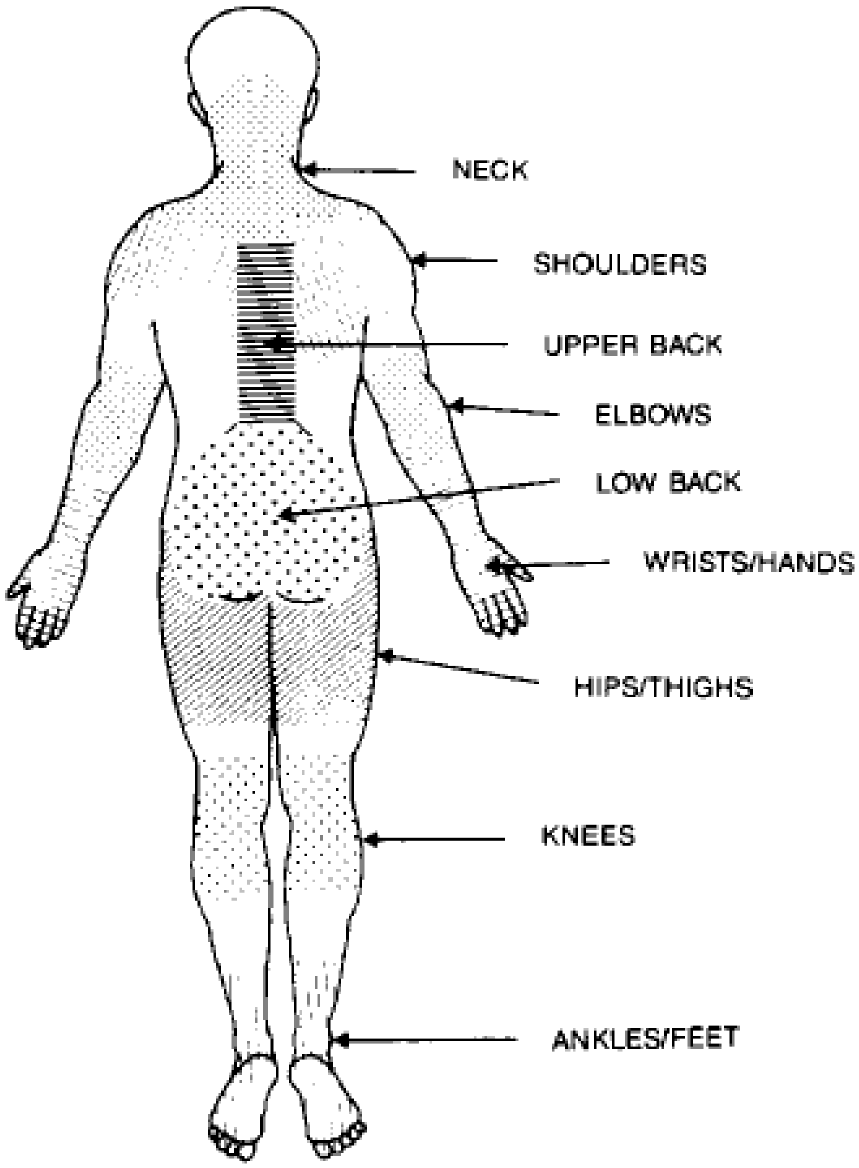


Figure 1.2 *Diagram used for the Standardised Nordic questionnaire. From (Kuorinka et al., 1987), p235*

Table 1.2 *Summary of work-related pain in standing workers in different job roles that reported prolonged standing.*

Reference	Job descriptions	n	Time (months)	Lower back	Hip/ Thigh	Knee	Lower leg	Ankle/ feet
(Alexopoulos *et al.*, 2004)	Dentists	430	12	46%	-	-	-	-
(Anton and Weeks, 2016)	Grocery Workers	254	12	51%	17%	29%	-	50%
(Dianat *et al.*, 2018a)	Surgeons	312	12	42%	29%	49%	-	28%
(Cheung *et al.*, 2018)	Nursing Assistants	440	0	41%	12%	38%	18%	28%
(Choobineh *et al.*, 2010)	Operating room nurses	375	12	61%	31%	58%	-	59%
(Garbin *et al.*, 2017)	Dentists	204	12	49%	15%	22%	-	16%
(Haukka *et al.*, 2006)	Female Kitchen Workers	495	3	50%	19%	29%	-	30%
(Karahan *et al.*, 2009)	Hospital Workers	1600	12	61%	-	-	-	-
(Shankar *et al.*, 2015)	Male commercial kitchen workers	114	12	66%	-	-	-	-
(Sheikhzadeh *et al.*, 2009)	Perioperative nurses and technicians	50	12	84%	52%	58%	-	74%
(Smith *et al.*, 2006)	Nurses (Japan)	844	12	71%	-	-	-	-
(Tojo *et al.*, 2018)	Nurses (Japan)	636	1	61%	-	-	-	23%
(Aweto *et al.*, 2015)	Hairdressers	299	12	76%	17%	33%	-	24%
(Reed *et al.*, 2014a)	Nurses	304	12	71%	37%	38%	-	55%
Average Values	-	6357	-	59%	23%	38%	18%	35%
(Urwin *et al.*, 1998)	General adult UK population	4710	1	24%	12%	24%	-	-
(Garrow *et al.*, 2004)	General adult population UK	3417	1	-	-	-	-	22%
(Hill *et al.*, 2008)	General Population Australia	3206	1	-	-	-	-	17%

** Where time frame is 0 months, participants were asked for pain at the time of asking. The rows shaded grey represent general population results. Average value is calculated as the total suffering pain from all studies / total participants from all studies combined for each region.*

Prospective studies add further evidence to the increased risk of musculoskeletal disorders in those undertaking prolonged standing, with the identification of odds ratios and risks (Table 1.3). A two-year prospective study completed by 3276 participants from various occupations identified in their final multivariate model that standing for half the time at work (30 minutes per every hour) was associated with an increased risk of lower back pain and any region pain with hazard ratios of 1.9 (95% CI 1.2-3.0) and 1.6 (95% CI 1.2-2.3) respectively (Andersen *et al.*, 2007). This was after adjustment for influencing factors such as age, occupation and gender. A second prospective study, this time over three-years in Norway (Sterud and Tynes, 2013), assessed lower back pain and associated factors. Respondents were asked if they worked standing, and if so to estimate the proportion of time (almost the whole working day, ¾ of working day, ½ of working day, ¼ of working day, very little of the working day). The final model suggested that the odds ratio for lower back pain increased with standing exposure time, with 1.1 (95% CI 0.81-1.58) for a quarter of the day, 1.24 (95% CI 0.96-1.59) for half of the day and 1.48 (95% CI 1.2-1.6) for three quarters of the working day. In another prospective study (Sterud, 2013), standing was also identified as a risk for long-term sick leave, in which standing for three quarters of the working day had an odds ratio of 1.32 (95% CI 1.04-1.69) and was also associated with the greatest population attributable risk of 8.18% (95% CI 0.07-15.86). This provides evidence of a relationship between standing exposure and risk of musculoskeletal disorders, as well as an impact on days off work.

Table 1.3 *Definitions of frequently used risk outcomes*

Term	Definition	Value given	Reference
Odds ratio	The odds that an outcome will occur given a particular exposure	<1.0=reduced odds 1.0=no difference >1.0 = increased odds	(Szumilas, 2010)
Hazards ratio	Estimate of the ratio of the hazard rate (risk of event) in control group and those exposed to the risk factor.	<1.0=reduced risk 1.0=no difference >1.0 = increased risk	(Kirch, 2008a)
Population attributable risk	The proportion of the incidence of a disease in the population that is due to exposure	Percentage (%)	(Kirch, 2008b)
Confidence Intervals (CI)	Used to estimate the precision of the above measures. A range of values that is expected to include the real value for the given population.	Larger = lower precision	(Ille and Milic, 2008; Szumilas, 2010)

1.2.5 The impact and costs of musculoskeletal disorders

Musculoskeletal disorders affect a large number of workers in Great Britain across a range of occupations (Buckle, 2005). The HSE in the Labour Force Survey 2018/19 (Office for National Statistics, 2019) report 498,000 workers were suffering from Musculoskeletal Disorders in that year, 40% (200,000) of which were in the lower back and 19% (95,000) in the lower limb. Over the year 2018-19 in Great Britain, they were responsible for 6.9 million working days lost (Office for National Statistics, 2019). The lower back was responsible for 2.8 million of these and the lower limb 1.5 million. The average number of days lost per case was 14 over the 12 months assessed.

In 2014, the HSE reported an estimated cost to the Great British society of £2.3 billion for new musculoskeletal conditions arising in that year alone (Health and Safety Executive, 2014). Around 57% of these costs were carried by individuals, which included costs associated with the loss of income and private healthcare. Employer costs came to around 22% of the total and were related to restructuring the workplace for absences, sickness payments, insurance and legal costs. Government costs were primarily for benefit pay, NHS treatment costs and loss of tax receipts and came to around 24% of the total costs. Musculoskeletal disorders can also impact the performance of tasks (Stack *et al.*, 2016), which could be costly if outputs are reduced due to work being completed more slowly.

Perhaps more costly to the individual is the reduction in quality of life associated with musculoskeletal disorders, both in and out of work. The stages of musculoskeletal disorders defined earlier (Table 1.1) describe musculoskeletal disorders impacting sleep and light tasks (Stack *et al.*, 2016; Canadian Centre for Occupational Health and Safety, 2019). This could result in a reduced ability to complete activities of daily living, increase time taken to perform daily tasks and even have a detrimental effect on an individual's mood. The impact of musculoskeletal disorders on physical quality of life outside of work was confirmed in a 28 month follow up study that reported the onset of such disorders had a marked effect on an individual's physical quality of life (Roux *et al.*, 2005).

Musculoskeletal disorders include diagnosed conditions such as osteoarthritis, which would likely be stage 3 or beyond on the discussed scales as the damage is irreversible. Osteoarthritis is a disabling disease that reduces quality of life in those who suffer from it (Cook *et al.*, 2007). Systematic reviews have identified that prolonged standing can contribute to knee osteoarthritis (Wang *et al.*, 2020) and perhaps to hip osteoarthritis too (Sulsky *et al.*, 2012). Osteoarthritis represents a growing financial burden to many countries (Chen *et al.*, 2012) alongside the increased disability that accompanies it, and could thus add to the cost of standing.

Overall, the effects of musculoskeletal conditions are vast. They influence an individual's quality of life, they cost money to individuals, employers and governments and they are responsible for a loss of workforce both temporarily and permanently. If left untreated, they can reach a point of becoming permanent (Stack *et al.*, 2016). Therefore, finding solutions to reduce musculoskeletal disorders is of high importance for the individual workers, employers and the economy.

1.3 Aims of this body of work

This body of work focuses on the relationship between musculoskeletal disorders of the lower back and below, occupational standing and footwear. The focus on the lower back and below is due to the need to develop a footwear solution, which would not be expected to influence the body above the lower back region as much as upper body activity would, such as lifting turning and twisting. Upper body demands vary between roles with similar lower body demands, so focusing on the lower body maintains a more generalisable solution.

The research papers within this body of work align to the process of the project from the initial literature search through to the development of the final footwear product. Each paper answers a specific question needed to develop an understanding of the topic area. The papers aim to both generate knowledge around the topic of prolonged standing and to progress the development of the footwear solution.

A mixed methods approach to research is used, with both quantitative and qualitative components. The lack of previous research in this topic area and thus the explorative nature of this research lends itself to this approach. The inclusion of end users in qualitative research integrates well with the company's market research requirements and product feedback, allowing the two to progress together.

The primary aims of this body of work are:

(1) To develop an understanding of prolonged standing and the associated demands on the body, particularly relating to musculoskeletal disorders.
(2) To biomechanically assess prolonged standing in conjunction with musculoskeletal disorders and determine if and how they are impacted by changes in footwear.
(3) Develop and evaluate a research-based, commercially viable footwear solution for prolonged standing that meets wearer requirements.

Chapter 2 : The published works and commentaries

This body of work is comprised of six journal papers published in a range of academic journals and presented at two international conferences (Table 2.1).

Table 2.1 *A list of the published works and conference proceedings. CONF = conference.*

Paper Number	Authors	Title	Journal/ Conference	Impact Factor	Date
1	Jennifer Anderson, Anita E Williams Christopher Nester	A narrative review of musculoskeletal problems of the lower extremity and back associated with the interface between occupational tasks, feet, footwear and flooring	Musculoskeletal Care	NA	2017
2	Jennifer Anderson, Malcolm H. Granat, Anita E. Williams Christopher Nester	Exploring occupational standing activities using accelerometer-based activity monitoring	Ergonomics	2.181	2019
3	Jennifer Anderson, Anita E Williams Christopher Nester	Musculoskeletal discomfort, foot health and footwear choice in prolonged standing workers.	*International Journal of Industrial Ergonomics*	*1.662*	*2021*
4	Jennifer Anderson Anita E. Williams Christopher Nester	An explorative qualitative study to determine the footwear needs of workers in standing environments	Journal of Foot and Ankle Research	1.604	2017
5	Jennifer Anderson, Christopher Nester Anita Williams	Prolonged occupational standing: the impact of time and footwear	Footwear Science	NA	2018
6	Jennifer Anderson Anita E. Williams Christopher Nester	Development and evaluation of a dual density insole for people standing for long periods of time at work.	Journal of Foot and Ankle Research	1.604	2020
CONF	Jennifer Anderson Anita E. Williams Christopher Nester	The effect of prolonged standing on the body and the impact of footwear hardness	Footwear Biomechanics Symposium. Gold Coast, Australia.	NA	20th-22nd July 2017
CONF	Jennifer Anderson Anita E. Williams Christopher Nester	The development of a multi-insole shoe for occupations requiring prolonged standing	Footwear Biomechanics Symposium. Calgary, Canada.	NA	28th-30th July 2019.

These works are broken into two parts. The first part (papers 1-3) explores the demands of prolonged standing to improve our understanding of what it is and the impact it has on the body. The second part (Papers 4-6) focuses on the development and evaluation of a footwear solution. The individual aim of each paper can be seen in Table 2.2, with a summary of the primary method used to address the aim.

Table 2.2 *Aims and primary methodology of each paper.*

	Paper Number	Title	Aim	Methodology
Part 1	1	A narrative review of musculoskeletal problems of the lower extremity and back associated with the interface between occupational tasks, feet, footwear and flooring	Identify current literature regarding the impact of prolonged standing on musculoskeletal discomfort to drive research protocols and product ideas.	Literature review
	2	Exploring occupational standing activities using accelerometer-based activity monitoring	Define standing as a range of movements to differentiate between the activity of different 'prolonged standing' jobs	Activity monitoring
	3	Musculoskeletal discomfort, foot health and footwear choice in prolonged standing workers.	Understand musculoskeletal problems and associated variables in surgical staff with a focus on foot health and footwear	Online questionnaire
Part 2	4	An explorative qualitative study to determine the footwear needs of workers in standing environments	Determine end-user perceived workplace demands, footwear needs and their views on how current footwear can be improved	Interview
	5	Prolonged occupational standing: the impact of time and footwear	Test the effect of prolonged standing on musculoskeletal discomfort and biomechanical factors and identify differences associated with changes in footwear hardness	Laboratory based biomechanical study
	6	Development and evaluation of a dual density insole for people standing for long periods of time at work.	Test insoles varying in hardness in different regions to identify a new insole product range that improves user comfort/ biomechanics and test these insoles in a real-world situation	Laboratory based biomechanical study + real world evaluation

2.1 Exploring the demands of prolonged standing

2.1.1 Paper 1 commentary

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

Reference: Anderson, Jennifer, Williams, A. E. and Nester, C. J. (2017). A narrative review of musculoskeletal problems of the lower extremity and back associated with the interface between occupational tasks, feet, footwear and flooring. *Musculoskeletal Care*, *15*(*4*), pp. 304–315. doi: 10.1002/msc.1174.

Open access version available: http://usir.salford.ac.uk/41005

The aim of this narrative review was to identify the current literature available regarding musculoskeletal disorders associated with prolonged standing in the workplace. This information provides the starting point for the project to develop from, driving both the design of a laboratory-based protocol and ideas for a feasible workplace solution.

With little knowledge around the topic prior to this paper apart from the initial company knowledge, the search strategy started as a broad identification of papers that related to prolonged standing. They included both laboratory-based studies that assessed the biomechanics of standing as well as prevalence-based studies to understand the extent of the problems. Once a range of literature had been identified, they were separated into topics. The first three topics investigated the associations between standing and musculoskeletal disorders of the lower back, lower extremity/ legs and the feet aiming to identify an idea of the prevalence and any associated measurable factors. The last two topics focused on solution-based papers, one on flooring and one on footwear. Flooring was included as it impacts the body-ground interface in combination with footwear, and therefore any benefits from flooring could potentially be incorporated into footwear.

The results of this study introduce the current research on prolonged standing at work and standing solutions to date, it identifies the methodologies used and where the gaps in the knowledge lie. It makes clear that musculoskeletal disorders are a widespread problem related to prolonged standing, although previous research had focused on the lower back and legs, largely ignoring the feet. In terms of solutions, most research had considered the use of flooring with only minimal information available regarding footwear.

Research Impact: At the time of writing, there were no other review papers of standing research that could be found. This review provided a summary of the literature available, bringing together information on musculoskeletal disorders, biomechanics and potential solutions. It further identifies knowledge gaps and limitations in previous methodologies with the aim of aiding future research.

Project Impact: With an insight into previous research, this paper identified the need to define activities in greater detail, leading to paper 2. It also collated the information on variables that should be recorded for paper 5, the confounding factors to include in the questionnaire study (paper 3) and initial ideas that underfoot cushioning could be important (as seen in the flooring research).

Commercial Impact: This was primarily used to build knowledge within the company, providing information for sales and marketing to use in meetings and pitches to build their brand as 'knowledge leaders' in footwear for standing.

2.1.3 Paper 2 commentary

Paper Title: Exploring occupational standing activities using accelerometer-based activity monitoring

Reference: Anderson, J., Granat, M. H., Williams, A. E. and Nester, C. (2019). Exploring occupational standing activities using accelerometer-based activity monitoring. *Ergonomics*, *62*(*8*). doi: 10.1080/00140139.2019.1615640.

Open access version available: http://usir.salford.ac.uk/51253

From Paper 1 it was clear that prolonged standing in the workplace had not been defined. Despite categorising numerous jobs as involving standing, it was unknown for how long these individuals were standing, what the definition of standing was and by how much the standing tasks varied between job roles. Understanding movement in the real-world work environment is important from an ergonomic, research and footwear manufacturing perspective. Ergonomically, understanding the 'dosage' of standing could be important for identifying risk factors or establishing safe exposure limits to prevent or limit the long-term impacts of a standing job. In terms of laboratory-based research, understanding the activities being undertaken in the workplace enables the replication of these movements to create an accurate representation of real-world tasks, thus results that are more generalisable to specific working populations. From a footwear manufacturing perspective, understanding the demands not only on the body but also on equipment such as footwear is important as it could have implications for equipment design, materials and safety testing.

Site visits and observations were undertaken in the workplaces of chefs and veterinary surgeons in order to inform the research design of this paper. At these visits, it was clear that an objective measure of activity was required due to the short duration of each activity being performed. It was through these observations that three new standing activities defined in this paper were identified. Objective measures of activity were taken using an ActivPal device, a small accelerometer-based device that attaches to the thigh. Using the previously developed ActivPal software, it was possible to verify that the new activities had all previously been classed under the broad term of 'standing'. The newly defined standing activities were:

Static Standing: Both feet remain in contact with the ground with no movement occurring

Weight Shifting: Both feet remain in contact with the ground, but weight is shifted between the feet

Shuffling: Sideways activity in which feet leave the ground but do not move the body forward. Activity is smaller than a walking step.

The results found that the three new standing movements were able to differentiate activity between two job roles, despite them having almost identical levels of overall standing time, as previously defined by the ActivPal. This provides evidence that standing is not a single activity and that considering it as one is too simplistic.

Research Impact: Prior to this paper, standing had been assumed to be a single activity, but this paper identifies that it can be divided into a range of activities of different intensities. This improves our understanding and provides a new tool for identifying differences between different standing jobs, with implications for identifying risk factors for musculoskeletal disorders.

Commercial Impact: This paper did not have a direct impact on the products but was used for marketing purposes, such as in sales presentations and blog posts. It aided towards the company's ambition of being 'knowledge leaders' in their sector.

Project Impact: This paper and workplace observations resulted in the development of the laboratory-based tasks in paper 5.

2.1.5 Paper 3 commentary

Paper Title: Musculoskeletal discomfort, foot health and footwear choice in prolonged standing workers.

Reference: Anderson, J., Williams, A. E. and Nester, C. (2021). Musculoskeletal disorders, foot health and footwear choice in occupations involving prolonged standing. *International Journal of Industrial Ergonomics*, *81*. doi: 10.1016/j.ergon.2020.103079.

USIR link: http://usir.salford.ac.uk/id/eprint/43663/

The need for this paper arose as a result of the lack of knowledge around foot health and footwear in standing populations. A number of papers had already assessed musculoskeletal disorders in surgical and nursing populations (Smith *et al.*, 2006; Karahan *et al.*, 2009; Sheikhzadeh *et al.*, 2009; Choobineh *et al.*, 2010; Reed *et al.*, 2014a; Dianat *et al.*, 2018b; Tojo *et al.*, 2018) but these did not include any information around footwear and the foot was generally combined with the ankle into a single region. This knowledge was important for the company to understand their marketplace and for the project to start to understand how foot health and footwear could be improved.

The scale of musculoskeletal discomfort was identified in this paper, with foot pain the second most common region behind the back and over a third reporting suffering from a known foot condition. The most common sites of foot pain were under the plantar surface, suggesting a need to focus on this region. A link between footwear comfort and musculoskeletal disorders was identified. Cushioning, support, breathability/ heat minimising and weight were all identified as important shoe components. Furthermore, some identified an inadequacy of footwear provided by employers.

Not long after the data was collected from surgical staff, the company split into two separate companies, with the research and new target markets being taken over by the new company, WearerTech. As a result, the new target market for the research became hospitality staff, specifically chefs. As the company required similar information from a questionnaire regarding chefs, musculoskeletal disorders and footwear, a similar questionnaire was distributed to this new population, the results from which are presented as additional data. Due to time constraints, a shorter version of the questionnaire was used, and these results are presented after the paper.

Research Impact: Although previous research has completed cross-sectional questionnaires, this paper provides detailed information regarding foot problems in a standing population for the first time. It also documents footwear and its relation to foot health.

Project Impact: The identification that footwear comfort could be an important variable to consider, alongside its relationship to cushioning and support, is a theme which is further explored through papers 4-6.

Commercial Impact: Percentage rates of musculoskeletal disorders and foot pain were strong marketing and sales tools due to the ease at which they could be understood by consumers and their own experiences at work.

2.1.7 Paper 3 additional data

Following paper three, the commercial direction of the company involved in the KTP changed. The original company split into two companies leading the sales focus to became primarily hospitality footwear. As a result, a similar questionnaire to that used in paper two was distributed to kitchen workers. The ethics approval application (Appendix 7) from paper 3 was amended to include this data set but a less extensive version of the questionnaire was used due to the need to quickly develop an understanding of this industry from a marketing perspective.

2.1.7.1 Results

There were 75 kitchen workers who completed the questionnaire, of which 73.7% were male, 21.1% female (the remainder did not answer). The average participant was 40 years old and had a BMI that was in the overweight category (25.0-29.9 kg/m^2). In total, 73.7% of participants were chefs (Table 2.3). In terms of workplace demands, on average they reported working for 54 hours per week with an average shift length of 10 hours, extending up to 16 hours. The average reported time on their feet at work was 84%, very similar to the 87.1% objectively recorded in kitchen staff in Paper 2.

***Table 2.3** Gender and job role of participants as a percentage of all kitchen workers*

Job Title	Percentage of all participants
Head chef	39.5
Exec Chef	17.1
Sous Chef	6.6
Senior Sous Chef	5.3
Junior Sous Chef	2.6
Chef de Partie	2.6
Restaurant Manager	2.6
General Manager	3.9
Other	14.5

***Table 2.4** Characteristics of kitchen workers*

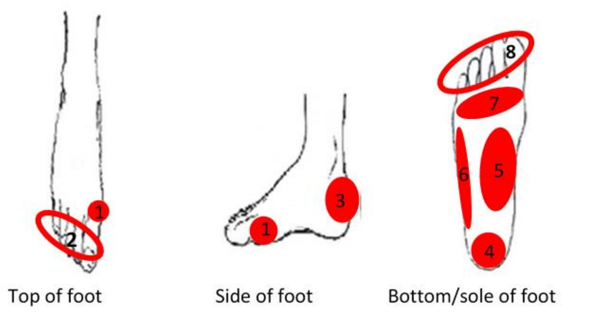
	Average	Minimum	Maximum	STD
Age (years)	40	20	64	10
Height (m)	1.79	1.55	2.10	0.11
Weight (kg)	88.2	52	170	21.7
BMI (kg/m^2)	27.8	16.8	46.1	6.6
Time working in hospitality (years)	20	2	45	11
Average hours/week	54	16	90	12
Time on feet (%)	84	10	100	18
Average shift length (hours)	10	6.0	16	2
Number of exercise sessions per week	2	0	7	1.7

Musculoskeletal discomfort was reported in at least one region by 96% of participants (Table 2.5). The back and feet were the most common regions for musculoskeletal disorders, with 72% reporting foot pain in the past 12 months. In total, 20% of respondents reported taking some time off work due to a reported musculoskeletal problem, with 46% having visited a health care specialist as a result.

Table 2.5 *Musculoskeletal disorders in kitchen workers (n=75)*

	Experienced pain in the past 12 months	Experienced pain in the past 7 days	Prevented from completing normal work	Taken time off work	Seen a doctor, physiotherapist or specialist as a result of the pain.
	%	%	%	%	%
Lower back	79	37	21	12	34
Hip	42	22	11	7	17
Knee	62	32	17	11	26
Calf	36	21	3	3	11
Ankle	32	20	5	3	8
Foot	72	34	17	7	18
Any region	96	63	37	20	46

Table 2.6 *Regions of foot pain in kitchen workers*



Region	% Total population	% Of those with foot pain
1 – inside of big toe	18	33
2 – top of toes	14	26
3 – back of heel	20	36
4 – bottom of heel	22	41
5 – under arch area	25	45
6 – outside edge of foot	20	36
7 – Ball of foot	36	65
8 – Underside of toes	9	17
9 – Between toes	3	5

Table 2.7 *Foot conditions self-reported in kitchen workers*

	% All participants
Corns	5
Calluses	8
Blisters	8
Plantar Fasciitis	8
High arch	5
Low arch	5
bunions	4
hammer toe	1

Table 2.8 *Percentage of kitchen workers wearing each shoe brand and example shoes. NB this is an identification of the main types of shoes available at the time of the questionnaire, not an extensive list.*

Company	% Participants	Examples of most worn shoes	Features
Crocs	**17**		EVA clog with slip resistant sole.
Birkenstock	**25**	 	PU clog with cork footbed Cork sole with leather upper (can have slip resistant sole).
WearerTech	**17**	 	EVA clog with EVA insole and slip resistant sole. EVA sole, leather upper, slip resistant sole.
Shoes for Crews	**5**	 	Leather or canvas upper with slip resistant sole. EVA clog with slip resistant sole.
Dr Martens	**4**		PVC/rubber sole, leather upper with textile lining, slip resistant outsole.

In those experiencing foot pain, the majority felt pain on the underside of the foot (Table 2.6) – under the heel, the medial arch and the ball of the foot, similar to that reported in surgical staff (Paper 3). However, 46% of the population reported pain in regions of the foot that could be related to the fit of a shoe. These include the back of the heel, between the toes, on the top of the toes or around the borders of the foot. Blisters were reported in 8% of the population, again a factor that could be a result of an ill-fitting shoe. In terms of foot conditions, 8% of the population reported suffering from plantar fasciitis.

Clogs were the preferred shoe type for chefs, with 62% wearing this style of shoe. Most kitchen workers were purchasing their own shoes (83%) although, as mentioned at the start, the distribution of responses were likely to be biased towards those who purchased their own footwear and those who were interested in the partner company's products. These individuals would be less likely to require a toe cap, as establishments that require toe caps must provide their own footwear, perhaps explaining why only 18% wore one.

Table 2.9 *Factors that could be improved in current footwear of kitchen workers (coded free text responses)*

Footwear Factor	Percentage of respondents
Cushioning	15
Improved slip resistance	11
More durable	8
Cheaper	8
Fit	7
Safety toe cap	7
Support	5
Lighter	4
Comfort	4
Breathability	3
Washable	3

Table 2.10 *Time that kitchen workers thought the grip on their shoe remained adequate*

Adequate Grip Length	Percentage of all participants (%)
0-3 months	9
4-6 months	18
7-9 months	25
10-12 months	24
More than 12 months	22

__Table 2.11__ Details of current footwear of kitchen workers

Question	Answer Options	% All participants
What type of shoe do you usually wear while at work?	Other (please specify)	12
	Work boots	3
	Flat dolly shoe/pump	7
	slip on with back	5
	Dress Shoe	5
	Trainer	5
	non-washable clog	28
	washable clog	34
Safety	toe cap	18
	no toe cap	80
Do you purchase your own work shoes?	Purchase own shoes	83
Insole use	off the shelf insoles	20
	prescribed insoles	1
What features do these insoles have? (Select all that apply)	arch support	9
	shock absorbing	12
	Cushioning	15
	Lateral Wedge	1
Colour of shoe	Black	88
Where do you normally purchase your work shoes?	Catering supplier	26
	Work shoe specialist	16
	Amazon	18
	Work wear supplier	3
	High street	11
What is the maximum that you would pay for a pair of work shoes?	£21-30	5
	£31-40	13
	£41-50	14
	£51-60	13
	£61-70	13
	£71-80	7
	£81-90	5
	£91-100	1
	£100+	8

Out of the 75 participants, 53 (71%) completed the free text question ‘How could your current work shoes be improved?’. Of those that answered the question, 21% mentioned cushioning in their response, with improved slip resistance the second most common answer. In terms of slip resistance, participants were also asked to select how long the slip resistance on their shoes remained adequate (Table 2.10). There was a wide range of responses for this question, but 40% of individuals reported wearing their shoes for a period of time greater than they believed the shoe had adequate grip.

2.1.7.2 Summary

In comparison to the operating theatre workers in Paper 3, it is clear that variations in demographics exist. Primarily, the majority of kitchen workers are male (73.7%) compared to only 23.8% of those in operating theatres. The average weight, height and BMI were also greater in those working in kitchens, likely at least in part due to the difference in gender. Kitchen workers also reported working longer hours, with 83% working more than 40 hours a week on average compared to only 29% of operating theatre workers. However, the self-reported time on feet was not too different at 73±22% in operating theatre and 84±18% in kitchens, which is reflective of the objectively measured time on feet from Paper 2 of 87±8% and 70.8±19 for chefs and veterinary surgeons respectively.

In terms of musculoskeletal disorders, 96% of kitchen workers reported suffering from them, which is similar to the 91% of operating theatre workers. The average reported problems were slightly higher in each region for kitchen workers, but most noticeable in the feet where 72% of kitchen workers report pain compared to only 55% of operating theatre workers. However, in both results, the main regions of foot pain were on the plantar side. The footwear being worn was largely similar between the two professions, with the majority choosing to wear a clog type shoe. For both, cushioning was the most commonly identified factor that needed improving, although slip resistance was identified by chefs only.

Overall, this provides an initial understanding of the musculoskeletal disorders and footwear among kitchen workers. It is clear that, as in operating theatre workers, musculoskeletal disorders are a large problem in kitchen workers. It must be noted, however, that this data set was perhaps skewed to an extent towards wearers of the partner company's shoes as it coincided with the development of a 'Customer Panel' – a list of wearers to test footwear with. Therefore, it is likely that it would have been of greater interest to people who have pain at work and/or purchase their own shoes. Nevertheless, it still provides an initial understanding of the current problems and footwear used by kitchen workers.

2.2 Summary of key points from part 1

- Lower back, lower limb and foot MSD are high in workers that undertake prolonged standing, including chefs and health professionals that work in surgical settings.
- Standing can be broken down into different activities to better understand workplace activity and distinguish between jobs that are on their feet for similar periods.
- In future research, the standing tasks used should be well defined, reflect that seen in the work environment and the protocol should be long enough to induce changes (at least 3-4 hours).
- Factors that have been related to MSD during prolonged standing bouts include: vascular blood pooling, age, weight and muscular factors.
- Altering the material between the foot and the ground through either footwear or matting appears to influence comfort, biomechanical and physiological factors.
- Individual variation in activity is evident, even between those with the same job title.
- Despite being previously overlooked, the foot was the second most commonly reported region of pain in standing workers (in surgical settings and kitchens) with the plantar surface most affected.
- Footwear appears to be an influencing factor in lower limb musculoskeletal disorders.
- Workplace footwear is important to workers in surgical and catering settings, with key factors being: comfort, cushioning, fit, support, breathability and weight of the shoes.

2.2 Developing and Evaluating Footwear Solutions

2.2.1 Introduction to footwear

Part 1 of this body of work has recorded the activity demands of prolonged standing workers in kitchens and veterinary operating theatres and demonstrated that musculoskeletal disorders are affecting most of these workers, including the target markets of individuals working in operating theatres and kitchens. Paper 3 and the additional data also provide an initial understanding of footwear in the workplace.

The main physical solution considered to date in response to the demands of prolonged standing has been flooring, primarily the use of anti-fatigue mats (Paper 1). However, footwear offers significant benefits in comparison. It's portable, it can be easily individualised, and it offers a much more diverse range of factors that can be altered. For example, specific locations on the foot can be targeted with alterations in a shoe as it remains in place on the foot. A review paper indicated that adding cushioning to insoles was more effective than cushioned flooring at reducing the development of musculoskeletal disorders and improving the recovery afterwards (Speed *et al.*, 2018), suggesting their relative proximity to the foot may enhance the benefit of the material.

In the UK, the Health and Safety Executive (HSE) currently recognise prolonged standing as a risk factor for lower limb musculoskeletal disorders (Health and Safety Executive, b), although it is not identified as a risk of back pain (Health and Safety Executive, a), despite the prevailing evidence for it (Coenen *et al.*, 2017). Although anti-fatigue matting is mentioned as a potential method for reducing lower limb pain, footwear is not mentioned in relation to musculoskeletal disorders, despite potentially being more beneficial (Speed *et al.*, 2018). In terms of footwear, the main priority of the HSE is reducing slips, trips and falls (Health and Safety Executive, c).

The importance of developing footwear is highlighted in Paper 3 and the additional data with 59% of those working in operating theatres and 64% of kitchen workers suggesting their footwear could be improved. This included physical factors related to sensation such as cushioning, support, fit and the in-shoe climate as well as technical factors including the weight of the shoe, it's cost and the slip resistance. Furthermore, the foot had the second highest prevalence of musculoskeletal disorders, behind the lower back, reported by 55% of operating theatre workers and 72% of kitchen workers. In terms of the relationship between footwear and musculoskeletal disorders, footwear provides the only link between the ground and the body, and thus can alter the forces passing from one to the other. It can alter muscle activation of the lower limb and back, kinematics and plantar pressure (Murley *et al.*, 2009).

Paper 3 identified a relationship between footwear comfort and musculoskeletal disorders of the hips, knees and feet, suggesting it could be an important factor to consider. Footwear comfort has been related to lower limb injury risk in sporting and military populations (Mündermann *et al.*, 2001; Kinchington *et al.*, 2011) and has been suggested to be important for 'all movement-related injuries to the lower extremity' (Nigg *et al.*, 2015). This suggests that a comfortable pair of shoes could reduce musculoskeletal disorders in the lower extremity. Participants in Paper 3 described footwear comfort as relating to no pain or discomfort, the need for it to continue for a prolonged time and the fact that if footwear is comfortable, they would remain unaware of it throughout the working day, suggesting the need to consider longer term as well as immediate comfort.

Therefore, the second half of this PhD will focus on footwear for standing workers, with the belief that they could provide a beneficial solution and help to address the evidently large number of musculoskeletal disorders in the foot, lower limb and lower back. The dissatisfaction from consumers indicates a commercial desire for better footwear to be made available and the need to involve end-users in the development of a new product. Therefore, the following research will explore the needs of the wearer, the impact of prolonged standing on the body and the effects of footwear design factors and comfort.

2.2.2 Paper 4 commentary

Paper Title: An explorative qualitative study to determine the footwear needs of workers in standing environments

Reference: Anderson, J., Williams, A. E. and Nester, C. (2017). An explorative qualitative study to determine the footwear needs of workers in standing environments. *Journal of Foot and Ankle Research*, *10*(*1*). doi: 10.1186/s13047-017-0223-4.

This paper aimed to address the need for information from end-users in order to understand more about the footwear currently being used in the kitchen and operating theatre environments, footwear requirements and how current footwear could be improved. This information would help to guide the project and product development and to aid the marketing team by identifying unique selling points most important to the wearers.

The semi-structured interview approach enabled the use of broad questions related to musculoskeletal disorders and footwear. Paper 3 had already provided some of the factors important to wearers, such as comfort, cushioning and support which created the prompts to discuss these factors in more detail if not mentioned independently.

The results highlight the impact of musculoskeletal disorders on day-to-day life. Almost all participants reported pain or discomfort while at work as expected, but it also became clear that this extended into the evening and even the next day. There was an attitude that this pain was expected as part of the job and often individuals did not notice the pain until they stopped working. In terms of footwear, the results from the interviews enabled the mapping of key footwear parameters. Although from a research perspective the wearer sensations and symptoms of discomfort were of most interest, important parameters related to footwear choice and the shoe functionality in the work environment were also mapped for the first time. From a footwear manufacturing perspective, some of the footwear preferences contradicted each other such as that between quality and price as well as weight and safety.

Research Impact: Provides the first insight into important footwear factors for standing workers, as defined by the wearers.

Commercial Impact: The identification of the footwear factors most important to the wearer was shared with marketing and sales to direct content. Product development also used these when developing the new shoe. The lack of good, lasting slip resistance on footwear also in part led to a spin off project for the footwear developer to work with the factories and experts in the field to develop a new material.

Project Impact: Identified several footwear design factors that were important to the wearer and thus should be included in the final product. Footwear comfort was arguably the most important factor, with cushioning most strongly related to it, identifying it as a key design factor. The verification of the results in Paper 3 of the importance of prolonged comfort as well as initial comfort led Paper 6 to assess comfort over a working day.

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RESEARCH

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An explorative qualitative study to determine the footwear needs of workers in standing environments

Jennifer Anderson*, Anita E. Williams and Christopher Nester

Abstract

Background: Many work places require standing for prolonged periods of time and are potentially damaging to health, with links to musculoskeletal disorders and acute trauma from workplace accidents. Footwear provides the only interaction between the body and the ground and therefore a potential means to impact musculoskeletal disorders. However, there is very limited research into the necessary design and development of footwear based on both the physical environmental constraints and the personal preference of the workers. Therefore, the purpose of this study was to explore workers needs for footwear in the 'standing' workplace in relation to MSD, symptoms, comfort and design.

Method: Semi-structured interviews were conducted with participants from demanding work environments that require standing for high proportions of the working day. Thematic analysis was used to analyse the results and gain an exploratory understanding into the footwear needs of these workers.

Results: Interviews revealed the environmental demands and a very high percentage of musculoskeletal disorders, including day to day discomfort and chronic problems. It was identified that when designing work footwear for standing environments, the functionality of the shoe for the environment must be addressed, the sensations and symptoms of the workers taken into account to encourage adherence and the decision influencers should be met to encourage initial footwear choice. Meeting all these criteria could encourage the use of footwear with the correct safety features and comfort. Development of the correct footwear and increased education regarding foot health and footwear choice could help to reduce or improve the effect of the high number of musculoskeletal disorders repeatedly recorded in jobs that require prolonged periods of standing.

Conclusion: This study provides a unique insight into the footwear needs of some workers in environments that require prolonged standing. This user based enquiry has provided information which is important to workplace footwear design.

Keywords: Occupational, Footwear, Shoes, Musculoskeletal, Interview, Injury, Workplace, Standing

Background

The nature of work related tasks and the design of many work places, makes standing the primary occupational posture. At least 50% of the employed population are exposed to the risks associated with prolonged standing [1, 2]. Prolonged standing, defined as standing for 50% or more of the working day [3], is associated with multiple health issues including chronic venous insufficiency, preterm birth, carotid atherosclerosis and work related musculoskeletal disorders [4]. The standing work places discussed in this paper include those that are predominantly standing with minimal ambulation.

Back and lower limb musculoskeletal disorders (MSD) are particularly prevalent with risk of low back and lower extremity/ foot pain being increased 1.9 and 1.7 fold respectively in those who stand for at least half their time at work [5]. Nealy et al. [6] reported that approximately 50% of nurses suffer MSD of the foot, substantially more than the 17.4% in the general population [7]. Similarly in

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perioperative staff, 43% reported pain in their leg or feet, compared to 12% in the general population [8]. The majority of staff (91%) attributed the pain to their work. For the employer, MSD can be costly in terms of absence and decreased efficiency [4].

As footwear provides the only interface between the body and ground when standing, alterations in footwear have the ability to influence the forces acting through the body, posture and movement [9], as well as to provide necessary protection against foot trauma and slips. Indeed, differences in footwear designs have been shown to affect fatigue and discomfort [10, 11], muscle activation and pressure under the foot [12, 13] all of which are factors relating to MSD. Therefore, wearing the correct footwear at work has the potential to reduce the risk of MSD and acute trauma.

A recent review paper highlighted that despite the detrimental impact of prolonged standing on the body, there is a scarcity of information relating to potential solutions, particularly in terms of flooring and footwear [8]. To ensure that workers wear the most suitable footwear, it is necessary to design and develop products based on both the physical environmental constraints and the personal preference of the workers. The limited research into the requirements of footwear from a workers perspective, particularly in relation to musculoskeletal symptoms, comfort, and design provides a starting point for understanding footwear in the workplace. By better understanding the footwear needs of workers, manufacturers may be able to produce footwear that will meet the requirements of the people who wear them and the environments they are worn in. For employers, this understanding can ensure the most appropriate footwear is identified, thus meeting their duty of care and reducing the likelihood of civil action from employees. Consequently, this study aims for the first time to explore workers needs for footwear in the 'standing' workplace in relation to MSD, symptoms, comfort and design.

Method

Following ethical approval (University of Salford), participants were recruited through purposive sampling in relation to two occupations where standing is predominant and environments 'challenging' (when compared to office workers for example). The recruitment criteria was workers who work in demanding environments that require standing for the majority of the day. Multiple kitchens and veterinary hospitals were approached and within those that agreed to participate (3 kitchens, 1 veterinary hospital) staff volunteered if they wanted to take part after reading the participant information sheet. A total of 14 participants were included (kitchen staff: 8 (male: 6, female: 2), veterinary hospital theatre staff: 6 (male: 2, female: 4)). The number of participants is similar to that seen in other studies focusing on in-depth perceptions of footwear on specific conditions [14–16]. Participants provided informed consent and data collection (semi-structured, individual interviews) took place at their place of work by the researcher (JA). The interview was recorded digitally with supplementary field notes.

The participant's job role, weekly working hours, time in job and type of shoes worn were recorded. The questions were non-specific to allow participants to talk about what was most relevant to them, but included their experiences and ideas of good/bad footwear features. Prompts were given during the interview where necessary. A list of questions and prompts can be seen (Table 1).

The words that are regularly used to describe work footwear from a manufacturer's point of view such as 'comfortable', 'supportive' and 'cushioned' were explored with each participant in relation to meaning and importance.

All interviews were transcribed verbatim by the researcher (JA). Thematic analysis was conducted in line with that described by Attride-Stirling [17]. The results were reviewed by a second researcher (AW) in order to confirm and agree meaning and interpretation.

Results

Participant's information was recorded at the beginning of the interview (Table 2). Basic and organising themes were grouped into a global theme of 'footwear needs' shown in Fig. 1. Table 3 displays the number of individuals that discussed each issue.

Chefs worked an average of 50 ± 8 h a week and time in work ranged from 1 to 17 years (average = 7 years). Veterinary hospital staff worked on average 40 ± 6 h per week and time in work ranged from 3 to 37 years (average = 17 years). Both environments consisted of hard flooring throughout. The chefs prepared, cooked and presented food predominantly around kitchen counters/ cookers. Veterinary workers were based standing around operating tables during surgery but also undertook inpatient care and cleaning. In both environments, tasks varied based on individual roles. All individuals purchased their own footwear.

Theme: wearer's sensations and symptoms

The sensations and symptoms of the wearer whilst wearing the shoe can be broken down into five sub themes: aches and pains, comfort, cushioning, fit and support.

Aches/ pains

Four participants mentioned aches or pains at work without prompting, despite 13 of the 14 interviewees admitting to suffering some pain whilst at work once prompted. The attitude was that discomfort and/or aches were to be expected due to the job demands, and over time you grew accustomed to it. 'After you've done it for quite a while you just sort of get on with it', 'I think

Table 1 List of questions and prompts used

Questions	Prompt examples
Do you experience any aches/ pains during work?	Where exactly?
Do you experience any aches/pains after work?	Can you point that out to me?
Do you experience any problems with your feet?	Anywhere else?
	How bad is the pain?
	Can you explain that further?
	Can you describe the pain?
What are the good aspects of your current shoes?	What do you mean by…?
What are the bad aspects of your current shoes?	Can you expand on that?
	What about the [insert part of shoe]?
Describe your perfect shoe	What do you mean by…?
	What would the [insert part of shoe] be like?
How would the style of the shoe be?	What do you mean by...?
	Can you expand on that?
If a shoe was described as comfortable, what would this mean to you?	What do you mean by…?
If a shoe was described as supportive, what would this mean to you?	Can you expand on that?
If a shoe was described as cushioned, what would this mean to you?	

I'm just used to it by now' and 'if you're up doing stuff for that long …things will hurt'. Working long hours, standing and walking were all attributed to aches and pains 'I'm standing for hours and hours, like 12 h days', 'after like a really long night…you really feel it, 'walking around most of the time, and running up and down the stairs a lot', 'it's just from standing I think'.

Both occupations described feeling discomfort or pain in the evening after work 'After work as well. Especially if it's a long day operating, then I'll go home and be like bleurghhh' and 'at the end of a really long shift … everything will ache' but also in the morning after a shift 'when I wake up on a Sunday morning after a Saturday night I feel like I've been wearing heels all night', 'for about a year and a half getting out of bed in the morning, it would hurt' and 'if I've done a really, really long shift, the next day I feel it'. Some participants described not noticing the pain during the day, due to being particularly busy 'I don't notice it I'm just so busy'. Further, some describe working through the pain 'you just get over it and carry on', 'After you've done it for quite a while you just sort of get on with it.'

Back pain was regularly mentioned with one chef stating 'everyone else who works here has a lot of back pain

Table 2 Participant job and footwear information

Male/ Female	Job role	Years in job	Hours/week	Footwear description	Footwear make
Female	Commis Chef	1.5	50	Leather shoe with steel toe cap	Steel Lites
Male	Head chef	15	52.5	Clog, leather upper, cork footbed	Birkenstock
Male	Apprentice chef	1	50	Leather shoe with steel toe cap	-
Male	Sous chef	17	52.5	Leather clogs	Abeba
Male	Chef de Partie	2	52.5	PU clog (cork footbed)	Birkenstock
Female	Kitchen assistant	11.5	31.5	EVA clog	-
Male	Chef de Partie	1.5	50	Clog, synthetic upper	Dr. Brinkman
Male	Pastry chef	5	60	Clog, microfiber upper	Abeba
Female	Veterinary Surgeon	11	45	EVA clog	Toffeln
Male	Veterinary Opthalmologist	37	32	Chelsea boot	-
Female	Veterinary Nurse	32	37.5	EVA clog	Crocs
Female	Veterinary Nurse	3	37.5	EVA clog	Crocs
Male	Veterinary Surgeon	14	50	Leather upper clog	-
Female	Veterinary Nurse	3	38.5	Leather upper clog	Clarks

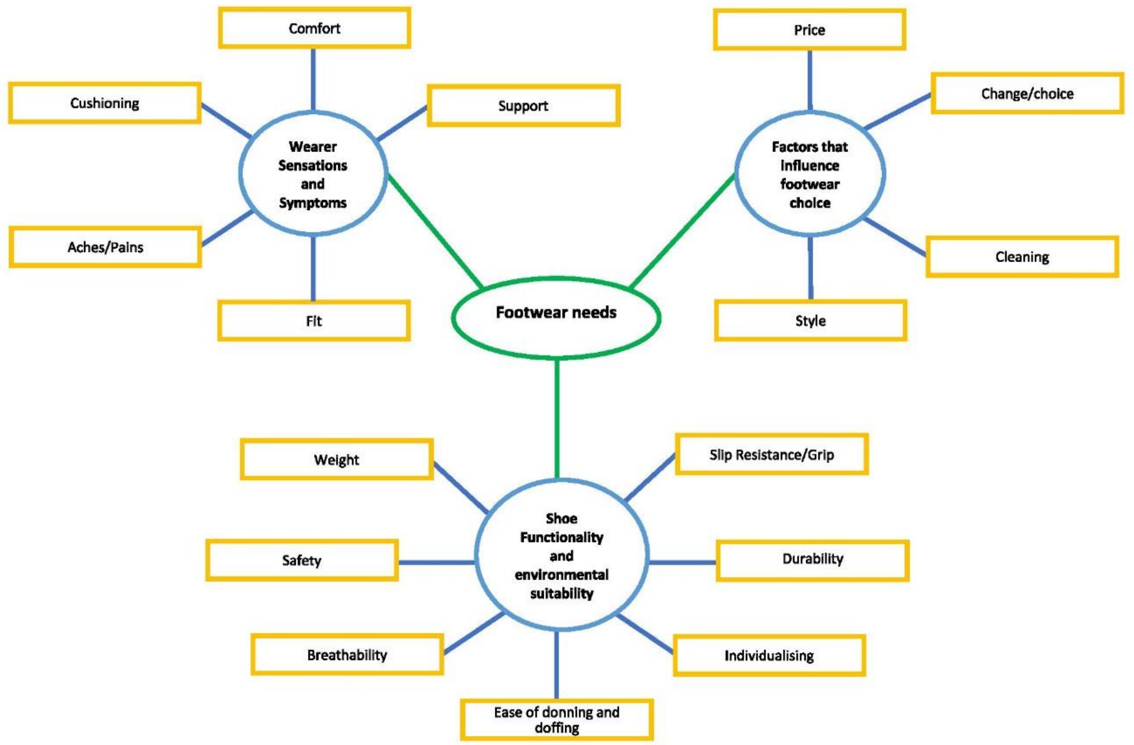

Fig. 1 Thematic network comprising the global theme, organising themes and basic themes

problems'. In vets this was generally attributed to long hours standing, particularly 'if I do a lot of surgery'. The ache from standing stationary and the ache after work were described as: 'you just get that chronic ache that kind of builds up and then afterwards you just get that kind of dull ache'. The shin, calves, knees and feet were also areas described as aching 'just like my calves and my feet ache', 'tends to be my feet and sometimes yeah in my legs actually', 'Knees, feet', 'knees sometimes'. One veterinary worker mentioned 'I've got plantar fasciitis' whilst two chefs complained of shin splints 'I've had shin splints for probably... 5 years'. Being focused on the job was a key reason for not noticing aches or pains until after work 'I don't notice it I'm just so busy'. There was also a belief by some that aches and pains weren't affected by the footwear 'I think I could be wearing any shoes and it would still hurt'.

Comfort

The word 'comfortable' was used to describe the ideal shoe 'it would have to be comfortable'. There was a need for both immediate comfort 'Straight away they felt really comfy' and long term comfort 'Comfort over long hours is the main thing'. Further to this, participants were asked what the word comfortable meant to them. A lack of pain or discomfort was described 'they don't hurt you in any way ', 'I guess like … not discomfort' as well as not having to think about the shoe 'it means that I don't really notice them'. Comfortable shoes were also described as being able to 'wear them anytime anywhere and you just don't really mind because they're comfy'.

Cushioning

Comfort definitions were strongly entwined to that of cushioning, with quotes including 'cushions your foot' and 'comfortable makes you think of like a pillow'. Similarly, when asked to explain what the word cushioning meant, many participants mentioned the word comfort 'Cushion is… even same as comfort', 'Just what gives it comfort' and similarly a lack of pain 'it won't hurt when you put it on'. Again, comparisons to slippers and pillows were given 'walking on pillows'. Suggestions that cushioning related to being 'bouncy and springy' were given 'when you walk, you feel like you have a bounce'. One participant stated a cushioned shoe 'conforms to your foot a bit more'.

Hard shoes were described negatively 'It's pretty hard it's not comfortable', 'not very forgiving on your foot' and 'flat and hard and you can feel like the sole'. On the other hand, cushioned shoes were thought to 'conform

Table 3 Break down of themes with number of participant who mentioned them with or without prompting

	Mentioned without prompt	Mentioned with prompt	Not discussed
Shoe functionality			
Grip	11	2	1
Heat/ Breathability	10	4	0
Durability	9	0	5
Ease to don/doff	9	0	5
Fit	7	1	6
Safety	6	5	3
Weight	6	2	6
Individualising	3	0	11
Sensations and Symptoms			
Comfort	12	2	0
Support	6	8	0
Cushioned	5	9	0
Aches	4	10	0
Decision Influencers			
Cleaning	11	0	3
Price	10	0	4
Change/ choice	4	0	0
Style	3	9	2

to your foot a bit more' and also decrease the impact walking ...'the impact isn't like as hard'. In chefs some described a negative relationship between cushioning and durability 'the problem with like really cushioned shoes is it wears away pretty quickly'. One participant suggested 'some bits of the sole need to be more cushioned than others perhaps... more cushioning in the heel'. Suggestions were made for a 'middle ground' between a hard and soft shoe.

Support
Numerous definitions were given to the word support in relation to footwear 'like the ankle support', 'fitted and it would be enclosed' and 'supports the arch of the foot'. Support also had connotations to comfort 'support is just like comfort', 'have to be comfortable so I suppose it has got be quite supportive of your foot'. The idea of spreading the foot pressure was also broached 'if your arch is well supported, it kind of spreads the pressure better'. Finally, some suggested it would have a beneficial impact on the rest of the body 'meant to stop you having back pains and leg pains' and it 'effects your whole posture'.

In terms of underfoot support, shoes with a flat footbed were negatively reviewed 'If you've got a flat shoe it kind of puts a lot of pressure on the wrong bits of your foot', 'my trainers before were so painful because they were just like flat'. A preference was given to having arch support 'I think they should have like all the support inside – like arch support and toe bits', 'it needs to support the flat part of my foot, like there needs to be a little arch in there'.

Fit
The main factor mentioned in relation to fit was that the footwear must remain on the foot. 'It needs to fit. ...needs to stay on my foot' and 'it needs to like fit well and my foot stays in the shoe'. Shoes that were loose on the foot were matched with a feeling of being unsafe 'I didn't feel safe in them because I thought they might just like fall off'. One method of keeping loose shoes on the foot was to 'curl your toes a bit as well to keep them on'.

Two participants mentioned having wide feet as a problem 'I've got wide feet so... they have to fit my feet'. One participant had problems purchasing the right size due to companies only selling whole sizes 'because the sizes are not halves... I've got to get a 10 or 11 so have to wear an insole'.

Theme: shoe functionality and environmental suitability
Shoe functionality and environmental suitability relates to any functions of the shoe and how they relate to the environment and job demands. It is comprised of 8 sub themes: grip, durability, safety, weight, breathability, ease of donning and doffing and individualisation.

Grip
Grip was a key factor, with 11 out of the 14 participants commenting unprompted on this theme. The high importance of it was emphasised in quotes, e.g. 'that [slip resistance] is like probably at number one', 'the best ones have the best grip... the kitchen's really slippery so you need grip'. Participants either described the underside grip on their shoe as being adequate 'good treads – I've never skidded over in them' or as being below their requirement 'they don't have much grip on the sole'. Some did not trust shoes marketed as slip resistant '... because a lot of shoes say they are [slip resistant] and they totally aren't'. A veterinary worker suggested an issue with the front of the foot catching on the floor 'I tend to catch the front of my toe and then I might go flying forward'.

Both vet and chef participants preferred to have grip on the inside of the shoe. 'You need to have good grip inside them', 'if you get more grip inside it's even better, even faster'. Whilst another stated 'they're easy to get wet and slippery on the inside' as a negative about their current shoe.

Durability
Durability aligned with comments on grip, with suggestions that the grip wore out before any other footwear

feature. This was supported by quotes such as 'the grip doesn't last very long' and 'the sole wears out really quickly' and it was identified as a safety issue 'The soles wear down really quickly and they just become like flat… which is really bad because you can just slip'. Grip durability was considered a point for future improvement 'If there was any way that you could change how long the grip lasts'. Asides from grip, robustness of footwear as a whole was important. 'They're just good and durable' was a positive whereas 'they fell apart quite quickly' and 'they probably lasted less time than these would' were negatives.

Safety

Toe protection was mentioned by chefs as a safety factor. Five (of 8) chefs thought safety toe caps should be used 'I think that's safer because I'm a bit clumsy – prone to dropping stuff', 'the safety bothers me, because anything can happen' and 'ideally it would have a toe cap'. However, the remaining three chefs did not feel a toe cap was necessary 'I have never ever heard of someone to drop anything on their foot that's going to like crush their foot'. This safety feature was of no concern to vets although one did state that 'you've got to have toes covered so they don't get trodden on'. Chefs identified further safety problems in their environments including knifes, pans and hot oil - 'I've seen someone drop oil and it kinda melted the shoe into their foot'.

Weight

Weight was deemed an issue by chefs. 'I don't think they can be too heavy because it makes your day harder if you've got really heavy shoes on' and 'heavy shoes aren't easy to walk around in'. In particular, some suggested heavy shoes became an issue as a result of constant moving 'I don't like anything heavy on my feet because I have to be up and down, up and standing… so heaviness will be a problem' and 'lighter is better... because here we do a lot of moving up and down, up and down' One participant was particularly against heavy shoes 'Heavy shoes is not an option for walking in the kitchen. No, I say no.' A toe cap was considered heavy and excessive in weight, with one advocating it was not worth it 'for the extra weight'.

Breathability

Heat and footwear breathability was considered to be a problem for both vets and chefs. Chef's in particular described the environment as an issue to which increased breathability was a solution. 'yeah breathable, it's so hot in the kitchen anyway… it was like 35 degrees the other night…we were all dying it was so hot', 'It's in the kitchen and the kitchen's hot' and 'you need air in the kitchen because it's warm'. Hot environments caused sweaty and odorous feet 'my feet sweated a lot in those shoes and I used to get very itchy feet from that', 'make your feet smell… really bad' and 'I don't like hot and sweaty feet'. Some participants removed their feet from their footwear to cool them 'I can just take out my foot sometimes' and 'I quite often take my feet out'. A need for improved ventilation was recognised 'maybe ones with some like breathing holes' and 'more ventilation would be quite nice'. An open back was also a positive as it would 'be more airy' and 'quite good for keeping it cool'. However, both holes and an open backed shoe became a problem if the environment became wet: 'if I had holes … I'd have soaking wet feet in 5 min'.

Ease of donning and doffing

An open backed shoe also linked to the theme of donning and doffing the shoes efficiently, which was mentioned by nine participants. It was a positive feature of current footwear 'very easy to put on and take off', 'they're convenient to put on as they just slip on' and a requirement in the ideal footwear 'something that's easy to put on and take off', 'being able to slip them on… there's no hassle'. Vets identified that shoes should be 'easy to slip on and off so you can get into theatre' but it was equally important for chefs 'they're convenient to put on as they just slip on'. Laces were seen as 'a bit of a pain' and it was easier not to 'undo laces or flap around'. Fastenings of any kind were deemed negative by most 'I'd definitely have like clog kind of things because I don't really like lace ups or Velcro'. An open back was seen to increase the 'the ease of getting them on and off quickly'.

Individualising

Individualisation of shoes in relation to fit and comfort was mentioned by 3 participants. 'I think they have got to be tailored to you'. Different reasons for this were given. 'Everyone has a different body, different feet…if you had like a foot analyst … and they worked out how we should have the shoes, like if people had low arches'. One proposed that this would reduce or eliminate the adjustment period to a pair of shoes 'almost prescription... so you don't have to let it mould to your foot'. Another stated that it would 'make it more comfortable… if your shoe fits better, then it will lessen the chance of injury'.

Theme: factors that influence footwear choice

These are the aspects that would influence the initial choosing of the footwear and can be broken down into four basic themes: cleaning, style, price and change/choice of footwear.

Cleaning

Cleaning was one of the most important factors relating to work footwear for both vets and chefs. Chef's concern was 'if you drop food on them' whereas vets were worried about 'blood, contamination'. The need for work footwear to be 'easily cleanable' and able to go in the washing machine were important factors. It was also important to be able to clean the inside of the shoe 'the cleaning of the inside of the shoe…there's odours you know'. Velcro or laces were a problem for chef's 'because if you drop food on them, it's all in the laces and that's just grim' and also to food getting stuck in the grip on the bottom of the shoe 'a real crucial one to me is the underside of the shoe…different shoes pick up different amounts of dirt'.

Style

The majority of individuals acknowledged that their work shoes and uniform were not attractive, 'We always look fairly ridiculous', 'they make your feet look huge' and 'I wouldn't wear them out [of work]'.However, all but one participant stated that the style was not of great importance with one chef stating 'It doesn't matter how it looks' and a veterinary nurse similarly saying 'look doesn't really bother me'. Style was secondary to the function of the shoe: 'I'm not too worried about the style, just about the comfort for me' and 'I'm more of a function over appearance'. Chefs and veterinary nurses outside of operating theatres expressed a preference towards black shoes 'everyone wears black' and 'practice protocol is black shoes' whereas inside the operating theatre the protocol was to wear white. 'We tend to have white in theatre and other colours for out, just so you know the difference. So you know what's clean and what's not.' One chef showed preference for a specific shoe brand 'all the chefs in London had them' and 'they're pretty trendy at the moment so I like them as a brand' but also acknowledged 'no one really cares that much'.

Price

Price was an essential factor in work footwear, with 10 participants mentioning it unprompted. When asked about their current footwear, one stated 'I didn't like the price'. There was a reluctance to spend money on new work shoes 'cost… that's why I haven't gone out and bought any more' and 'you go through so many shoes, you don't want to be spending so much money on a pair of shoes'. However, there was a trade off with price and durability with a willingness to spend more money on a pair of shoes if they were going to last and be of a higher quality. 'It's cost effective at the end of the day. If it's going to last you know, twice as long as these, I'm happy with that', 'I'd probably spend a little bit more if I knew that they were going to last' and 'I would pay a bit more for a decent quality shoe'. Cheap shoes were described as inadequate 'not made to your feet' and 'they skidded everywhere'.

Change/ choice of footwear

Some described having found a good shoe and wanting to stick with it 'I just kept with them just because they fit my feet' and 'I've worn that sort of shoe for years and years'. Conversely one participant was unable to find the right shoe and described changing his shoes regularly 'I got different shoe, different insoles so I got a lot of different shoes' which was reinforced by another participant 'It takes a good few years to work out what shoes actually work for you'. When choosing a shoe, there appeared to be a desire to fit in with everyone else and shoes were often purchased based on recommendations. 'I just wore them because everybody else wore them'.

Discussion

This is the first study to provide a unique insight into the footwear needs of workers in prolonged standing environments from a qualitative perspective. The footwear needs of vets and chefs can be broken into three key themes: sensations and symptoms of the worker; the function and suitability of the shoe for the environment and factors that influence footwear choice. Creating footwear that workers will adhere to wearing with the correct safety features and ergonomic design is a possible mechanism for injury prevention as it could improve safety [18] and reduce MSD [12, 19, 20]. Therefore this research has important implications for footwear design and manufacturing.

There was a high proportion of work related MSD reported (93%) that workers associated with the long hours on their feet. In agreement to previous studies that also found high rates of MSD in jobs requiring prolonged standing, the main areas affected were the back and lower extremities [5, 21, 22]. MSD were described as being obscured by occupational demands and participants identified a need to work through these aches and pains. This could cause conditions to develop and worsen as the summation of wear and tear from prolonged standing over time can result in chronic issues such as joint degeneration and chronic venous disease [4, 8, 23]. Furthermore, the reluctance to mention MSD in the workplace and the perception that they were an expected part of the job could reduce the chance of professional help being sought. Workers were affected both during and after work as well as the day following a long shift, signifying that quality of life outside of work could also be impacted.

Despite some beliefs that MSD are independent of the footwear worn, research indicates there is some potential to reduce aches, pains and feelings of fatigue through alterations in footwear or orthotic design [12, 19, 20, 24].

However, nothing specific to work place enviroments has been produced thus far. A few indications were made to the importance of footbed shape by relating flat footwear to an increase in pain and demonstrating a preference towards arch support. The literature supports this as a medial arch support increases the contact area and redistributes the plantar pressure of the foot [12]. However, due to the mix of beliefs regarding the link between MSD and footwear, educating workers on how different shoe features may impact on specific complaints could be required to avoid poor footwear choices, and this could include when to seek help from a health professional.

The work environments necessitate distinct footwear requirements. The specific flooring in both environments and high level of fluids result in a need for slip resistance. This was identified by almost all of the participants in this study as being of primary importance and has been demonstrated in previous studies to reduce slip rates by more than 50% [18]. Despite some misgivings about suitability of the slip properties of their current shoes, many participants still wore the footwear they deemed unsuitable. Due to the strong link between subjective and objective measures of friction [25], it is expected that use of a shoe that is perceived to have inadequate slip resistance would be detrimental to safety. Problems with the durability of the footwear grip was identified, and therefore it can be recommended that manufacturers should work to improve this or educate as to when footwear should be replaced. This is important for both safety and to align with criteria concerning generalised 'durability' and value of the footwear. Footwear that incorporated a method to identify when slip resistance reached an unsafe level could promote safety.

Heat is also an environmental concern for both vets and chefs. High temperatures were associated with hot, sweaty and odorous feet. High temperatures cause feet to sweat, creating a humid microclimate in the shoe, which results in discomfort [26] and exacerbates frictional forces that cause blisters [27]. Furthermore, sweat causes the surface of the skin to become more alkaline, promoting the development of pathogenic bacteria and fungi. As a solution to the discomfort, workers in both environments reported removing their feet from the footwear in order to cool them down, consequently exposing the foot to hazards. Therefore, it is clear that manufacturers must develop methods to maintain cooler in-shoe climates to improve comfort and reduce the risk of foot conditions developing.

The design of the shoe also influences the temperature, with an open back identified as much preferred due to the circulation of air it allows alongside the ease of donning/doffing the shoes. However, an open back and ventilation holes were unfavourable when the environment became wet. It is not always possible to create a perfect shoe for all environments and therefore features must be prioritised, or customised [28]. For these environments, allowing air into the shoe was the primary issue and therefore we would recommend prioritising the open backed shoe. However, feelings of being unsafe were promoted from shoes that did not remain on the foot. If the shoe did not hold the foot, workers had to resort to physical methods to hold the shoe on. Curling the toes whilst walking, a mechanism that is also adopted when wearing flip flops [29, 30], was used to hold the shoe in place. This could alter the way in which workers move as well as how the muscles are activating consequently impacting injury risk. A strap on an open backed shoe could improve the stability of the shoe on the foot whilst maintaining breathability.

Fit was an important footwear characteristic that was mentioned in its own right as well as in relation to comfort, donning and doffing of shoes and footwear individualisation. A good fitting shoe was given as a reason for not changing footwear, demonstrating its overall importance to footwear comfort and choice. Previously, it has been shown that fit is an important influencer of comfort, with other factors only influencing comfort when the fit was correct [31]. In particular, it was suggested that people with wide or narrow feet had issues purchasing good fitting footwear and there was a need for half sizes to improve the fit. Manufacturers can also play a role in guiding individuals to the correct size footwear, be it through online technology or in retail shops.

Initial and lasting comfort are both essential in work footwear. There is a similar high priority of footwear comfort for mail delivery, construction and care home workers with some workers choosing comfortable footwear over that with the correct safety features [28]. Comfort is related to the footwear, the task or activity and the characteristics of the individual worker such as skeletal alignment [32–35]. This highlights a potential requirement of different footwear for different occupations and reinforces that one shoe will not fit all. Comfort had positive associations with support, cushioning and the idea of footwear individualisation. Individualisation of the footwear or footbed shape was proposed to improve comfort and reduce injury. The literature reinforces that footwear customisation can enhance fit, comfort and prevent injury [36]. Whilst mass customisation would be extremely costly, there could be the option of using a best-matched fit method in which several options are made available and the individual worker chooses the most suitable. This could either be done for the whole shoe or just the footbed or insole and could be a cost-effective way to enhance comfort, meet customer desires [37] and perhaps reduce MSD.

There are a number of factors that can also influence footwear choice. It must be easy to clean and therefore have no fastening on the top that dirt can stick to. There is also a reluctance to spend money on work shoes and indeed it has previously been highlighted that leisure footwear is given higher financial priority than work footwear [28]. This study identified a price-quality trade off in which more money would be spent on a product if it was durable and of high quality. The perception of the factors involved in this trade off could be fundamental in terms of communicating the features of footwear, its benefits, and how this value proposition is proportional to price. Style is a secondary concern to the shoe function and comfort. This differentiates the needs of work footwear from that of leisure wear, where it has been suggested that style is preferential to comfort [38] and provides manufacturers an element of leeway in the shoe design. Chefs were more concerned with shoe appearance than vets, with mention of desirable brands. In these environments, general protocol dictates white or black shoes. It is also worth noting that the visual appearance of the shoe conveys perceptions about the shoe, including that relating to its function, performance and ergonomic quality, which could affect the purchase of the product [39, 40]. In this manner, footwear can be designed to match the consumers perceived needs and thus increase the chance of a worker choosing the shoe.

User preferences for work footwear and concerns regarding work related MSD have been largely ignored and this is the first study that we are aware of that focuses on user preferences for footwear in prolonged standing environments. Therefore this research is novel and provides a starting point from which the wider issues can be investigated. The use of open questions allowed identification of topic areas that were important to the participants. Using a small study sample of 14 participants decreases the generalisability of the results although this was not the aim of the study and the study aim of gaining an in-depth understanding from a few was met. Further, respondent bias could result from the self-volunteering nature of participant selection. The outcome that some preferences are work environment specific means that other environments might require separate investigation. The mixed group of participants from different environments in this study could also be a limitation, although they both met the purposive sampling criteria of standing for prolonged periods. In the future, a larger study could be used to investigate any differences between the two groups and to quantify any relationship between footwear and MSD..

Conclusion

When designing the ideal work footwear for standing environments, the functionality of the shoe for the environment must be addressed, the sensations and symptoms of the workers taken into account to encourage adherence and the decision influencers should be met to encourage initial footwear choice. If any of these criteria are not met, workers are forced to choose based on favoured criteria, which can result in a decrease in safety features, comfort or both and could potentially lead to MSD or injury. Health professionals should take this into account when prescribing footwear or orthotics and footwear manufacturers must aim to meet all criteria. Future research is necessary to understand the link between footwear choice, work demands and MSD. The correct footwear and education regarding foot health and footwear choice could improve working conditions for workers and perhaps impact the high number of MSD repeatedly recorded in jobs that require prolonged periods of standing.

Abbreviation

MSD: Musculoskeletal disorders

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Availability of data and materials

Please contact author for data requests.

Authors contributions

JA collected data, performed the initial data analysis and drafted the manuscript. AW provided a secondary agreement of results. All authors read, commented on and approved the final manuscript.

Ethics approval and consent to participate

Ethical approval was gained (University of Salford, HSCR 16–09) and consent for participation was given by all participants prior to study commencement.

Consent for publication

All authors have approved this paper for submission. This work is original and has not been published elsewhere, nor is it currently under consideration for publication elsewhere.

Competing interests

The authors declare that they have no competing interests.

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2.2.4 Paper 5 commentary

Paper Title: Prolonged occupational standing: the impact of time and footwear.

Reference: Anderson, J., Nester, C. and Williams, A. (2018). Prolonged occupational standing: the impact of time and footwear. *Footwear Science*, *10*(*3*), pp. 189–201. doi: 10.1080/19424280.2018.1538262.

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With more information about the participants needs from footwear, the next step was to start to test differences in footwear over prolonged standing tasks. Footwear cushioning was chosen for multiple reasons. Firstly, the narrative review in paper 1 identified that flooring hardness seemed to impact musculoskeletal disorders so it was likely a similar effect could be seen in footwear. Secondly, it was identified as one of the most important factors by wearers in papers 3 and 4, interlinked strongly with descriptions of comfort. Thirdly, from a footwear manufacturing perspective it was a cost-effective solution. Making single variations to footwear is not easy for manufacturers. At the time of making the test footwear, the partner company focused on EVA injected footwear. This is made from a single mould into which the material is injected and then expands on release. These moulds are expensive at approximately £10,000 per shoe size. However, the factory could create footwear varying in hardness without the need to purchase multiple costly moulds.

However, altering the material hardness in the production process was trickier than initially thought. Although the factory could to an extent edit the hardness of the EVA by blowing different levels of air into it, this could only vary by a certain amount for a given material composition. Initially the aim was to test three levels of footwear hardness, the current footwear, one softer and one harder version. However, when it was produced, the softer footwear was not any softer than the normal shoe, leaving only two hardness variations. Although limiting the number of conditions, this did mean that the testing time could be lengthened, which on reflection was beneficial.

The results from this paper add to the limited literature to date on the impact of prolonged standing on biomechanics, particularly for plantar pressure for which no previous recording could be found. Recording increases in discomfort, calf circumference, plantar pressure, kinematics and kinetics, 3 hours of standing was enough to cause measurable biomechanical changes. Between footwear differences were few, but there was a reduced rate of lower back discomfort development seen when wearing the softer shoes and variations in plantar pressure. Although plantar pressure values were generally higher to start with in the hard shoe, they increased at a slower rate than the softer shoe, further verifying the need to consider footwear over a longer period to determine its comfort. Most importantly, this study identified there was not one single preferred shoe, with some individuals preferring the harder and some the softer shoe with an indication that this could relate to anthropometric factors such as height as well as to biomechanical factors such as medial midfoot contact area.

Research Impact: Footwear for prolonged standing that changed in just a single variable rather than testing multiple different commercially available shoes was novel, especially over the length of time used. This was also the first identification that footwear for standing might need to be customised in order to optimise comfort and the first attempt to record plantar pressure in the lab over prolonged standing periods to map how it changes with time.

Commercial Impact: Being able to demonstrate the impact of long hours of work on the body was important for presenting information to chefs and individuals investing in the company. Furthermore, it provided knowledge that striving for the ‘perfect’ hardness was not a path to follow as it is not the same for everyone.

Project Impact: Identification of the need to provide a range of cushioning levels to improve footwear comfort and to focus on long term footwear comfort due to the changing relationship between the foot and shoe over time.

2.2.6 Paper 6 commentary

Paper Title: Development and evaluation of a dual density insole for people standing for long periods of time at work.

Reference: Anderson, J., Williams, A. E. and Nester, C. (2020). Development and evaluation of a dual density insole for people standing for long periods of time at work. *Journal of Foot and Ankle Research*, *13*(*42*). doi: https://doi.org/10.1186/s13047-020-00402-2.

With the identification from paper 5 that preference for footwear hardness or cushioning varies per person, it was clear that in order to improve comfort a choice of underfoot cushioning/ hardness would need to be offered. The decision to focus on comfort rather than biomechanical factors was made for several reasons. Firstly, the changes in individual biomechanical factors were broad and inconsistent between individuals thus optimising these would not be likely with a single shoe. Furthermore, research in running and military populations had both found that footwear preference varied between individuals, with some initial data suggesting footwear comfort, rather than a single optimised shoe were linked to injury risk. This added more weight to the idea that aiming for the 'perfect shoe' and particularly, the 'perfect cushioning' was not a realistic target.

Commercially, it was decided that any variations would have to be done through an insole. Having a range of shoes would mean extra cost in terms of storage and perhaps an inability to hit minimum order quantities set by factories. Investigating cushioning under specific regions of the foot was of interest due to the variations in plantar pressure changes. As the medial midfoot was a key region for comfort based on the plantar pressure in Paper 5, this was separated from the rest of the insole to create the two segments, the heel/forefoot section and the medial midfoot.

Part one of the paper identified the preference for underfoot cushioning predominantly varied under the medial midfoot, and the company developed a range of insoles accordingly. However, as sales were predominantly made online, through distributors or through employers it was generally not possible for end-users to try each insole first to determine which was the most comfortable. Hence part two of the study combined a trial of the new shoes and insoles in the workplace with the assessment of longer-term comfort (over one day) and development of subjective questions to aid the identification of the most comfortable option.

Research Impact: Identified that variation in cushioning preference is predominantly under the medial arch, not the whole foot. Further, it provides the first insight that longer-term comfort can vary from short term comfort and attempts to identify if a participant's own recordings of their feet and footwear preference can be used to identify the preferred shoes.

Commercial Impact: From this paper, the final product was derived. A range of three insoles to fit inside a new shoe. It also provided a sales tool for guiding individuals to the insole that is likely most comfortable to them, which was vital considering most end-users could not try the shoes on prior to purchase.

Project Impact: This paper used the information learnt throughout the project and previous publications, both in terms of methodologies and footwear factors to develop and test the final product in the real world.

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RESEARCH Open Access

Development and evaluation of a dual density insole for people standing for long periods of time at work

Jennifer Anderson*, Anita E. Williams and Chris Nester

Abstract

Background: Appropriate footwear is important for those who stand for prolonged periods of time at work, enabling them to remain comfortable, healthy and safe. Preferences for different footwear cushioning or hardness are often person specific and one shoe or insole will not be the choice for all. The aim of this study was to develop a range of insole options to maintain comfort during long periods of standing at work and test insole material preferences in the workplace.

Methods: The study consisted of two parts. Part one evaluated 9 insoles of the same geometry that varied in hardness under 2 different plantar regions ($n = 34$). Insole preference, plantar pressure and selected anthropometric foot measures were taken. Three insole designs based on the most preferred options were identified from this part.
In part two, these three insoles were evaluated with 22 workers immediately after trying them on (1 min) and after a working day. Foot anthropometric measures and subjective questions concerning material hardness preferences and self-reported foot characteristics were used to investigate whether either had a relationship with insole preference.

Results: Part one found insole preference predominantly varied according to material hardness under the medial arch rather than the heel/forefoot. Softer material under the heel and forefoot was associated with a reduction in peak pressures in these regions ($p < 0.05$). The most preferred insole had lower pressures under the hallux and first metatarsal phalangeal joint, and greater pressures and contact area under the medial midfoot ($p < 0.05$) compared to the least preferred insole. Height and foot anthropometrics were related to insole preference.
In part two, under real world conditions, insole preference changed for 65% of participants between the immediate assessment (1 min) and after a whole workday, with dorsum height related to the latter ($p < 0.05$). Subjective questions for self-assessed arch height and footwear feel identified 66.7% of the insole preferences after 1 day at work, compared to 36% using immediate assessment of insole preference.

Conclusion: Preference for material hardness varies underneath the medial arch of the foot and is time dependent. Simple foot measures and questions about comfort can guide selection of preferred insoles.

Keywords: Footwear comfort, Standing, Shoes, Insoles, Arch height, Customisation, Personalisation, Occupation, Workplace

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Background

Footwear comfort is extremely important for workers spending prolonged periods of time on their feet [1–3]. Uncomfortable shoes may be rejected by workers and replaced by their own alternatives [2], potentially compromising safety in some work settings. The importance of footwear comfort is further emphasised by the relationship between footwear comfort, preference and musculoskeletal injury risk [4–6].

Although footwear comfort is subjective, complex and affected by multiple physical and psychological factors, preferred footwear can be quickly identified when a shoe is tried on [7–9]. Previous research considering footwear comfort has largely focused on running [8–10] or military recruits [5, 11]. The specificity of these populations and the associated physical activity limits the transferability to understanding footwear for workers who stand for long periods of time. Furthermore, studies of shoe and insole design frequently vary in more than one variable (e.g. changes in both insole geometry and materials), preventing an understanding of the effect of each independent design variable on footwear comfort.

Despite the limitations of previous research, material hardness, or cushioning, has been identified as a dominant factor influencing footwear comfort in running and military populations [5, 12, 13]. Qualitative research with working populations, including those undertaking prolonged standing, identify self-reported links between footwear comfort and footwear cushioning [1, 2], suggesting that material hardness is also important for these populations. Although softer insoles have been associated with greater comfort scores [10, 11], insoles rated as less comfortable by the majority are still the preferred choice for other individuals [4, 5, 14]. Indeed, our previous research identified preference variations between individuals for footwear sole hardness over 3 hrs of standing [15]. This strongly suggests that comfort and cushioning preferences are person specific. Therefore, to improve comfort, footwear solutions may need to include variations in cushioning that the wearer can choose for themselves.

For workplace footwear and online footwear purchases, it is often not possible to try footwear on and allow wearers to explore their comfort preferences. As such, other methods that might allow a person to select their preferred choice without trying any shoes on are desirable. Objective measures have been associated with footwear comfort, including person specific biomechanical variables such as plantar pressure, joint kinematics, joint kinetics, and muscle activity [8, 14], as well as body and foot arch height, foot and leg alignment, and foot sensitivity [5, 15].

Although it is not possible for a lay person to evaluate their own foot characteristics to a level comparable to a health or research professional, simple factors such as concepts of foot arch height have the potential to provide an indication of a measure since they can be visually assessed. Self-assessment could lead to improved selection of preferred footwear at the point of sale, especially for online sales. Therefore, we also consider the relationship between footwear preference and pragmatic self-assessments of foot measurements that could be presented in an online tool with no training requirements.

This study aimed to investigate the impact of insole material preferences on footwear comfort, focussing on the specific needs of those involved in long periods of standing at work. The work comprised two parts:

(1) To investigate the impact of variations in heel/forefoot and medial arch material hardness on insole comfort, plantar pressure and its relation to wearer characteristics to inform the development of a range of insoles.
(2) To test the developed insoles from part one in a real-world setting and investigate the ability of wearer characteristics and subjective questions to predict the selection of the preferred insole.

Part 1: methods

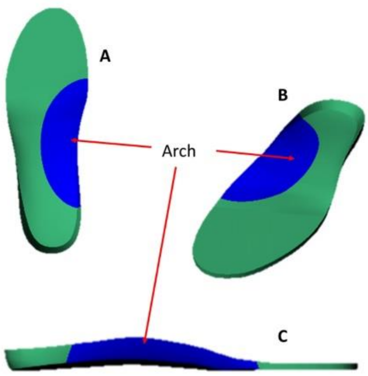
Aim: To investigate the impact of variations in heel/forefoot and medial arch material hardness on insole comfort, plantar pressure and its relation to wearer characteristics to inform the development of a range of insoles.

Participants

Thirty-four healthy participants (male: 14, female: 20) aged 18–55 years and with shoe size UK 5–9 were recruited from a University population. Ethical approval and individual written consent were gained prior to testing.

Footwear

Nine different insoles were produced, varying only in hardness. The insole was a minimum of 5 mm thick and had a contoured medial arch based on the profile of a current product with an in-built arch shape (EziKlog, WearerTech). Each insole comprised two parts, a heel/forefoot piece and a medial arch piece (that was secured to the heel/forefoot piece, Fig. 1). Three different EVA materials were used for each section: soft, medium and firm (Shore A: 23, 45 and 59), creating 9 different insoles. A microfiber layer covered the top and bottom of the insole to maintain its integrity. The insole was designed to fit a work shoe made from EVA (Energise, WearerTech, Fig. 2).



Insole	Hardness (Shore A)	
	Heel/forefoot	Arch
A	Soft (23)	Soft (23)
B	Soft (23)	Medium (45)
C	Soft (23)	Hard (59)
D	Medium (45)	Soft (23)
E	Medium (45)	Medium (45)
F	Medium (45)	Hard (59)
G	Hard (59)	Soft (23)
H	Hard (59)	Medium (45)
I	Hard (59)	Hard (59)

Fig. 1 Insole from bottom (**a**), top (**b**) and medial view (**c**) and hardness combinations for each insole

Protocol

Participants were recruited from a University population, none of who worked in occupations requiring prolonged standing and were excluded if they had any current lower limb injuries. Participant characteristics were measured during bilateral standing (Table 1).

There were 10 conditions presented in a randomised order, one for each of the developed insoles and one randomly selected insole that was tested twice to assess the repeatability of the comfort measure. Participants were blind to the insole differences and unaware that there was a repeat condition.

Participants were asked to wear a comfortable pair of their own shoes for a control walk (≈20 m) that took place prior to each of the 10 test conditions. This process created a “washout” effect, because footwear worn prior to a test can impact comfort ratings [18] and we sought to standardise this for the different test conditions. Participants were handed the test shoe with the insole already inside. Thin socks were worn throughout. Between trials participants sat down for the duration of

Fig. 2 Shoe used for part 1. The entire shoe is made from EVA with a slip resistant sole. The interior of the shoe has no arch shape so all underfoot contouring is from the inserted insole

Table 1 Measures taken in part 1 and 2 of study

Measurement Variable	Equipment	Part 1	Part 2
Age		•	•
Height	Stadiometer	•	•
Weight	Scales	•	•
Foot Length	Brannock Device	•	•
Foot Width	Brannock Device	•	•
Foot Arch Length	Brannock Device	•	•
Q angle	Goniometer	•	
Dorsal height at 50% foot length	Digital Calliper [16]	•	•
Height of Navicular Tuberosity	Digital Calliper	•	
Height MTPJ1	Digital Calliper	•	
Height MTPJ5	Digital Calliper	•	
Heel Width	Callipers	•	
Ball of foot circumference	Gulick II tape measure	•	•
Short heel circumference	Gulick II tape measure	•	
Foot Posture Index	[17]	•	•
Foot mobility magnitude	Digital Calliper [16]		•
Plantar Pressure	Pedar-X	•	

each footwear change either side of the control walk. They were told they could pause for a longer break if required at any point, although this was not required by any participant.

Three work-based movement tasks were undertaken in each condition: a walk up and down the room (≈20 m), one static standing task (screwing nuts onto bolts) and a dynamic standing task (hitting coloured targets on the corners of a 150x40cm desk according to instructions set out on a laptop screen in front of the participant). Both standing tasks were completed at a desk 0.9 m high, lasted 1 min each and aimed to simulate work-like standing tasks. Instructions were given to keep feet on the floor and not to rest weight on the desk surface.

At the start of the protocol, participants were advised to note down any thoughts regarding the comfort of the condition after each individual insole had been worn to help them to rank the insoles once testing was complete. This note taking was at their own discretion. At the end of the session, when all insoles had been worn, the insoles were ranked from 1 (most preferred) to 10 (least preferred).

Plantar pressure data was collected for 23 of the 34 participants, using the Pedar-X (Novel GmbH, Germany) system operating at 50 Hz. A target sample size of 20 had been identified based on similar research and prioritising plantar pressure data [14, 16]. However, our advertising led to over recruitment (n = 34) and we decided to only use plantar pressure data we needed (albeit with 3 extra data sets) so as to reduce participant burden while also taking advantage of the added value that the more subjective measures of comfort necessarily require (i.e. n = 14 extra data sets).

Data analysis

Plantar pressure data was analysed using Matlab (2016b). Pressure data was cropped to remove steps associated with gait initiation, cessation and turning. Single strides were identified using a 5 kPa threshold for heel strike and toe off. Standing tasks were broken into four 15 s epochs with average values calculated for each task. For all data, the foot was divided into 9 regions: the whole foot, heel, medial midfoot, lateral midfoot, metatarsal phalangeal joints 1 (MTPJ1), 2–3 (MTPJ2–3), 4–5 (MTPJ4–5), hallux and lesser toes. The following variables were calculated for each area: mean pressure, peak pressure and percentage contact area. Contact area was defined as the area covered by sensors registering a pressure of greater than 5 kPa [15]. Average values of the left and right feet together were taken for the steps of each participant and for the 4 epochs in each standing task.

All statistical analysis was completed using SPSS (v23, IBM). To assess the differences in plantar pressure between task and insole, a two-way repeated measures ANOVA with a Bonferroni post hoc correction was used. Task (walk vs static standing vs dynamic standing) and insole (A-F) were the two independent variables. Differences in plantar pressure variables between the preferred and least preferred insole were tested with one-way between subject ANOVAs with Bonferroni post hoc correction with task (walk vs static standing vs dynamic standing) and insole (preferred vs least preferred) as the independent variables. One-way between subject ANOVAs and independent t-tests identified differences in participant characteristics (height, weight, foot measurements) when they were grouped according to their preferred insole. Comparisons were made between any insole that was the preferred choice of 5 or more participants (A vs B vs C vs F); those that had a preference for a soft or medium heel/forefoot section (A, B, C vs D, E, F); and those that had a preference for a soft, medium or hard arch (A, D, G vs B, E, H vs C, F, I). Prior to statistical analysis, the FPI data was converted into its Rasch transformed score to enable parametric analysis [19]. A Friedman test was used to determine any differences in the ranking of the insoles. For post hoc tests, a Wilcoxon rank tests with Bonferroni corrections resulting in an adjusted significance level of $p <$ 0.0014.

Part 1: results

Participant characteristics are presented in Table 2. Insoles with the soft heel/forefoot section (A, B and C) were the most preferred, being ranked number 1 by 32, 21 and 21% of participants respectively, and therefore 74% of participants in total (Table 3). In the arch area, 42% preferred a soft, 24% a medium and 36% a firm material. There was a statistically significant effect of the ranking of the 9 insoles ($\chi^2(8) = 36.893$, $p < 0.001$) with post hoc tests finding insole A ranked significantly lower than insoles G and I (i.e. was more preferred), and insole B ranked lower than insole G.

The insole that was repeated was used to assess the reliability of the ranking process. The average difference in ranking position for the same insole was 3.125, where a difference of 1 would mean they had been ranked next to each other. In total, 38% of individuals had a difference of 1 rank, 37% had a difference of between 2 and 4 while the remaining 25% had a difference of between 5 and 7. This likely reflects comments made by a few participants about the difficulty of ranking some of the insoles. When comparing the plantar pressure between preferred insoles, a comparison was only made between the highest and lowest ranked insole (1st and 9th) as this was always larger than the difference in ranking for the repeated insole case.

Table 2 Participant characteristics for part 1 (n = 34). Absolute refers to direct measurements whereas normalised refers to measurements normalised to foot length

Variable		Mean	SD	Min	Max
Age (years)		31.6	10.4	18	54
Height (m)		1.69	0.06	1.54	1.81
Weight (kg)		70.7	12.6	55	99
BMI (kg/m^2)		24.8	4.8	19.2	37.9
UK Shoe Size		7	2	5	9
Q angle (°)		8.6	2	5.5	12.5
FPI		3.9	2.7	−1	8
Foot Length (mm)		252.1	9.5	236.5	276.5
Arch Length	Absolute (mm)	182.2	7.1	173	199.5
	Normalised (%)	72.3	1.4	70.0	77.3
Foot Width	Absolute (mm)	92.4	4.8	84.5	102.5
	Normalised (%)	36.7	1.8	33.5	40.4
Dorsal Arch Height	Absolute (mm)	61.8	5.7	51.5	72.0
	Normalised (%)	24.5	2.1	20.6	28.3
Navicular Height	Absolute (mm)	43.8	6.6	28.5	57.0
	Normalised (%)	17.3	2.5	11.5	22.1
MTPJ1 height	Absolute (mm)	34.0	3.7	20.0	39.5
	Normalised (%)	13.5	1.4	8.1	15.5
MTPJ5 height	Absolute (mm)	23.0	2.3	19.0	30.0
	Normalised (%)	9.1	0.9	7.7	11.5
Heel Width	Absolute (mm)	58.2	5.2	46.5	70.0
	Normalised (%)	23.1	2.1	18.6	27.1
Ball of foot Circumference	Absolute (mm)	236.7	15.2	209.5	289.5
	Normalised (%)	93.9	5.7	85.5	114.7
Heel circumference	Absolute (mm)	276.5	11.9	255.5	300
	Normalised (%)	109.7	3.8	103.0	117.7

SD Standard deviation; *FPI* Foot Posture Index

Plantar pressure

The average number of steps analysed for each insole was 30 ± 3 and there was no meaningful difference of insole on foot contact time ($F_{5,91}$ = 0.669, p = 0.635), a representative measure of walking speed [20]. All data is shown in Table 3.

Peak pressure for the whole foot, heel, medial midfoot, MTPJ1, hallux and toes, increased as the heel/forefoot piece got harder (Table 4). In the lateral midfoot, insole A (soft heel/forefoot, soft arch piece) had significantly lower pressure than insoles C, F and H (all with hard/medium arch pieces). The MTPJ1 region displayed significantly lower pressures for insole A (soft heel/forefoot, soft arch piece) than D (medium heel/forefoot, soft arch piece) and H (firm heel/forefoot, medium arch piece). In the MTPJ2–3 and toe regions there were lower pressures in insole C (soft heel/forefoot, firm arch piece) than insole D and E (medium heel/forefoot, soft and medium arch pieces). Contact area differences were seen for the lateral and medial midfoot only. In the medial midfoot, the greatest contact area was seen for insoles B and C (soft heel/forefoot, medium/firm arch piece) with lowest values seen for insole D (medium heel/forefoot and soft arch piece) and for insoles with the firm heel/forefoot insole sections (G, H, I).

Comparing the most and least comfortable insoles (Table 5), the preferred insole had greater medial midfoot mean pressure (+ 22%), peak pressure (+ 16%) and contact area (+ 15%) compared to the least preferred. Whole foot peak pressure was on average 22% lower for the preferred insole compared to the least preferred. Peak pressure was 19 and 18% lower for the MTPJ1 and hallux in the preferred insole compared to the least preferred. A significant interaction between task and insole hardness occurred as a result of a much greater differences between insoles during walking.

Individual wearer characteristics

There was a significant main effect of arch length on insole preference ($F_{3,29}$ = 3.05, p = 0.047) with a greater absolute arch length (p = 0.041) in those who preferred insole F (medium heel/forefoot, firm arch) in comparison to insole A (soft heel/forefoot, soft arch).

Compared to those preferring a soft heel/forefoot section, those that chose a medium heel/forefoot section were taller ($t_{18.6}$ = 2.9, p = 0.009, soft heel/forefoot = 1.67 ± 0.06 m; medium heel/forefoot = 1.73 ± 0.04 m) and had a greater absolute arch length (soft = 180.1 ± 5.5 mm; medium = 188.3 ± 8.0 mm, $t_{10.8}$ = 2.85, p = 0.016).

A smaller normalised heel width was present in those who preferred the harder arch piece ($F_{2,33}$ = 3.43, p = 0.045) with post hoc results finding a greater normalised heel width in those preferring the soft arch compared to the hard arch (soft arch = 23.9 ± 1.6%; hard arch = 21.7 ± 1.9%, p = 0.044). Although not significant, there was a trend towards a greater FPI score (lower arched feet) in those preferring the firm arch piece ($F_{2,33}$ = 2.57, p = 0.093).

Part 2: methods

Aim: To test the developed insoles from part one in a real-world setting, and investigate the ability of wearer characteristics and subjective questions to predict the selection of the preferred insole.

Participants

Participants were all kitchen workers (n = 22), selected because our previous research demonstrates that they are spending an average 87% of work time on their feet, of which around ¾ is spent performing standing tasks [21]. Exclusion criteria included anyone under the age of

Table 3 Ranking of insoles for part 1 where a ranked position of 1 indicates the most preferred insole and 9 the least preferred. N.B. totals add to 101% due to errors caused by rounding to whole numbers

		% of individuals ($n = 34$)								
	Insole	A	B	C	D	E	F	G	H	I
	Heel/forefoot	Soft	Soft	Soft	Medium	Medium	Medium	Firm	Firm	Firm
	Arch	Soft	Medium	Firm	Soft	Medium	Firm	Soft	Medium	Firm
Ranked Position	1	32	21	21	6	3	15	3	0	0
	2	9	26	15	18	15	3	6	6	3
	3	21	12	9	6	9	18	9	9	9
	4	3	15	6	18	24	6	0	18	12
	5	9	3	15	12	3	12	15	12	21
	6	9	6	9	12	21	15	6	9	15
	7	3	3	0	18	12	21	18	21	6
	8	6	6	12	6	15	6	21	6	24
	9	9	9	15	6	0	6	24	21	12

18, anyone who did not work back of house in the kitchen or was not on their feet for most of the day and anyone with diagnosed foot conditions or lower limb injuries.

Footwear

Based on the outcomes of part one, three insoles were developed, all made from EVA with the same contouring and fabric top cover (Fig. 3). All had a soft heel/forefoot section of Shore A 30, but the arch piece was either soft (Shore A 30), medium (Shore A 40) or firm (Shore A 50). This choice reflected the results of part 1 where preference predominantly varied about the insole arch hardness, with most participants preferring a soft heel/forefoot section. This was supported by the reduction in peak plantar pressure values under the heel and forefoot associated with the softest material.

Each participant was given all 3 insoles and a lace-up shoe suitable for their workplace setting ('Relieve Custom Pro', WearerTech, Fig. 3), with an EVA midsole, slip resistant rubber outsole, a microfibre upper and neoprene stretch lining.

Protocol

Participant characteristics were measured during bilateral standing (Table 1). These measures were chosen pragmatically based on time available, which was limited with the working population, and factors that individuals would potentially be able to provide an indication of themselves. Each participant tried the shoe on with each of the 3 insoles in a randomised order (approximately 1 min per insole), blind to the differences between insoles. They were told they could walk around and assess the comfort dynamically but were not given specific instructions. They were asked to rank the insoles in order of preference. This process aimed to replicate how a shoe may be selected in a shop prior to purchase and provide an indication of immediate preferences.

After the initial testing session, participants completed 7 questions in an online survey that subjectively rated their own foot characteristics (Table 6). The link to the online questionnaire was sent once the researcher had left to ensure it was completed alone. This provided a means of exploring whether participants could independently evaluate their own feet in ways that could predict their preferred insole, mimicking the potential point of sale or circumstances when they might choose footwear without trying them on. This included questions regarding foot characteristics that have previously been related to footwear comfort, such as medial arch height, foot arch flexibility and foot sensitivity [5] as well as questions regarding their preference for material under the whole foot, arch of the foot and how supportive they liked a shoe to feel.

The participants wore each insole (soft, medium and firm arch materials) in the shoe for an entire day at work in a randomised order. They were asked to ensure a similar length of time in each insole and to wear them on consecutive days at work. The time the insole had been worn was recorded at the end of each day. Once each insole had been worn for a full day at work, participants were asked to rank the insoles in order of preference.

Data analysis

A Friedman test was used to assess the differences in rankings of the insoles. Prior to statistical analysis, the FPI data was converted into its Rasch transformed score to enable parametric analysis [19]. One-way between subject ANOVAs were used to identify differences in

Table 4 Plantar pressure differences between insoles ($p < 0.05$). MP = mean pressure (kPa); PP = peak pressure (kPa); CA = contact area (%). Arrows indicate significant post hoc differences between insoles. (↓ = insole has values less than …; ↑ = insole has values greater than …). ^{s} = significantly different to static standing value, ^{y} = significantly different to dynamic standing value, ^{w} = significantly different to walking value. [a] significant interaction effect for insole and task

Region	Variable	Insole									Mean			
		A	B	C	D	E	F	G	H	I	Walking	Static Standing	Dynamic Standing	
Whole foot	MP										32.23^{sy}	22.10^{wd}	21.22^{ws}	
	PP	↓EFGHI	↓DEFGHI	↓EFGHI	↓GHI↑B	↓GHI↑AB	↓GHI↑ABC	↑ABCDEF	↑ABCDEF	↑ABCDEF	296.82^{sy}	96.83^{wy}	143.04^{ws}	a
	CA										51.88^{s}	59.19^{wy}	53.92^{s}	
Heel	MP										42.96^{sy}	32.27^{w}	33.91^{w}	
	PP		↓DEGHI	↓GHI	↑B			↑B	↑BC	↑B	216.13^{sy}	83.50^{wy}	113.0^{ws}	a
	CA										54.91^{sy}	69.39^{w}	68.25^{w}	
Lateral midfoot	MP	↓CFH		↑A			↑A		↑A		28.86	27.79^{y}	26.00^{s}	
	PP										112.99^{sy}	60.71^{wy}	90.57^{ws}	
	CA	↓H							↑A		57.89^{sy}	75.29^{wy}	66.68^{ws}	
Medial midfoot	MP	↑DGHI	↑DFGHI	↑DFGHI	↓ABCEFH	↑DG	↓BC	↓ABCE	↓ABC↑D	↓ABC	15.19	16.19	14.96	
	PP	↑GH	↑DGHI	↑DGI	↓BC	↑G	↑G	↓ABCEF	↓AB	↓B	83.69^{sy}	45.53^{wy}	63.45^{ws}	
	CA	↓C↑DG	↑DGI	↑A	↓ABCE	↑DG	↓C	↓ABCE	↓C	↓BC	37.42^{sy}	51.05^{wy}	44.19^{ws}	a
MTPJ 1	MP	↓DH		↓D	↑AC					↑A	46.15^{sy}	26.63^{wy}	21.18^{ws}	
	PP	↓GHI	↓DGHI	↓GI	↑B		↓GHI	↑ABCF	↑AB	↑ABCF	210.42^{sy}	66.03^{wy}	100.27^{ws}	a
	CA										63.86	67.99^{y}	58.16^{s}	a
MTPJ 2–3	MP			↓DE	↑C	↑C					41.98^{sy}	22.58^{wy}	19.06^{ws}	
	PP			↓DEFGHI	↑C	↑C	↑C	↑C	↑C	↑C	200.54^{sy}	53.58^{wy}	92.83^{ws}	
	CA										64.60^{y}	64.74^{y}	55.18^{ws}	
MTPJ 4–5	MP										27.91^{sy}	19.33^{wy}	17.92^{ws}	
	PP										148.48^{sy}	50.64^{wy}	85.59^{ws}	
	CA										54.26	58.13	51.70^{s}	
Hallux	MP										38.09^{sy}	17.87^{w}	16.94^{w}	a
	PP	↓GH	↓EGHI	↓EFGHI	↓GHI	↑BC	↑C	↑ABCD	↑ABCD	↑BCD	258.19^{sy}	48.89^{wy}	106.88^{ws}	a
	CA										52.68	52.59^{y}	46.79^{s}	
Toes	MP			↓DE	↑C	↑C					41.14^{sy}	23.10^{wy}	19.57^{ws}	
	PP		↓EH	↓DEGHI	↑C	↑BC		↑C	↑BC	↑C	200.21^{sy}	23.85^{wy}	94.46^{ws}	a
	CA										63.27	65.96^{y}	56.54^{s}	

Table 5 Significant plantar pressure differences between the preferred and least preferred insole. Percentage change is the difference from the least preferred insole to the preferred (i.e. a negative % difference indicates the value is reduced in the most preferred)

Region	Variable	Most preferred (Mean kPa)	Least Preferred (Mean kPa)	% difference	F	P	Interaction effect
Whole Foot	PP	158.83	204.75	−22%	26.94	< 0.001	a
Hallux	PP	125.02	152.18	−18%	7.83	0.01	a
MTPJ1	PP	115.94	142.71	−19%	12.52	0.002	a
Medial Midfoot	CA	50.19	43.58	+ 15%	10.07	0.004	a
	MP	18.07	14.81	+ 22%	10.37	0.004	a
	PP	72.39	62.6	+ 16%	4.89	0.038	

[a] significant interaction effect for insole and task. *PP* peak pressure, *CA* contact area, *MP* mean pressure

Fig. 3 Insoles and shoe given to kitchen workers (part 2)

characteristics between individuals that preferred each insole (soft arch vs medium arch vs firm arch). For the subjective questions answered by the participant, a chi squared test determined any relationship with the preferred insole (both immediate (1 min) preference and after one workday preference). As well as the FPI total score, the analysis was also completed with the score for 'height and congruence of the medial lateral arch' due to the similarity between this measure and the visual assessment of arch height. Subjective questions with a relationship to insole preference of $p < 0.25$ were used to identify the preferred insole.

Part 2: results

The length of workday (i.e. time wearing each insole) varied from 7 to 16 h between individuals (average: 9.4 ± 2.8 h) but individual participants wore each insole for a similar length of time (i.e. the person with a working day of 7 h wore each insole for 7 h). This is reflected in the fact that there was no overall difference in the length of time each insole was worn for the entire group ($p > 0.05$). Participant characteristics can be seen in Table 7. Two participants did not complete the protocol so were removed from the analysis, one due to a job change and contact was lost with the second.

Insole preference

The Friedman test identified no overall difference between the rankings of the insoles (p > 0.05). In total, 65% of participants changed their insole preference between the immediate assessment after 1 min of wear and after wearing each insole for one day at work.

Individual characteristics

There was no relationship between initial insole choice and any of the measured characteristics in Table 1 (p > 0.05). For the preferred insole choice after one workday, the only variable related to insole preference was dorsum height as a percentage of foot length ($F_{2,16} = 4.221$, $p = 0.034$). Those preferring the insole with a softer arch had a greater dorsum height (soft = 26.3 ± 1.1; medium = 24.4 ± 1.4; hard = 24.0 ± 1.7).

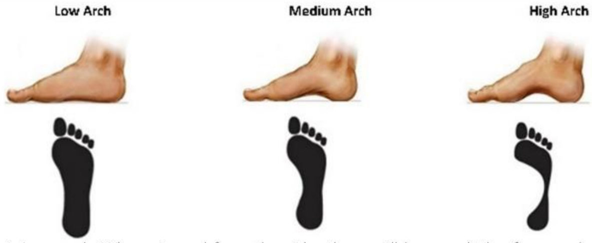
All but one participant rated their arch height as low or medium, therefore high arch was removed from the statistical analysis and an independent t-test was used in place of the ANOVA. Independent t-tests found a significant difference in dorsum height (as a percentage of foot length) between those rating their own arch as "low" compared to "medium" ($t_{16} = 2.136$, $p = 0.048$; CI = 0.014–3.77) and a trend towards a greater FPI score (i.e. a lower arch) in those with a self-reported low arch (Table 8).

Subjective questions

For the immediate insole preference, questions 5, 6 and 7 regarding foot sensitivity and question 4 ('How do you prefer a shoe or insole to feel under your foot?') had p values below 0.25. As all the sensitivity questions assessed the same factor, only the question 'How do you feel when walking barefoot on a hard floor (concrete or tiles)?' was included as it had the strongest association with insole preference. Using these two questions, the model could identify 68.4% of individuals immediate preference.

For the insole preference following a full workday, only questions 1 and 3 had a p value below 0.25. These were the self-assessment of arch height and the question 'How do you prefer a shoe or insole to feel under your foot?'. These two questions could identify 66.7% of insole preferences after a whole working day. Based on these two questions a tool to assist a

Table 6 Multiple choice questions for the self-assessment of foot characteristics by participants

Question		Answer Options
1	Please identify what type of foot arch you have when standing (image selector)	 1. Low arch: When viewed from the sider there will be very little, if any arch shape to the foot, with no room to put a finger under the arch. Almost the entire sole of the foot will make contact with the ground causing the wet footprint to be filled in with very little narrowing in the band connecting the heel and forefoot. 2. Medium arch: When viewed from the side there will be a visible arch from the heel to the ball of the foot with just enough room to fit an index finger under. In the wet footprint, the forefoot and heel will be visible but there will be an obvious narrowing in the band connecting them. 3. High arch: When viewed from the side there will be a very visible arch. An index finger will be able to fit under the arch with room to move. In the wet footprint, the forefoot and heel will be very narrow or non-existent.
2	Do your feet look more arched when the weight is taken off them?	1. No, my feet look the same sitting and standing 2. Yes, my feet get slightly more arch shape to them when I take the weight off them 3. Yes, my feet get a lot more arch shape to them when I take the weight off them
3	How do you prefer a shoe or insole to feel under your foot?	1. Soft with less support 2. Medium firmness with some support 3. Firm material for more support
4	How do you prefer a shoe or insole to feel under the arch of your foot?	1. Soft with less support 2. Medium firmness with some support 3. Firm material for more support
5	How do you feel when walking barefoot on a pebbly beach?	1. Ouch! I really struggle to walk barefoot on a pebbly beach. 2. Uncomfortable but I can manage. 3. Not a problem, I'm happy to walk barefoot on a pebbly beach
6	How do you feel when walking barefoot on a hard floor (concrete or tiles)?	1. Ouch! I really struggle to walk barefoot on a hard floor. 2. Uncomfortable but I can manage. 3. Not a problem, I'm happy to walk barefoot on a hard floor
7	How sensitive are the soles/underside of your feet?	1. Not at all sensitive 2. Slightly sensitive 3. Very sensitive

wearer to self-identify their preferred insoles was created (Table 9).

Discussion

This paper documents the research-led development of an insole product range that aims to improve the comfort of a shoe specific to workplace settings that demand prolonged standing. It identified that variation in preferences for material hardness was related mainly to the medial arch area (part one). Also, that most participants changed their footwear preference between the immediate assessment (1 min) and the assessment after wearing each insole for a whole workday (part two), highlighting the challenge of using first try on, or online purchases, in ensuring that preferred shoes are chosen. Finally, self-reported arch height and underfoot material preference were found to assist in the identification of the preference after a whole workday (part two), and thus there may be potential to use simple questions to guide footwear selection.

The preferred insole in part one had greater medial midfoot pressure compared to the least preferred insole

Table 7 Participant characteristics for part 2 (n = 20). Absolute refers to direct measurements whereas normalised refers to measurements normalised to foot length

		Mean	SD	Min	Max
Age (years)		30	7.9	20	53
Height (m)		1.72	0.09	1.56	1.90
Weight (kg)		78.8	18.5	51.7	126.6
BMI (kg/m^2)		26.7	5.2	19.7	39.5
UK Shoe Size		8	2	4	12
FPI		2.7	2.8	0	11
Foot Mobility Magnitude		1.4	0.4	0.7	2.1
Foot Length (mm)		257.7	15.8	231.0	289.5
Arch Length	Absolute (mm)	188.5	13.1	168.5	217.0
	Normalised (%)	73.1	1.2	71.3	75.2
Foot Width	Absolute (mm)	96.3	6.0	83.0	106.5
	Normalised (%)	37.4	1.6	34.1	40.0
Dorsal Arch Height	Absolute (mm)	63.7	5.1	55.7	72.3
	Normalised (%)	24.6	1.8	21.6	28.0
Ball of foot Circumference	Absolute (mm)	241.2	16.0	214.5	267.0
	Normalised (%)	93.6	3.28	85.8	98.7

SD standard deviation; *FPI* foot posture index

and a resultant reduction of pressure in other regions. This is in agreement with previous walking and standing research [14, 15, 22, 23] and suggests that for these work-based tasks lower plantar pressure was an important component for comfort. Medial midfoot pressure was increased by using a softer material in the heel/forefoot section or by having a harder material under the medial arch. A softer material under the heel/forefoot presumably compresses more readily than the harder materials, thus allowing load to be transferred to the medial arch area. Indeed, the least preferred designs were those in which there was a softer material under the arch than in the heel/ forefoot section. This outcome also reveals that material choice alone can manipulate plantar pressure distribution and perceived comfort, independent of the much-discussed changes in insole geometry [24–26].

Only one participant selected an insole with a firm heel/forefoot section as their preferred choice in part one indicating that there is possibly a maximum hardness value above which comfort is less likely to be achieved. Furthermore, one study that tested insoles with a hardness of 52–75 shore A (similar to our hardest material) did not find a preference for insoles at the lower (softer) end of this range [27]. This perhaps suggests that above this maximum hardness value variations in hardness do not link to variations in comfort or preference. Defining the range of hardness values over which comfort and preferences vary could be important in personalising footwear options since it will offer genuine options for users to adjust their comfort and preferences.

Previous research has highlighted a preference for the entire insole to be harder for individuals with a lower medial arch height [5]. Based on our results this relationship is only true for the medial arch area, meaning a softer material can be used in other regions to improve comfort. The preference for harder arch materials in those with lower arched feet might be due to an increase in foot arch height that the material provides [28]. A softer arch material may enable contact with the arch in medium and high arched feet [29] and this contact may

Table 8 Difference in arch height between self-assessed arch heights of low and medium (only one person selected a high arch, so they were removed from analysis)

	Low Arch		Medium Arch		P value
	Mean	SD	Mean	SD	
Absolute Dorsum height (mm)	61.3	7.2	64.5	5.0	0.309
Dorsum height (% foot length)	23.4	2.1	25.3	1.4	0.048
FPI score	3.6	2.1	1.6	1.8	0.063

Table 9 Selection tool to determine insole preference after one workday. High arch column is based on only 1 inidividual reporting a high arch

		What type of foot arch do you have when standing?		
		Low arch	Medium arch	High arch
How do you prefer a shoe to feel under the arch of your foot?	Soft material with less support	Medium Insole	Soft Insole	Soft Insole
	Medium firmness with some support	Firm insole	Medium Insole	Soft Insole
	Firm material for more support	Firm Insole	Firm Insole	Medium Insole

affect comfort [14, 15]. However, we did not measure the actual response of the arch geometry and foot joints to the insoles.

Due to the inability of most workers and online purchasers to try on footwear, methods that might allow a person to select their preferred insole without trying any shoes on or have objective measures taken are desirable. Results from this study suggest self-assessed arch height and preferred materials seem likely to enable a prospective wearer the opportunity to identify an insole that would be their preferred choice for longer-term use (e.g. after day at work). Based on the results, these two pieces of information would allow identification of the preferred insole in 67% of individuals, an improvement on using the immediate selection (36%). The difference in objective foot arch height measures between those rating themselves as having a low or normal arch suggests this measure could be a good indicator of arch height, but a larger study is warranted to verify this, especially focussing on the inclusion of more high arched participants.

The change in insole preference in part two following wear over a day at work (lasting 7–16 h) compared to a few minutes use could be a result of adapting to the insoles, changes in the feet due to prolonged standing, changes in the insoles over time, or a combination of these. For example, we know that prolonged standing causes changes in the pain pressure threshold [30], lower limb swelling [15, 31] and plantar pressure [15, 32]. In running, a reduction in arch height is also seen over time [32, 33]. Although this has not been assessed during prolonged standing, increases in medial midfoot pressures and contact area suggests that this might be the case [15]. Any changes in arch height or foot morphology from swelling could alter comfort and insole preference. This highlights the importance of developing a method to enable a user to identify the optimum footwear choice in the longer-term even if using only immediate assessments of their feet and footwear options.

In terms of the comfort assessment selection, ranking shoes has previously been shown to be the most reliable method of assessing comfort [9, 34], although the maximum number of footwear options that can be tested has not been reported. The use of ten different insoles in part one could have made it difficult to rank them, as noted by a few participants, and it assumes the difference between insoles are large enough to produce repeatable ranking. Although some studies suggest only using individuals who can rate comfort 'reliably' [34, 35], this may remove individuals with important characteristics, such as those with a low foot sensitivity, a factor that impacts insole preference [5]. This work took a more pragmatic approach because it had a specific target audience.

This study had several limitations. The variation in shoes used for part one and two was necessary as the shoe designed to accommodate the insoles was under development itself during part one, which is typical of real-world industry linked research. However, insoles were selected based on rankings and the footwear designs would have to dramatically affect rankings, not just comfort scores, to lead to different outcomes. While standardising the shoe for each part was important for the methodology, in a real-world context the use of a range of shoes means the transferability of these insoles to different shoes with varying midsole cushioning and geometries is unclear. Changing other aspects of the footwear may produce different results and interact with the insole effects we report here. The footwear development had commercial limitations, including the fact that the number of insole options was limited due to tooling and logistics costs. The number of participants recruited in part two of the study was limited by the number of pairs of sample shoes and insoles that the factory was willing to produce rather than developing recruitment numbers through a power analysis. Further research should test the self-assessment of arch height with a larger population, assess the accuracy of the subjective questions for identifying the preferred insole, and investigate changes in variables such as arch height and insole material properties over a working day. Considering the geometry (height and length) of the arch piece is also required.

Finally, we do not know the effect of wearing comfortable footwear on long term musculoskeletal disorders and injury risk at work. The comfort paradigm [4] suggests that a comfortable shoe might be one that is best for the body and therefore reduce lower body injury risk, as reported for military personnel and rugby players [5, 6]. We do not currently know if a similar protective effect would stem from comfortable footwear during prolonged standing at work, but if it impacted musculoskeletal disorders and overall discomfort, it could be beneficial for employers, employees and workplace safety policies.

Conclusion

This study used preferred insole choices and plantar pressure data to enable the personalisation of insole choice for workers undertaking prolonged standing wearing specialist workplace footwear. There were differences in the preferences for insole material hardness between immediate assessment and assessment following one workday in each insole. The use of self-assessment of foot arch height and material preferences offers an opportunity to guide insole selection at the point of choosing footwear. The strength of this research lies in the practical application of data to the design and evaluation of new insole products that aim to protect prolonged standing workers.

Abbreviations

MTPJ: Metatarsophalangeal joint; SD: Standard Deviation

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Authors' contributions

JA completed the data collection and analysis. AW and CN contributed to the study conceptions and design with all authors involved in the writing of the paper. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

Ethical approval was provided by the University of Salford for both parts of the study (part 1: HSR1617–145 part 2: HSR1819–001) and each participant signed a consent form prior to participation.

Consent for publication

Not applicable.

Competing interests

The lead author (JA) was employed by the University of Salford while this work was conceived. Thereafter JA was employed by footwear company WearerTech for a period during the data collection. WearerTech products were tested in this paper. WearerTech only provided the shoes and had no input on data collection, analysis or write up, which was completed with the University of Salford. At the time of submission, JA is an employee of the University of Salford.

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Publisher's Note

2.3 Summary of papers and outcomes

	Paper Title	Project Outcome
1	A narrative review of musculoskeletal problems of the lower extremity and back associated with the interface between occupational tasks, feet, footwear and flooring	• Identified the main problems associated with prolonged standing • Identified the need for improved definitions of workplace activity, leading to paper 2 • Defined basic protocol and variables for paper 3 and 5
2	Exploring occupational standing activities using accelerometer-based activity monitoring	• Defined activity for the specific study populations • Guided the activity of the lab-based protocol (paper 5)
3	Musculoskeletal discomfort, foot health and footwear choice in prolonged standing workers.	• Determined the prevalence rate of musculoskeletal disorders • Identified footwear comfort as an important factor associated with musculoskeletal discomfort (explored further in papers 5 and 6)
4	An explorative qualitative study to determine the footwear needs of workers in standing environments	• Defined footwear design factors required by end-users • Consumers identified the need for the correct footwear cushioning as important (explored further in papers 5 and 6)
5	Prolonged occupational standing: the impact of time and footwear	• Identified biomechanical changes associated with prolonged standing • Found a link between footwear preference and plantar pressure • Identified differences in footwear hardness preference between individuals • Guided the insole design for paper 6
6	Development and evaluation of a dual density insole for people standing for long periods of time at work.	• Developed and defined the final insole design • Tested the concept with end-users • Developed a tool to aid product selection for online sales

Table 2.12 *Summary of paper outcomes*

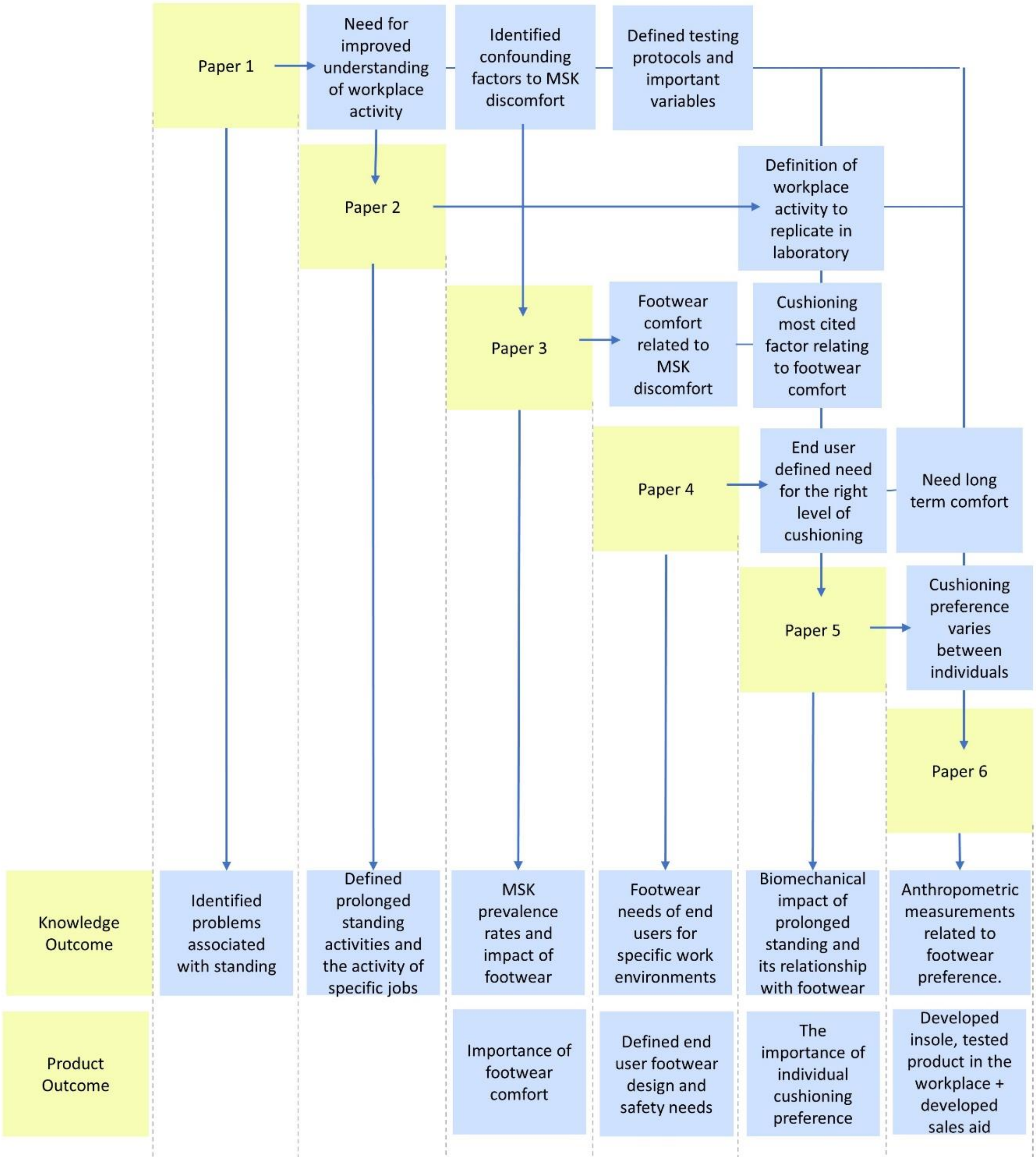


Figure 2.1 *How the outcomes from each paper helped to generate subsequent papers and knowledge/ product outcomes*

Chapter 3 : Critical review

This chapter will explore and critically review the published works presented here and consider where the research sits within the wider research field of prolonged standing. It will include the following:

(1) The contribution and impact of this research academically, commercially and the footwear recommendations that can be drawn from these works for prolonged standing workers.
(2) A critique of the methodologies used within the papers with a comparison to other published literature.
(3) The KTP project and integration of commercial and academic work including an analysis of how this project workers with a business.
(4) A critical analysis of the overarching limitations: is standing always bad, and what are the limitations of footwear as a solution?
(5) An analysis of literature published since the papers here and suggestions for future research.

3.1 The contribution and impact of this research

3.1.1 Contribution to the current literature on prolonged standing

The papers comprised in this body of work fill gaps in the under-researched topic area of prolonged standing at work. Firstly, they identify the importance of considering musculoskeletal disorders of the feet. Even cross sectional prevalence studies, the most common methodology in this topic area, previously combined the ankle and foot into one region (Kuorinka *et al.*, 1987) obscuring the true prevalence in the feet. The works presented in this thesis highlight the need to consider the feet, identifying them as the second most prevalent region of pain in the lower body (Paper 3) and recording the impact that poor foot health can have not just during a work shift but also on quality of life outside of work (Paper 4).

Although standing had previously been identified as a potential risk factor for musculoskeletal disorders, there has been confusion as to what constitutes prolonged standing and as a result, a lack of evidence to link the two together (Messing *et al.*, 2015). Previously, all upright activity in the workplace has been broadly defined as either walking or standing (Lunde *et al.*, 2017; Nielsen *et al.*, 2017), resulting in definitions that lack precision (Messing *et al.*, 2015). Paper 2 increases this precision by defining 3 distinct standing activities, and providing a greater ability to determine how much movement an individual demonstrates in the workplace. The relevance of this is emphasised through the identification that two professions that spend almost identical percentages of their working day ‘standing’ as previously defined (Veterinary surgeons = 65%; Chefs = 66%) show large variations in the how dynamic the standing tasks are that they perform. This is important as the dynamic nature of an activity is related to the development of musculoskeletal disorders during prolonged standing (Balasubramanian *et al.*, 2009).

The second half of this body of work focuses on occupational footwear, a topic that has received limited interest in previous research and is almost non-existent in comparison to that of athletic or sports footwear. Indeed, in the most recent international footwear symposium at the time of writing with over 120 presentations (Wannop *et al.*, 2019), only one keynote (Steele and Dobson, 2019) and two presentations considered occupational footwear, one looking at the testing of steel toe caps (Dirksen *et al.*, 2019) and ours (Anderson *et al.*, 2019). A handful of studies prior to the papers presented here had considered footwear for standing workers but the methodologies and tested footwear limited their use from a design perspective. Papers included those on shod vs unshod (Lin *et al.*, 2012), the impact of different models of footwear that varied in multiple design factors (Hansen *et al.*, 1998; Chiu and Wang, 2007) or focused on the addition of an insole with no control for footwear (King, 2002; Orlando and King, 2004). The works presented here develop a greater understanding of the impacts of footwear on an individual and their biomechanics, including an in depth understanding of a single footwear design factor (underfoot cushioning). However, it also broadened the previous quantitative focus to include qualitative research, which has not been previously recorded but was essential for understanding the needs of the wearer, knowledge translation and product development.

Footwear comfort is one of the main themes in this thesis and it has recently been described as a re-emerging footwear topic (Wannop *et al.*, 2019), although it remains centralised on running footwear. This PhD uses some of the theory and methodology from running research such as the assessment of footwear comfort and the link between individual anthropometrics and footwear comfort but applies it to footwear for standing workers for the first time. It also had to develop new methodological factors such as how to assess biomechanical measurements and comfort for an extended period of time where most research focus on only a few minutes.

Part of the drive for the novel research in this body of work stemmed from the need for the transfer of knowledge to a final footwear product. Thus, these works also provide documentation of the development of a new research-led footwear product. This was enabled through the collaborative nature of the project that ensured the publication of the research, something which is normally kept in house by companies. Combining these papers in this thesis enhances the story through the narrative it provides, making it a useful source for future commercially linked academic projects.

3.1.2 The academic impact of these works to date

All the works presented here have been published within the last 4 years, with the papers that are expected to have more impact both on future work and in citations published more recently.

However, the works have been cited a number of times and there is evidence of their impact starting to emerge. Authors have used these works to demonstrate a link between footwear, comfort/ musculoskeletal disorders and biomechanics (Gonçalves and Sato, 2020; Kołcz *et al.*, 2020). The potential need for customised shoes suggested in Paper 4 was identified by Tarrade *et al.*, (2019) who went on to assess the impact of custom made orthotics in standing workers. The same paper has also been used as the only source to develop the workplace footwear criteria in a dress code for Muslim Female Healthcare Personnel (Saidun *et al.*, 2018), suggestive of one way in which these works can be translated to address a real world problem. Paper 2 was evaluated in a systematic review on 'contemporary and emerging uses of inertial sensing in occupational ergonomics' (Lim and Souza, 2020), verifying its novelty. Other works have also cited these papers to justify the development of their own studies, such as looking at foot load in nurses (Kołcz *et al.*, 2020) and in the development of a foot health service for nurses (Stolt *et al.*, 2020).

3.1.3 The commercial impact of this research

The main impact outside of academia of these papers is the developed products that arose from the research. The new range, known as 'Custom Pro' and 'Smart Sole' to the partner companies is commercially available and allows users to choose the style of shoe and insole that works for them. The partner company also have the footwear selection tool on their website developed from paper 6 to prevent the need to provide all three insoles with each shoe (see Appendix 3), reducing the cost of the product and wastage from unused insoles. Dissemination from a company marketing perspective is also clear, with videos, blog posts and a page on the research link with Salford on both the partner companies' websites (Appendix 2).

For the partner company, an ongoing customer panel was also established, which had about 150 chefs signed up when I left the company in September 2019. The impact of the research further extended to helping gain contracts with large catering companies towards the end of my time with the company. I presented information on our research to key decision makers within these companies, something which made the partner company particularly attractive given their focus on the health and wellbeing of staff. Catering is an industry that has more jobs than chefs, so ensuring the wellbeing of their staff was important for staff retention in a competitive market.

Finally, I think the last and perhaps the most important impact of this research is on the education of the workers and employers themselves. I had the opportunity to connect with a range of chefs in different ways: by presenting information about foot health and footwear to chef apprentices at the start of their career and head chefs in corporate companies; through meeting chefs involved in the research and the customer panel; and also, through events held by the Chefs' Forum, an organisation that brings top chefs and students together. Although this reached only a small proportion of chefs, I believe that the future impact of this research will be helped through this communication and education in the future.

3.1.4 Potential wider impact for this research

This thesis focused on developing footwear from a research and commercial perspective but the findings are applicable to a wider audience. The identification of the high incidence of foot musculoskeletal disorders, including chronic problems like plantar fasciitis suggests that working in a prolonged standing environment should be a consideration for podiatrists and other health professionals. The identification of footwear needs of these populations (Paper 4) provides guidelines for meeting footwear needs for work and defines the type of shoes typically worn, which is beneficial given clinicians often don't see workplace footwear brought to clinic (Williams, 2018).

Farndon *et al.* (2016) developed a toolkit to enable health professionals, particularly podiatrists to understand the contribution of footwear on a broader level than just the physical properties of the shoe and their effect. This toolkit aimed to promote discussion between patients and health professionals to ensure footwear fitted with a patient's life and beliefs, which would in turn promote adherence to wear. It identified practical factors such as the cost and purchasing methods, the mental fit of the shoe that included an individual's identity and image, the purpose of the shoe, such as the activity it would be used for and finally the social fit based on social interactions and fashion norms. The works presented here provide information regarding the acceptable footwear for these workplaces, including style and colour; it identifies the activities and environments that they are being used for and considers practicalities such as how footwear is purchased and the acceptable price.

With these factors in mind, we can identify ways in which work footwear should be considered different to everyday leisure footwear by practitioners. For example, in terms of practical factors, there was a preference to spend less money on work footwear than leisure footwear, with workers reluctant to replace it. Footwear purchasing habits were different, particularly when provided by the employer where limited choices were given and there were health and safety restrictions. In terms of the mental and social fit, the footwear worn was not chosen to look good in general, and in fact many expressed that it would not be acceptable to be seen in work footwear away from work, but the style was reflective of that worn by colleagues and deviations too far from this norm were still not acceptable.

3.1.5 Footwear Recommendations from this thesis

As mentioned in the introduction to footwear, the HSE do not currently identify footwear as a risk factor for work related musculoskeletal disorders. However, this thesis identifies that footwear does have a relationship with musculoskeletal disorders (Paper 3) and is associated with biomechanical differences (Paper 5). From the second part of these works, it is possible to identify a number of footwear recommendations for the workplace. Combined with other research, it can be identified that a range of footwear should be offered to ensure workers can find a pair of shoes that fits correctly and is comfortable for the wearer, to meet work safety standards and promote good foot health (Stolt *et al.*, 2018). Specific footwear recommendations from these works are provided (Figure 3.1).

Footwear recommendations for workers who experience prolonged standing

Footwear comfort

Comfortable footwear is that which does not cause any pain or discomfort meaning workers are unaware of it during the day.

- Footwear should be chosen or provided based on the individual
- A ‘one footwear fits all’ approach should not be taken.
- Footwears should either be tried on or an alternative method used to identify comfortable footwear prior to purchase
- Variations in footwear fit should be offered (length and width)
- Variations in medial midfoot cushioning or support should be offered
- Footwear that increases medial midfoot contact area will likely increase comfort
- Underfoot heel/ forefoot cushioning should not be too hard
- Long term comfort should be a priority in workplace footwear due to changes in the foot-shoe relationship over time

Footwear Functionality

Footwear should be functionally designed for the environment it is being used in

- Footwear should not be too heavy
- Footwear should be easy to don and doff
- Footwear should be breathable and minimise heat/ moisture inside the footwear
- Slip resistance should be durable and indicate when it needs replacing
- For chefs, shoes with and without toe caps should be offered

Footwear Factors

- The ability to add the wearers own insole or orthotic is useful
- Footwear must be affordable for the employees they are developed for
- Footwear should be easy to clean

Figure 3.1 *Footwear recommendations developed from this thesis*

3.2 Critique of Methodology

The following stage of this thesis will consider the methodologies used in the research papers, justifying the approach taken in comparison to other methods and identifying any potential limitations.

3.2.1 The approach to research

These works were split into two parts, the first part with the aim of exploring the demands and resulting consequences of prolonged standing and the second part to develop a footwear solution. Nevertheless, it is clear from the summary of outcomes (Figure 2.1; Table 2.12) that part one is integral to informing the methodologies and research questions of part two. For example, the initial information about footwear from the questionnaire (paper 3) identified the key themes to consider for the interviews (paper 4) and the laboratory tasks to replicate workplace movement (paper 5) were derived from observations and data from Paper 2.

Prior to this body of work, as is evident from the review in Paper 1, prolonged standing was a quantitative research topic. The divide between qualitative and quantitative research or the scientific paradigm (primarily quantitative) and constructivist/ interpretivist paradigm (primarily qualitative) is suggested to be a result of the differences in their philosophical underpinnings (Haq, 2014), perhaps explaining why most papers focus on one or the other. While the scientific theory revolves around objectivity, in which a single reality is believed to exist, a constructivist approach instead believes realities are social constructs and thus more subjective (Shah and Corley, 2006; Haq, 2014).

This thesis used a multiphase mixed methods design (Caruth, 2013), in which quantitative and qualitative research were used throughout a series of studies. This approach was pragmatic, considering both the quantifiable facts and the constructivist concept regarding the need to identify the objective reality. This approach aligned with the need to explore the complex parameters of pain and comfort but was able to narrow down enough to inform the development of products. Some go as far as to argue that social reality can only be understood by taking a mixed approach to research (Haq, 2014). Combining the strengths of both research types gave a more comprehensive understanding of the topic, as previously identified (Johnson *et al.*, 2007; Tariq and Woodman, 2010). It enabled the exploration of not only the biomechanical impact of footwear but also the perceived needs, lived experiences and beliefs of the end users. It is the combination of these factors that enabled the creation of a product that was both biomechanically reasoned and commercially viable.

It is acknowledged that the use of a mixed methods approach can result in the corroboration (Johnson *et al.*, 2007) or contradictions in results (Denscombe, 2014), both of which are evident in our findings. The link identified in the interviews between comfort and footwear cushioning (Paper 4) agrees with our quantitative data that identifies a link between footwear cushioning, musculoskeletal discomfort and biomechanical variables (Paper 5/6). However, there was an overarching preference for footwear to be soft and cushioned from the participants in the interview study, which is in contradiction to the results that identify some individuals prefer harder footwear than others (paper 5).

The mixed methods approach also aligned well with an industry-based project as it enabled an exploration of the market alongside the research. In fact, some of the research overlaps with more traditional market research that includes the investigation of customer attitudes and needs as well as opportunities for new sales (Forsyth and Birn, 2002). The interviews included the investigation of current products and the need for future improvement while the questionnaire contained information about current purchasing habits and footwear spending. Thus, the results from a mixed methods approach also integrate more widely with the commercial setting and the informational needs of core departments such as sales, marketing and product development.

3.2.2 The use of a narrative review

The need for a broad overview of current research defined the need for a narrative approach as opposed to a systematic one. A narrative review is used to define the current dearth of knowledge, to develop future rationales and to speculate on interventions (Ferrari, 2015). In contrast, a systematic review is typically used to answer a well-defined question with a clearly identified inclusion criteria (Ferrari, 2015). Considering we were at the start of a research journey in an under researched field, it was not possible to identify a single, well-defined question from which the entire research project could be defined. Instead, there was a need to develop an overview of multiple questions including: what are the main problems associated with prolonged standing; what are the current solutions that have been tested; and what are the protocols used along with their limitations.

At a similar time to our review being completed, two systematic reviews with meta-analyses were published on the topic of prolonged standing at work. Each focused on a single research question, one to consider the associations between undertaking long periods of prolonged standing at work and musculoskeletal discomfort (Coenen *et al.*, 2016) and the second to review the evidence regarding the acute development of musculoskeletal development in laboratory based studies (Coenen *et al.*, 2017). These papers had the strength of identifying the effect sizes of the relationship between prolonged standing at work and WMSDs and were able to suggest practical factors, such as a recommended safe exposure time. However, they were not able to consider the broad research topics that we did, and would have been particularly limited in relation to the research areas of flooring and footwear solutions as the methodologies were inconsistent and papers were limited. Thus, the systematic reviews would be important for generating guidelines and policies for workers undertaking prolonged standing but would not have been able to consider the broad range of topic areas that the narrative review did or guide the research project in the way that the narrative review could.

The focused and narrow research questions of systematic reviews would have further prevented the natural development of a hypothesis, instead creating a narrow research focus early in the project, preventing a broad understanding of the topic. The narrative review enabled the exploration of multiple topic areas: the prevalence of musculoskeletal disorders in the real world; the acute laboratory research in terms of musculoskeletal prevalence and biomechanics; the effects of flooring and footwear independently; and the numerous confounding factors. The results guided the methods of papers 5 and 6, from the tasks used to the identification of parameters to measure. It identified the need for more data regarding observational studies, which identified the need for paper 2 and the need to understand foot WMSD in more detail, which became a focus of paper 3.

3.2.3 Activity Monitoring – relevance of the defined activities and their limitations

The three standing movements defined in this paper (static standing, weight shifting and shuffling) enabled the differentiation of standing activities in occupations spending a similar amount of time standing overall. The importance of defining these activities for future use in WMSD research is clear from differences in the biomechanics of the two standing tasks used in paper 5. One of these was a dextrous task that ensured static standing and one involved touching targets across a desk of 1.5m by 0.9m most similar to weight shifting (feet did not generally leave the ground). These two movements showed significant variations in the joint loading at the ankle as well as the underfoot pressure variables (Figure 3.2). For the static task, where the weight was distributed evenly on both feet, the peak pressures were lower across the entire foot. Mean pressures and average contact area show how loading varied across the regions of the plantar foot surface, with a greater mean pressure in the heel for the static tasks compared to the more dynamic task that resulted in a greater forefoot load. There is a relationship between pain onset and the magnitude/ location of plantar forces (Wiggermann and Keyserling, 2015), suggesting that differences in plantar loading could impact the regions in which foot pain is experienced. These differences could also impact the risk of WMSD further up the body as differences in loading could stress different parts of the musculoskeletal system.

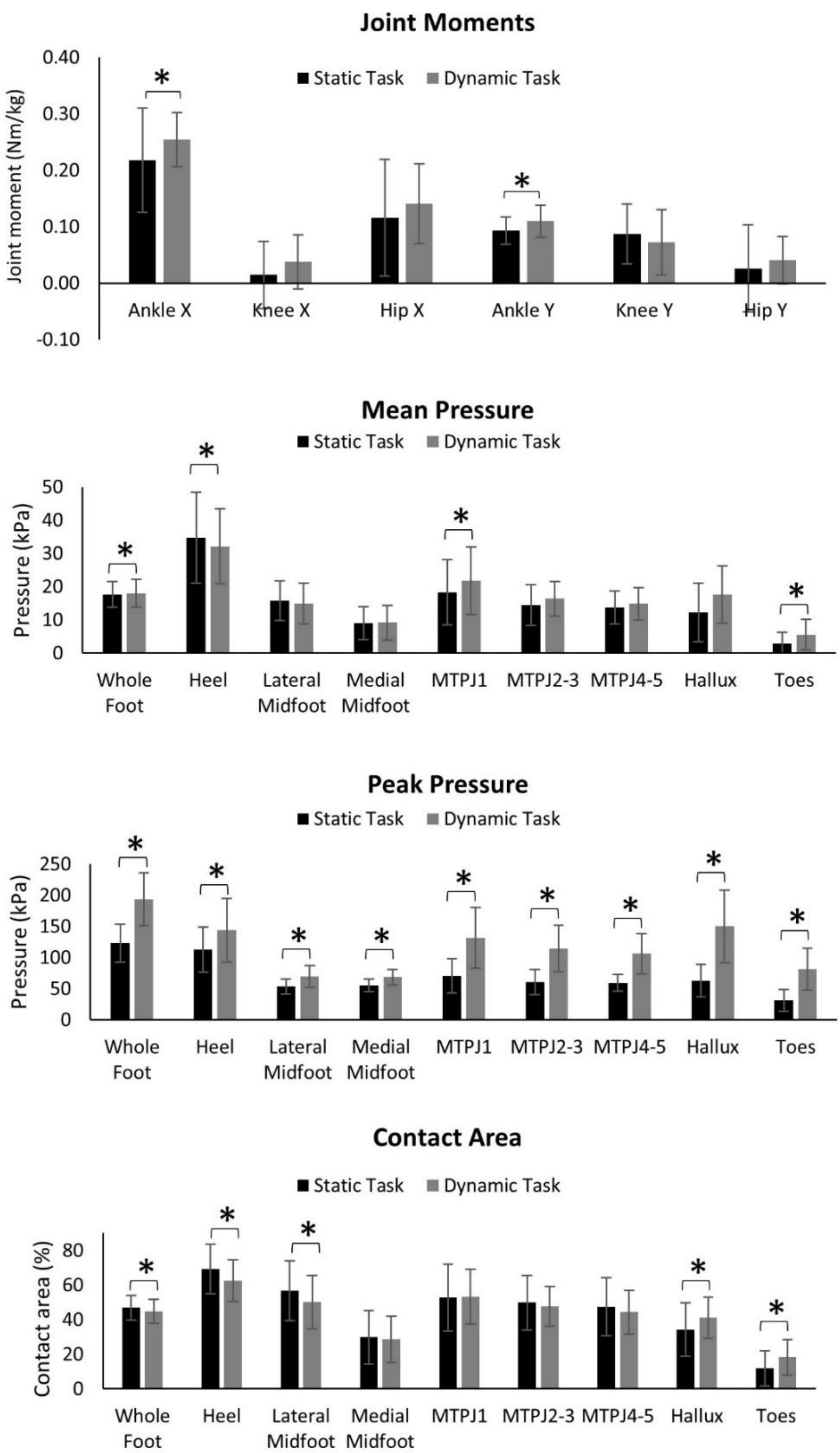


Figure 3.2 *Comparison of kinetics and plantar pressure between static and dynamic tasks in Paper 5*

It must be considered, however, that there are a few activities that could impact lower body loading that were outside the scope of this study and should be included in research investigating a link between activity and musculoskeletal disorders. Stair climbing was not separated from level walking but stair ascent and descent are associated with altered kinematics and kinetics in comparison to level walking (Riener *et al.*, 2002) that would likely impact the load on the body over a working day. This could be particularly relevant in kitchens that operate across multiple floors. Secondly, during periods of static standing, with the accelerometer placed on the thigh it was not possible to identify if any surfaces or walls were being leant on. Leaning on a surface would be expected to reduce the load through the lower body and has also been shown to result in altered muscle activity (Damecour *et al.*, 2010) that could affect musculoskeletal fatigue or discomfort. Therefore, any future study that uses the defined standing activities to assess WMSD risk should also attempt to account for these activities, especially given there is currently no knowledge about the length of time in these activities.

3.2.4 Limitations of the musculoskeletal questionnaire

A cross sectional design was used for the questionnaire in Paper 3 as the project required the information in a short time frame to help drive the remaining research. It also provided the first tangible outputs to the marketing team, which were expected throughout the project. A prospective questionnaire was neither feasible given the project time constraints or necessary based on the research questions. However, it is worth acknowledging the main limitation of cross-sectional studies, which is that of identifying causality. Although the multivariate analysis found links between variables such as BMI and foot WMSD, insoles and calf WMSD or footwear comfort and knee, hip and ankle WMSD, it is unknown which preceded. For example, does BMI increase as a result of reduced activity caused by WMSD or does the extra weight cause the WMSD? Is low footwear comfort a result of general pain or discomfort of the lower limb from WMSD or does a low footwear comfort result in WMSD?

In terms of assessing musculoskeletal disorders, the Standardised Nordic Musculoskeletal Questionnaire (Kuorinka *et al.*, 1987) was selected as it was developed specifically for occupational assessment and has been used in most cross-sectional musculoskeletal prevalence studies. The validity and reliability have been tested and it has gone through multiple iterations resulting in the improvement of the wording and questions (Kuorinka *et al.*, 1987; Dickinson *et al.*, 1992). A review paper identified a range of between 0 and 25% rate of nonidentical answers at two time points (Baron *et al.*, 1996), although it is likely that this reliability was confounded by changes in symptoms over the 1-3 weeks that were left between the first and second questionnaire completion. In any case, it has been deemed an acceptable repeatability for a screening or prevalence study (Baron *et al.*, 1996) and it is clear that even with the largest error suggested, our results would still demonstrate significantly greater prevalence rates than seen in the normal population.

Perhaps the greatest limitation of the questionnaire study was the low response rate, estimated to be about 10% of those who were invited. Although a number of criteria were met that have been suggested to boost response rate (Oppenheim, 1992): the questionnaire was sent out twice, information sheets were provided with the reasons for the research and an incentive was offered to take part (money off shoes for everyone and a prize draw for a voucher), our response rate remained low. This is especially clear when compared to similar previous studies that reported response rates of up to 62%-80% (Karahan *et al.*, 2009; Choobineh *et al.*, 2010; Reed *et al.*, 2014b; Dianat *et al.*, 2018a). This is most likely a result of the different methods of approaching participants. All of the above cited studies used paper versions of a questionnaire and were able to get individuals to complete the questionnaire in person, hand it to each individual (Choobineh *et al.*, 2010; Dianat *et al.*, 2018a) and in some cases even check their questionnaire on completion to ensure nothing had been missed (Karahan *et al.*, 2009). In paper 3, the online questionnaire was distributed by email, primarily due to the different ethics requirements for going into hospitals that would have caused considerable delays. It also had to be emailed out by the research departments or department leads within the hospital. This could have been prohibitive to response as return rates are reduced in correspondence with level of work required by the participants such as through the independent distribution and returning of questionnaires by the workers (Dickinson *et al.*, 1992). Similar to our low response rate, a postal questionnaire to surgical staff received only a 27% response rate (Szeto *et al.*, 2009), perhaps boosted slightly by chase up phone calls, and another that used email responses and had a 22% response rate (Wauben *et al.*, 2006).

The independent return of questionnaires could also add a greater bias to results, with completion more likely in those who suffered from pain (Dickinson *et al.*, 1992), suggesting that our recorded prevalence might have been higher than the true value. Comparing it to the most similar populations available that had much higher response rates (Table 3.1), the reported prevalence of lower back and hip pain in Paper 3 were higher than others, including a systematic review, but knee pain was lower. Unfortunately, there was no obvious comparator study from the UK, even within the systematic review, meaning differences in the workplace and populations would have also likely resulted in differences.

Online completion can be beneficial, however, in terms of the removal of geographical limitations. Those that have previously handed questionnaires out in person have had to focus on a single city, or a single hospital in order to complete visits (Smith *et al.*, 2006; Choobineh *et al.*, 2010; Reed *et al.*, 2014a). The nine hospitals included in our study were randomly selected and spanned NHS trusts across England in: Devon, Durham, Dorset, Blackpool, Norwich, Manchester, Harrogate and Burton-on-Trent. Different regions and different hospitals likely vary in their environments, working conditions and policies, including that for footwear. Therefore, this study would have captured much more of this variation than using a single site, making it more generalisable to hospitals across England despite the low response rate.

Table 3.1 *Response rate and prevalence in surgical staff musculoskeletal prevalence studies – a comparison to Paper 3*

<table>
<tr><th>Reference</th><th>Job title</th><th>Response Rate</th><th>n</th><th>Time (months)</th><th>Lower back</th><th>Hip/ Thigh</th><th>Knee</th><th>Lower leg</th><th>Ankle</th><th>Feet</th></tr>
<tr><td>(Dianat et al., 2018b)</td><td>Surgeons (Iran)</td><td>62.4%</td><td>312</td><td>12</td><td>42%</td><td>29%</td><td>49%</td><td>-</td><td colspan="2">28%</td></tr>
<tr><td>(Choobineh et al., 2010)</td><td>Operating room nurses (Iran)</td><td>80%</td><td>375</td><td>12</td><td>61%</td><td>31%</td><td>58%</td><td>-</td><td colspan="2">59%</td></tr>
<tr><td>(Szeto et al., 2009)</td><td>Surgeons</td><td>27%</td><td>135</td><td>12</td><td>68%</td><td>-</td><td>-</td><td>-</td><td colspan="2">-</td></tr>
<tr><td>(Tavakkol et al., 2020)</td><td>Operating theatre workers (review)</td><td>NA</td><td>-</td><td>NA</td><td>61%</td><td>27%</td><td>43%</td><td></td><td colspan="2">57%</td></tr>
<tr><td>Paper 3 (Anderson et al., 2021)</td><td>Operating theatre workers</td><td>~10%</td><td>147</td><td>12</td><td>71%</td><td>42%</td><td>40%</td><td>28%</td><td>16%</td><td>55%</td></tr>
</table>

3.2.5 The use of semi-structured interviews

Given the research aim of this paper was ‘to explore workers needs for footwear in the standing workplace in relation to musculoskeletal disorders, symptoms, comfort and design’ (Paper 4), both focus groups and semi-structured interviews would have been feasible options. In terms of interview methodologies, semi-structured interviews were chosen as structured interviews would not have allowed for the in depth exploration of topics that was required while unstructured interviews would not have allowed for a focus on the emerging themes that had been identified in papers 1-3 (Gill *et al.*, 2008). Although focus groups would have enabled discussion around the footwear, that could potentially lead to a more comprehensive understanding (Namey *et al.*, 2016), interviews were sufficient for identifying the key factors. On reflection, there was a general agreement across the interviews in regard to the important footwear factors, suggesting that discussion in a focus group setting would have mostly resulted in agreement and few, if any, extra factors. Research on the two methods actually suggest that more topics can be identified in interviews than focus groups (Guest *et al.*, 2017) and they further ensure each participant has the opportunity to speak. However, a focus group would be useful for factors outside the scope of this research paper such as for the prioritisation of contradictory design factors that were identified, such as the need for a safety toe cap compared with the need for lightweight shoes.

The resources required for interviews are also considered to be lower than that for focus groups. The logistics of arranging a focus group and the increased transcription time result in a greater total time (Coenen *et al.*, 2012; Guest *et al.*, 2017), a greater total number of participants to reach the same level of data saturation (Guest *et al.*, 2017) and a greater cost (Namey *et al.*, 2016). Getting a group of chefs or even veterinary surgeons together would have been time consuming given the variation in shift times and the long shift lengths worked by many. Finding a location would also have been challenging for focus groups and would likely have included the additional cost of hiring a space. On the other hand, interviews could be conducted at an individual's workplace, during the participants shift, which minimised the effort required by the participants to take part and did not use up their already limited leisure time, thus increasing motivation to participate. The choice of interviews is further cemented by more recent attempts by the company to arrange focus groups with chefs that did not work as too many participants did not show up for unknown reasons.

3.2.6 Comparison of activity in the laboratory study to real world activity

When designing the tasks for the laboratory protocol, replicating the movements made in the real world was important. However, sitting and walking were not included. This decision was taken to maximise the impact of standing over the three hours, as it represented only a small portion of the 8-12-hour shifts that the chefs and veterinary surgeons were completing daily. Sitting and walking both reduce the effects of standing such as by lowering musculoskeletal discomfort (Gallagher *et al.*, 2019; Wall *et al.*, 2019) and increasing the venous pump action (Balasubramanian *et al.*, 2009; Wall *et al.*, 2020). Thus, including them might have reduced the changes observed over time and obscured differences between footwear conditions.

Comparing the activity in the laboratory protocol to that in the real-world data collected in Paper 2, the emphasis on the surgical market at that point in the project is clear. Table 3.2 and figure 3.3 display the standing time in each case divided into static standing, weight shifting and shuffling. The activity much more closely resembles the largely static standing seen in veterinary surgeons than the dynamic standing seen in chefs. As mentioned, greater static standing could be beneficial in terms of increasing the rate of changes that were observed. However, a greater amount of static standing could also have altered the loading of the body and shoes, as reported earlier in Figure 3.2. For example, the observation that dynamic activities resulted in lower mean plantar pressures but higher peak pressures, could impact the behaviour of the underfoot shoe material. The greater peak pressures would be expected to compress the material more, but the shoe would also have time to recover or decompress during unloaded periods. Unfortunately, it is not known if one would result in a greater compression of the underfoot materials over time and thus have a different impact on the biomechanics or if it would balance out.

Table 3.2 *Mean time spent in each standing task as a percentage of overall standing time*

	Static stand (%)		**Weight shift (%)**		**Shuffle (%)**	
	Mean	***SD***	**Mean**	***SD***	**Mean**	***SD***
Laboratory Protocol	72.4	*8.8*	25.7	*7.7*	1.9	*1.8*
Veterinary Surgeons	66.7	*8.7*	22.9	*4.9*	10.4	*4.6*
Chefs	31.1	*8.1*	38.3	*6.0*	30.6	*6.7*

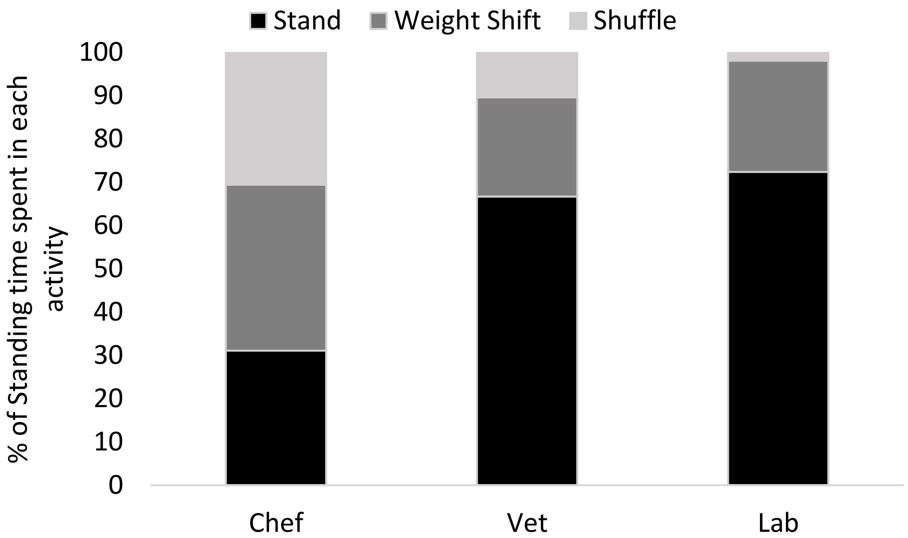


Figure 3.3 *Comparison of time spent in each standing task for chefs, veterinary surgeons and participants in the laboratory study*

3.2.7 Pedar for in-shoe pressure over a prolonged period

Biomechanical equipment is generally used for testing short periods of movement, most commonly to assess gait. Collecting data over 3 hours of standing meant addressing the limitations on the equipment and considering their accuracy and repeatability over long periods of time. Pedar (Novel, Germany) has been found to be suitably repeatable when tested in-vivo during gait (Ramanathan *et al.*, 2010) and through the application of a known mechanical load (Hsiao *et al.*, 2002; Price *et al.*, 2016). In fact, Pedar has been shown to be the most accurate and repeatable device of three commonly used in-shoe pressure systems (Price *et al.*, 2016). However, these studies have been completed over a short period of time, with loads that are representative of gait, whereas the protocol in Paper 5 included constant low loads for long periods. One study that considered the accuracy and repeatability of the Pedar device over such loads found the percentage error to increase substantially with time as a result of drift (Hurkmans *et al.*, 2006). At time zero, the percent error ranged from -2.2 to -1.5% at 5 N/cm^2 (50 kPa) between insoles, but by 3 hours this had increased to 17-20.5% error. Running a similar test on the insoles used in Paper 5 using the TruBlue calibration device (Novel, Germany) to apply a constant load of 100kPa, a similarly large increase in percentage error was seen (Figure 3.4). Starting at 4.3% and 7.3% for each insole this increased to 17.5% and 22.3%, respectfully over three hours.

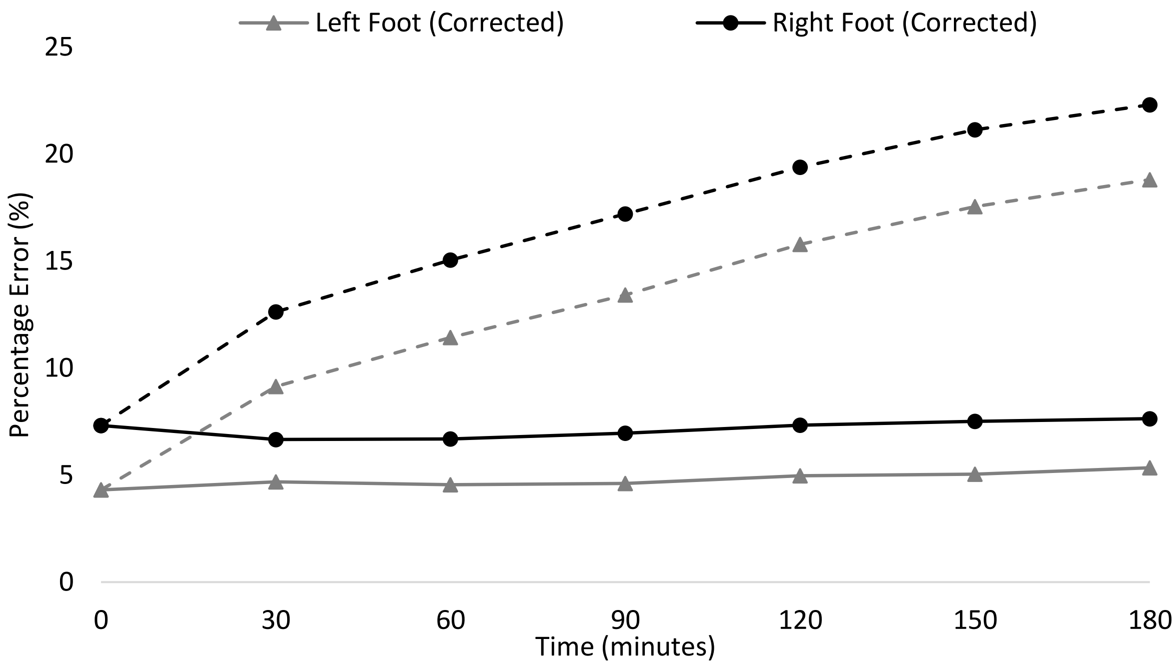


Figure 3.4 *Percentage error of two Pedar insoles (left and right) over 3 hours with 100kPa of pressure applied using the TruBlue calibration device. Shown with no correction and correction using the average error recorded in the heel, as described and used in Pa*

As the primary interest in the paper was change in plantar pressure over time, it was of high importance to remove the increasing values associated with drift. One method would have been to reset the device, but this would have detracted from the standing protocol as resetting requires the insoles to be unloaded for a period. Instead, participants performed a heel raise, where they stood on their toes for a split second, minimising the disruption. The average value in this offloaded period in the heel was then taken and subtracted from all cells to remove the drift that occurred. Figure 3.4 shows this protocol used on the insoles loaded with the constant 100kPa. This successfully maintained the percentage error within 1% of the initial error value throughout the 3 hours, demonstrating the successful removal of the drift associated with the insoles and ensuring that the reported changes are a genuine result of change over time.

3.2.8 Calf circumference as a measure of blood pooling/ oedema

As in paper 5, there is an agreement in the literature that oedema/ blood pooling in the lower leg increases with time (Coenen *et al.*, 2017; Speed *et al.*, 2018). However, differences between conditions such as footwear and flooring do not display consistent results. Some, as with the results from paper 5, do not find any difference between conditions of footwear or flooring that vary in cushioning (Cham and Redfern, 2001; Zander *et al.*, 2004) whereas others do (Lin *et al.*, 2012). Calf circumference, as used in Paper 5, is an indirect measure of blood pooling (Wiltman *et al.*, 2019). The Gulick II tape measure has a tension meter on one end to ensure the same tension is applied each time, but it still relies on the user putting it around the limb in exactly the same location each time and ensuring the level placement around the limb. The circumference of the calf and ankle taken with a spring tape measure, like the Gulick tape measure, reported a coefficient of repeatability of ±5.1mm (Labs *et al.*, 2000). The average change in calf circumference recorded in paper 5 over 3 hours was 6mm, thus any differences between conditions would have been below 6mm and therefore likely below the repeatability threshold. This means that calf circumference, as measured with a spring tape measure, might not have been sensitive enough to distinguish between conditions if differences did occur. In order to determine these differences, a more direct measure of blood pooling might be useful such as the use of near infrared spectroscopy to look at oxygenated/ deoxygenated haemoglobin, that has identified differences between flooring conditions over just one hour (Wiltman *et al.*, 2019).

3.2.9 Between day repeatability (Paper 5)

In the study design of paper 5 considerable thought was given to removing equipment errors such as drift that occurred over the 3-hour protocol. This was essential given the novelty of protocol duration compared to previous research that measured short dynamic movements. However, this focus perhaps lead to the between day repeatability being slightly overlooked. Between day repeatability is important when considering the reported changes between the footwear conditions in paper 5 as the shoes were assessed on different days due to the fatigue caused by 3 hours of standing. Although the order of shoe testing was randomised, there was still a need to reapply the markers and sensors in each session. This was improved by marking the locations onto the participant with permanent between sessions. However, potential differences between days still needs to be considered.

In terms of the 3D kinematics measured by the Vicon camera system, error can be induced by intrinsic factors, such as variation in movement by the participants, or by extrinsic factors (McGinley *et al.*, 2009). Extrinsic factors can be related to the system such as calibration and calculation errors, movement of the skin and soft tissue over the bony landmarks as well as error by the researcher such as through marker placement and identification of anatomical landmarks (Monaghan *et al.*, 2007). It is these extrinsic factors that impact the between session repeatability (McGinley *et al.*, 2009). A systematic review (McGinley *et al.*, 2009) reports that between day repeatability for sagittal plane values was generally very good with reported coefficient of multiple correlations (CMCs) and intraclass correlation coefficients (ICCs) over 0.8, apart from for pelvic tilt. Errors were greater in the transverse and sagittal planes. Overall, measurement variation mostly fell between 2-5° between sessions. This brings into question the small changes reported in hip adduction in paper 5 of about 1° difference between the shoes given frontal plane errors have been reported at about 2° (McGinley *et al.*, 2009). Despite being statistically significant, these differences are likely not relevant given they are within the reported between session error range. However, there is no assessment of repeatability for static tasks such as standing, which may differ as you would expect factors such as soft tissue artifact to be reduced. Furthermore, differences in marker locations between sessions, which is considered a key contributor to between day repeatability (Monaghan *et al.*, 2007; McGinley *et al.*, 2009), was standardised in this study with the markings on the legs, likely reducing the error.

Pedar measurements including contact area, PTI and peak pressure have been shown to be very repeatable between days for walking tasks with the heel, midfoot and metatarsal areas more repeatable than the toes (Putti *et al.*, 2007; Ramanathan *et al.*, 2010). The coefficient of repeatability for the heel, midfoot and metatarsals as a percentage of the mean value when walking ranged from 1.2-3.0% for contact area, 2.4-7.7% for peak pressure and 3.5-7.6% for the PTI (Putti *et al.*, 2007). For a static loading measurement over 7 hours, the percentage difference in error recorded between days ranged from -3.7% to 1.14%, with an average value of -0.9% for the insoles combined for a 5 N/cm^2 (50kPa) pressure (Hurkmans *et al.*, 2006). This difference was very small compared to the 17-28% error recorded over 3 hours continuous measurement, which was accounted for in Paper 5. Considering that in paper 5 the difference in plantar pressure values between the preferred and least preferred shoes ranged from 12-32%, which is greater than any reported error values, suggests that this is likely a valid finding and the conclusions hold true.

3.2.10 The impact of the individual

In paper 5, it was found that individuals varied in their preference for footwear cushioning, and differences in biomechanical responses were found in relation to preference rather than condition, demonstrating that there are variations between individuals in response to standing tasks. However, when considering changes over time, it was the group effects alone that were considered. This assumes that we expected to see a non-individual response to prolonged standing that would be visible as an overall group effect. However, research has reported differences in responses between individuals, such as differences in the development of pain (Nelson-Wong *et al.*, 2008; Nelson-Wong and Callaghan, 2010a), associated muscular differences (Gregory *et al.*, 2008) and varying responses to standing on a slope (Nelson-Wong and Callaghan, 2010b). This suggests that the response to standing varies between individuals and actually, a greater number of participants might have been beneficial to enable the identification of groups of individuals that did respond in the same way to standing. This was outside the scope of the aims of this project, and a prioritisation was made for a longer protocol with fewer participants, but it is worth considering this in future research.

3.2.11 Footwear comfort measurements

Footwear comfort is a key theme of the works presented here but comfort is complex and derived from both physical and psychological sensations that arise from the interaction between the foot and shoe. As such, the measurement of it is also complex and impacted by many factors that can affect the reliability of measurements tools. Papers 5 and 6 used a rankings system of footwear comfort/preference. Compared to the other two most commonly used scales, the Likert Scale and the Visual Analogue Scale, the ranking scale offers the most repeatable measure (Mills *et al.*, 2010; Lindorfer *et al.*, 2018), something which has been attributed to its low complexity (Hoerzer *et al.*, 2016). Although ranking does not provide information regarding the size of the differences between footwear (Hoerzer *et al.*, 2016), given the aims of this project in identifying the most preferred footwear, the relative comfort provided sufficient information. Moreover, it is more representative of how footwear would be chosen at point of purchase, where the favourite shoe would be selected.

The reliability of comfort assessments are dependent not only on the tool but also the individual using the tool (Hoerzer *et al.*, 2016; Lindorfer *et al.*, 2018). To make it more complicated, an individual's reliability has been shown to be scale dependent (Schwameder, 2019). There are many factors that can influence the ability to assess footwear comfort: foot sensitivity (Mündermann *et al.*, 2002), the psychological state or mood of an individual (Hoerzer *et al.*, 2016) and even the description (Chan *et al.*, 2020), brand or aesthetics (Taylor *et al.*, 2011) of a shoe. In paper 6, there was a range of reliability in the ranking scale when comparing the ranking given to the insole that was tested twice (Table 3.3). Almost 40% of individuals ranked the insoles next to each other (i.e. the most reliable) and a further 40% between 2-4 places apart from each other. This variation in individual repeatability could be viewed as a disadvantage, but it reflects the natural variations within a population. Removing certain individuals based on their reliability would remove those with specific characteristics, such as those with a low foot sensitivity, making the results less generalisable. In order to account for this variation in reliability, Paper 6 part 1 only assessed differences between the most and least preferred insole options, a difference in ranking that was greater than the worst repeatability difference.

Table 3.3 *Difference in rankings given to the repeated insole in Paper 6, Part 1.*

Difference in rankings between the repeated insole *	Percentage of participants (%)	Cumulative percentage of participants (%)
1	38	38
2	9	47
3	9	56
4	19	75
5	6	81
6	13	94
7	3	97
8	3	100
9	0	100

**A difference of 1 indicates maximum reliability*

When using the rankings, participants in these works were instructed not to rank conditions at the same level, i.e. each had to have a unique number. This was to ensure the identification of the shoe or insole that they would have chosen if they were purchasing the product and that it was possible to compare the most and least preferred insoles. It is suggested that forced rankings such as these can lead to artificial differences between shoes when a participant actually views two or more conditions as equal in comfort (Lindorfer *et al.*, 2018). Given a few participants commented on the difficulty of distinguishing between their preference for some of the insoles in Paper 6 part 1, it is likely that given an option they would have ranked the insoles at the same level. However, again, as comparisons were only made between the most and least preferred insole, the impact of forcing rankings on the results were likely very low.

There are some unknowns in regard to footwear comfort testing that could have impacted results. First, the number of options that had to be ranked. In Paper 6 part one, there were 10 insoles to rank. Most previous studies have used fewer conditions than this (Table 3.4), with the highest number of conditions for a ranking scale at 6 (Lindorfer *et al.*, 2018). One previous study has also used 10 conditions, although a different comfort questionnaire was used (Jordan *et al.*, 1997). Unfortunately, there is no research available on the maximum number of conditions that can be compared reliably, but it would be expected that there would be a decrease in reliability as the number of conditions increased. Although this could have impacted the order of ranked conditions in Paper 6 part 1, it is unlikely to have resulted in a complete reversal of order and thus the insoles carried over to part 2 of the study still likely reflected the preferred, or at least near preferred, options.

Table 3.4 *Length of time footwear was trialled before rating footwear comfort and number of conditions*

Reference	Time frame	Scale used	Number of test conditions
(Mills *et al.*, 2010)	2-minute walk, 2-minute jog	Likert, VAS, Ranking	5 (Own shoe + 4 insoles)
(Lindorfer *et al.*, 2018)	2 min run treadmill	Likert, VAS, Ranking	6 (5 test shoes + own shoe)
(Mündermann *et al.*, 2002)	450m run	VAS	4 insoles
(Miller *et al.*, 2000)	Standing – unknown time Walking – 200m Running – 600m	Borg Scale Rating	3 shoes
(Mündermann *et al.*, 2001)	March – 500m	VAS	7 (shoe + 6 insoles)
(Jordan *et al.*, 1997)	10m Walk	Comfort questionnaire	10 shoes
(Jordan and Bartlett, 1995)	25m walk at set speed (+ habituation time)	5-point Likert scale	3 shoes
(Kong and Bagdon, 2010)	400m Walk 400m Run	Ranking (preferred)	3 shoes
(Chan *et al.*, 2020)	5-minute Running	VAS	2 shoes
(Mei *et al.*, 2018)	20km run	VAS	1 shoe
(Chen *et al.*, 1994)	Walking. Running until a comfort score could be indicated	Ranking	4 insoles
(Mills *et al.*, 2011)	Walking 2 min/ Jogging 2 min 25m walk or jog	VAS Ranking	4 insoles

A further methodological factor with an unknown impact is the length of time that a shoe is trialled prior to comfort assessment. As seen in Table 3.3, almost all studies assessing comfort do so over a few minutes of walking or jogging. Similarly, paper 6 part 1 used a 20m walk and 3 minutes of standing for the initial insole assessment. This is most representative of how a shoe is tried on prior to purchase in the real world but is also a reflection of the trade-off between available lab time and the number of conditions. When putting a shoe on, there is likely an adaptation period where the shoe material responds to the foot inside it. Indeed, our results from paper 5 suggest the interaction between the shoe and the foot continues to change over three hours, as evidenced by changes in plantar pressure. This has also been found in running 20km, where morphological changes in the foot are associated with changes in plantar pressure and comfort over the average 100 minutes of running (Mei *et al.*, 2018). A recent paper identified EMG changes in the leg muscles for the first 7 minutes or 600 strides when running, after which a steady state was reached (Mohr *et al.*, 2021). This was attributed, based on the preferred movement path paradigm, to be due to neuromuscular adaptations to the individual's most efficient running style. Paper 6 saw a change in order of insole ranking following a full day compared to a few minutes that suggests that the change over time does not have a consistent effect on comfort but a footwear specific one. This information reinforced the need to test comfort over the period in which the shoe will be worn, to develop solutions to predict the best shoe or to identify a time period in which the footwear comfort becomes stable.

3.2.12 Participant characteristics

In total, 329 participants were used for all the studies combine. A summary of their characteristics can be seen in Table 3.5. One strength of this research is the number of participants included from the working populations that were studied. Papers 1, 3, 4 and 6 part 2 all included individuals working in prolonged standing environments, i.e. those who were habitual standers. Although in an ideal world, all research would have included workers, this was unpragmatic given recruitment and adherence to visits around the long work shifts and geographically the testing being in Manchester and most contacts living in Bristol where the company was located. Therefore, the laboratory studies (paper 5 and 6 part 1) used participants from a university population rather than a working population.

3.2.12.1 Height, weight and BMI

In 2018, the NHS health survey (NHS, 2018) reported that the average height for men was 175.6cm, weight was 84.8kg and BMI was 27.5kg/m^2. For women the average values were a height of 162.1cm, weight of 72.4kg and BMI again of 27.5kg/m^2. The largest samples of chefs and surgical workers were collected from the questionnaires but due to the nature of the study, the results regarding characteristics were self-reported. This would likely impact height, weight and BMI, with research reporting that self-reported height was generally over-reported, weight was under-reported and BMI was either about right or under-reported (Engstrom *et al.*, 2003; Gorber *et al.*, 2007). Despite this, the height, weight and BMI reported by the operating theatre staff were in line with the general population values. The chef data (Paper 3) represents both males and females who reported being slightly taller and heavier but with similar BMIs to the general population, although the data that was physically measured in chefs in paper 6 part one was more similar to the average NHS data.

All of the data collected from the workplace represents a population of individuals that are, on average, in the overweight category, as defined by their BMI. In contrast to this, the participants in the laboratory studies were of a similar height to chefs that were measured but they weighed less and had lower BMI's. In paper 2, it was found that BMI was related to foot discomfort. Both prospective and retrospective research has similarly found a greater prevalence of MSD, including foot discomfort in those with greater BMI's (Andersen *et al.*, 2007; Irving *et al.*, 2007; Hill *et al.*, 2008; Nealy *et al.*, 2012). Therefore, using individuals with a slightly lower BMI could have reduced the development of musculoskeletal disorders in paper 5. However, the results still identified significant increases in all regions for musculoskeletal discomfort as well as differences in lower back pain discomfort between footwear conditions, thus the differences in BMI were not enough to prevent the occurrence of MSD. However, if changes in discomfort were lower, it might have acted to obscure differences between conditions.

Table 3.5 *Participant data from all the works presented in this thesis*

	Paper 2	**Paper 3**	**Chef Data**	**Paper 4**	**Paper 5**	**Paper 6 (1)**	**Paper 6 (2)**
Sample Size	27	147	75	14	12	34	20
Occupation	Chef / veterinary surgeon / office workers	Operating theatre staff	Chef	Chef / veterinary surgeon / nurse	University	University	Kitchen
Gender (% male)	Chef: 91% Vet: 43%	24%	73%	Chef: 75% Vet: 33%	42%	40%	65%
Age	-	<40: 27% 40-50: 36% >50: 37%	40±10	-	28±5	32±10	30±8
Height (m)	-	M:1.76±0.10 F:1.63±0.09	M:1.82±0.10 F:1.67±0.08	-	M: 1.70±0.05 F: 1.67±0.06	M:1.72±0.04 F: 1.67±0.06	M: 1.75±0.08 F: 1.64±0.05
Weight (kg)	-	M: 83.7±14.5 F: 70.4±14.7	M: 91±20 F: 77±26	-	M: 70±15 F:67±9	M: 68±11 F:73±14	M: 82±16 F: 68±11
BMI (kg/m^2)	-	M: 27.1±3.5 F: 26.0±6.2	M: 28.0±6.3 F: 27.1±8.0	-	M: 24.2±4.0 F: 23.9±2.8	M: 23.0±3.5 F: 26.1±5.2	M: 26.7±1.2 F:25.7±4.8
Time in job (years)	-	0-10: 29% 11-20: 33% 21-30: 21% 30+: 16%	20±11	Kitchen: 1-17 Vet: 3-37	-	-	-
Hours/Week (hours)	-	<40: 70% >40: 29%	54±12	Kitchen 50±8 Vet: 40±6	-	-	-
Shift Length	-	8-12	10±2	-	-	-	9.4±2.8

** Shaded boxes indicate self-reported measures*

Greater BMI values have also been associated with changes in foot structures and morphology that could impact comfort and result in differences in plantar pressure. For example, a greater FPI has been reported in individuals with a high BMI indicative of a flatter foot (Butterworth *et al.*, 2015; AlAbdulwahab and Kachanathu, 2016), which radiographic studies identify is a result of structural changes rather than just the observation of the increased fatty tissue. The higher loading associated with greater body mass causes greater peak pressures across all regions of the foot and an increased contact area under the medial midfoot that aligns with a lower medial arch and greater FPI score (Butterworth *et al.*, 2015). However, this study used individuals with an average difference in BMI of 11.5 kg/m^2, and it must be noted that our difference of 2.54 kg/m^2 is relatively small. In terms of weight, this was a difference of 9.5 kg. A previous study found an increased body weight of 10kg resulted in increased peak pressure under the heel and first metatarsal only, with no significant impact on the midfoot (Arnold *et al.*, 2010). In paper 5 identified increases in plantar pressure over time suggested to be, at least in part, a result of the footwear material deforming under the foot. A greater rate of change would likely have been observed in participants with a greater weight, due to the corresponding increase in load.

3.2.12.2 Gender

The results presented here indicate a primarily female workforce in the operating theatres and a primarily male workforce in the kitchen. For both laboratory studies, the proportion of females was around 60% of the tested population, which is higher than that seen in the kitchen, but lower than that seen in surgical staff.

Gender has been shown to influence activity, something which was not considered in these works. Previously, in restaurant staff, female participants spent about 12% less time standing, but a greater time walking than their male counterparts (Laperrie *et al.*, 2006). When walking, it was also recorded that they had longer step sequences and an increase in the number of steps per second. This has in part been attributed to the shorter step length of women but this does not explain the differences in full (Messing *et al.*, 2015). Furthermore, it has been identified that even within individuals with identical jobs, tasks still differ between males and females (Messing and Elabidi, 2003; Messing *et al.*, 2015). Paper 2 does not contain enough participants to identify any differences between gender (Table 3.6), particularly the chefs where there was only one female participant. The average values for the veterinary surgeons show a greater amount of time spent standing statically for the female staff, but the spread of data is high, and the small numbers do not warrant a statistical comparison. If there are gender differences in standing activity, it could mean that the results recorded for chefs are biased towards male workers.

Consistently, women are recorded to report higher and more intense musculoskeletal pain that men (Bingefors and Isacson, 2004; Choobineh *et al.*, 2010; Messing *et al.*, 2015). This agrees with the findings of paper 3, where being female was identified in the multivariate analysis as a risk factor for low back, hip, calf and foot pain. This could be due an increased 'acquired risk' for women, be it through ill designed equipment designed for men, exposure to different tasks or activity at work, or even differing demands outside of work such as an expectations in the home or family (Bingefors and Isacson, 2004; Strazdins and Bammer, 2004). Psychosocial variations, differences in the willingness to report pain and biological risks related to sex hormones and physiology might also play a role (Bingefors and Isacson, 2004).

Table 3.6 *Difference in activity reported for male and female participants in paper 3*

		Chef				**Vet**			
		Male (n=10)		**Female (n=1)**		**Male (n=3)**		**Female (n=4)**	
		Mean	***STD***	**Mean**	***STD***	**Mean**	***STD***	**Mean**	***STD***
% Overall time	**Sit**	13.4	*8.2*	8.3	-	29.5	*24.6*	22.8	*15.8*
	Static Stand	20.7	*6.7*	17.3	-	41.3	*20.5*	52.6	*13.2*
	Weight Shift	24.9	*3.9*	24.8	-	15.8	*8.0*	15.1	*4.7*
	Shuffle	20.5	*6.8*	18.7	-	7.0	*3.2*	5.2	*0.6*
	Walk	20.5	*7.7*	31.0	-	6.4	*2.1*	4.3	*2.6*
	Upright Time	86.6	*8.2*	91.7	-	70.5	*24.6*	77.2	*15.8*
% Upright time	**Static Stand**	24.3	*7.9*	18.8	-	56.7	*12.0*	67.7	*3.4*
	Weight Shift	28.7	*3.2*	27.0	-	21.9	*5.6*	19.4	*2.8*
	Shuffle	23.4	*6.5*	20.3	-	10.6	*4.6*	6.9	*1.4*
	Walk	23.7	*8.7*	33.8	-	10.7	*6.3*	6.0	*4.3*

3.2.12.3 Habitual Standing

A major difference between the University population and workers, is the difference in habitual standing for long periods. Only two studies from the same research team were found that assessed differences in prolonged standing in habitual versus non-habitual standers. A larger proportion of habitual standers (53%) developed low back pain compared to non-habitual standers (25%) over a 4.5 hour standing protocol (Wall *et al.*, 2019), suggesting they might be predisposed to lower back pain development. In a protocol that included 4.5 hours of standing, no differences were observed in oedema related measurements between habituated and non-habituated males with similar characteristics. However, there were some differences observed in muscle fatigue (Wall *et al.*, 2020). The authors therefore suggest a possible adaptation to motor unit recruitment in those habituated to standing work that temporarily delays fatigue but does not prevent it. Paper 5 did measure muscle fatigue over 3 hours of standing, although no clear changes were observed in the EMG measurements. Due to the restraints regarding the time that most laboratory studies can be completed over, including paper 5, it might have actually been a benefit for EMG measures to recruit non-habitual standers in order to have a better chance of measuring fatigue in the allotted time. This, however, assumes that the habitual standers would have the same response but at a delayed rate, which requires further research.

3.2.13 Sample size

The number of participants recruited for each study were mostly limited by time and resources rather than being led by a power analysis, as is the gold standard approach (Knudson, 2017). The sample size in paper 5 was limited due to the prioritisation of collecting data for a longer period of time, as identified as necessary by previous research (e.g. Cham and Redfern, 2001). Paper 6 was limited by the number of shoes available from the company for testing.

The limitation of sample sizes due to practicalities is not just an issue with these works, however, with one report suggesting that in 2009, the median range of subjects in biomechanics papers for specific journals was 12-18 (Knudson, 2011) and another suggesting most studies had 2-20 participants (Vagenas *et al.*, 2018). Similar study numbers have been shown for the past 20-30 years (Knudson, 2012; Vagenas *et al.*, 2018) but concerns around sample size numbers are being raised (Oliveira and Pirscoveanu, 2021).

Limitations to participant numbers can increase the number of biases such as through being underpowered, showing exaggerated effect sizes and results with poor replicability of results due to not being completely in line with the general population (Knudson, 2017). A recent study looking at running determined that low study numbers, in their case below 20 participants, could hide significant differences in the majority of variables (Oliveira and Pirscoveanu, 2021). They also reported that variables not expected to be affected showed an increased chance of being statistically different when participant numbers were below 25. Despite differences between running and standing and likely differences in repeatability, this does demonstrate that low study numbers have the potential to create false positive and false negative results statistically. Therefore, it would be recommended that future work building on the works here consider power calculations or studies to determine the impact of participant numbers. As to the effect on the results here, the results presented still give an important understanding of a new topic area, but the limitations of the statistical findings should be taken into consideration when drawing conclusions.

3.2.14 Statistical analysis

The statistical analysis used in these papers were overall appropriate choices for the data collected. Parametric data tests were run to determine whether an ANOVA could be used on the data. Furthermore, Bonferroni corrections and Wilcoxon rank tests were used for the post hoc tests within ANOVA and Friedman tests, respectively. If anything, this was perhaps more conservative than required, with suggestions that exploratory studies should use less conservative correction methods than the Bonferroni in order to limit type II errors and avoid missing any potential effects (Armstrong, 2014).

Paper 5, and to a lesser extent paper 6, considered a vast range of dependent variables due to the observational nature of the studies. They therefore used multiple ANOVA tests to test all the dependent variables. The use of many ANOVA tests within one study is common in biomechanics (Vagenas *et al.*, 2018) but this can also inflate the rate of type 1 errors or the experiment-wise error rate (Knudson, 2009). This error can be controlled for, although most biomechanics studies do not do so (Knudson, 2005, 2009). Although our papers used a Bonferroni correction within each independent ANOVA test run, no correction was added for the use of multiple ANOVA tests on many dependent variables. While not perhaps necessary in these papers, particularly given their exploratory nature, the impact of using this many tests should be considered going forward.

As identified above in section 3.2.10, individuals show variations in how they stand, such as in their pain development, footwear comfort scores and biomechanical measures. Inter and intra participant variation can impact the reliability and the statistics in studies. Grouping participants together under the assumption that there will be a single overall effect can mask individual differences (Mullineaux *et al.*, 2001). In paper 2 it is clear that participants, even within the same profession, showed large differences in their time spent in each activity. For example, time spent sitting for veterinary surgeons ranged from approximately 5% to 50% of their time at work despite having the same job role. Presenting just a mean value would have meant this variability was lost. In paper 5 we know that individuals developed different levels of pain in different areas, and perhaps there might also have been variations in biomechanics. Thus, further presenting individual data in more cases throughout might have added to the applicability of the data in the future.

Given the limitations associated with statistical tests, such as perhaps being too conservative with the Bonferroni corrections and as discussed earlier the low power associated with the low participant numbers, it might have been preferential to present more raw data, regardless of the statistical significance of the results. This is emphasised in recent recommendations for biomechanics statistics that suggests that non-significant p-values should not be considered as evidence of no effect (Harrison *et al.*, 2020). Further investigation and presentation of individual results would also have been useful for future investigations considering whether grouping participants is appropriate. However, the statistics used were overall appropriate choices, which is evidenced in the fact that they were published in peer-reviewed journals.

3.3 The KTP project and integration of commercial and academic work

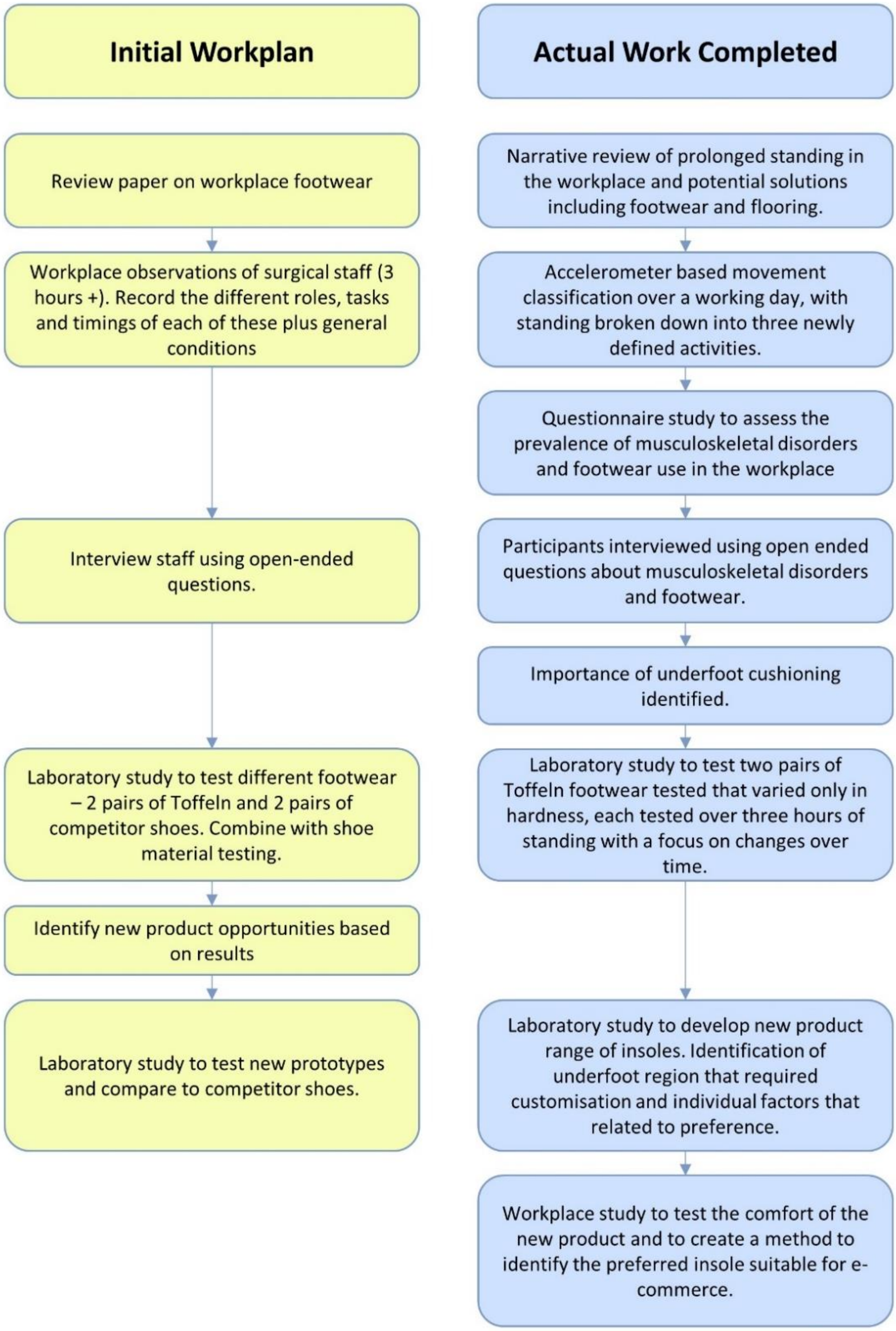


Figure 3.5 *Initial KTP workplan vs actual work completed*

3.3.1 Comparison of completed work to KTP plan

As part of a KTP project, there was an initial workplan submitted for the project funding, which I was given at the start of the project. This workplan provided a base to work from but was flexible to change, which occurred throughout the project guided by information from the literature, to align with business decisions and to ensure a final research driven project could be delivered (Figure 3.5).

The initial literature search identified minimal information around workplace footwear as well as no broad review of the prolonged standing research. This resulted in the initial footwear review to be replaced by a much broader scope, that was more beneficial for the project as it included a review of research techniques and opened it up to the inclusion of flooring, which helped to identify the importance of underfoot cushioning. The initial planned observations were replaced with the objective accelerometer measure, and the breaking down of standing into 3 new activities. A questionnaire was added to aid the understanding of current musculoskeletal problems and associated factors as well as to identify current footwear habits.

In terms of the development of the footwear, the initial workplan identified two steps, testing current footwear against competitors and then identifying new product opportunities that would then be tested. However, the literature review reported one of the major limitations of footwear research to be a lack of understanding surrounding distinct footwear design factors. Testing different footwear that varied in multiple characteristics would not have solved this and might have prevented the identification of new footwear opportunities. Instead, with the results from the first 4 studies, the importance of cushioning was identified as the important design factor. Variations in cushioning were then tested to see their impact over time (Paper 5). This identified the importance of individual footwear preference leading the second study to focus on the development of a range of insoles that varied in hardness. An additional part was added (Paper 6, part 2) that then tested these insoles for an entire day in the workplace and developed a method of identifying the preferred insole that was suitable for e-commerce.

3.3.2 Integrating research with business

Overall, this project worked well to meet its aims, with both parties working collaboratively throughout. This is evidenced through being one of three finalists for the award 'Best KTP Partnership' out of 798 companies and 105 universities that had projects ending in the year 2018-19. This award is described as 'recognising the collaboration that has excelled in the benefits achieved by all three participants – business partner, academic partner and associate'.

The reasons behind the partnership's success are captured well in a conceptual model derived from a systematic review investigating factors that impact industry-university partnerships, shown in

Figure 3.6 (Rybnicek and Königsgruber, 2019). In our KTP project the objectives and outputs were clearly defined from the start with a strong compatibility of goals formed between the business and university. Although changes were made during the project, both partners were open and flexible to developing solutions together to meet the shared outcomes. The team's expertise complimented each other, with the university having the equipment, research and prior knowledge transfer experience where the business had the production facilities, expertise and ability to bring a product to market. Communication was aided by my role, as I spent time at both locations, with regular catch ups with both teams.

As acknowledged by Rybnicek and Königsgruber, (2019), the scale of the business can have an impact on a project. The fact that the business was a small family business meant that everyone was invested in the research project. Internal communication was strong and ensuring the involvement from all departments such as through research sessions and updates meant all aspects of the business could understand the importance of the work and use the developed knowledge effectively.

However, small businesses can be more unstable and likely to alter their business strategy more frequently (Barnes *et al.*, 2002). This held true for this KTP with the original company dividing into two companies part way through the project. The new company took over the research, but their target market became hospitality rather than the surgical market although the outputs from the KTP remained shared. This change is evident in this body of research as the initial emphasis on surgical staff, particularly in paper 3, resulted in a combination of workplaces for papers 2 and 4 and a final hospitality focus in paper 6. Fortunately, the focus on prolonged standing remained, with paper 3 and the equivalent hospitality data demonstrating similar musculoskeletal problems within both environments, thus the research problem remained the same. Although it did require the development of a new group of end-users to work with, the benefits of not working with NHS staff made ethics and communication much easier. Furthermore, the branding and marketing of the new partner company focused heavily on the research, reflected in its name that integrates the concepts of focusing around the wearer and on the 'tech' side to improve the products.

Changes in personnel within the new company also impacted the project, a factor that has been identified to potentially be disruptive (Barnes *et al.*, 2002). The restructuring of the business led to both new investors and new management. The commercial benefits from this were clear, with decision making and business functions improved. However, it did create a more driven environment, with greater pressure on research to deliver products that emphasised the different expectations in commercial and research timelines (Klimstra and Raphael, 1992). As this occurred towards the second half of the project, there was no major disruption that occurred, but it will be interesting to see the impact this has on ongoing research. Relationship factors such as trust develop on an individual basis

(Barnes *et al.*, 2002), thus it was important to ensure new members were integrated within the project and that they became invested in the outcomes. This included providing a clear understanding of research timelines and expectations where individuals had not worked with academia before and developing an understanding between all those involved of the benefits of scientific rigour. One particularly beneficial change in personnel was the appointment of a footwear developer. Their expertise with footwear factories, materials and manufacturing methods enabled the final product to be developed and in a much shorter time frame than would otherwise have been possible.

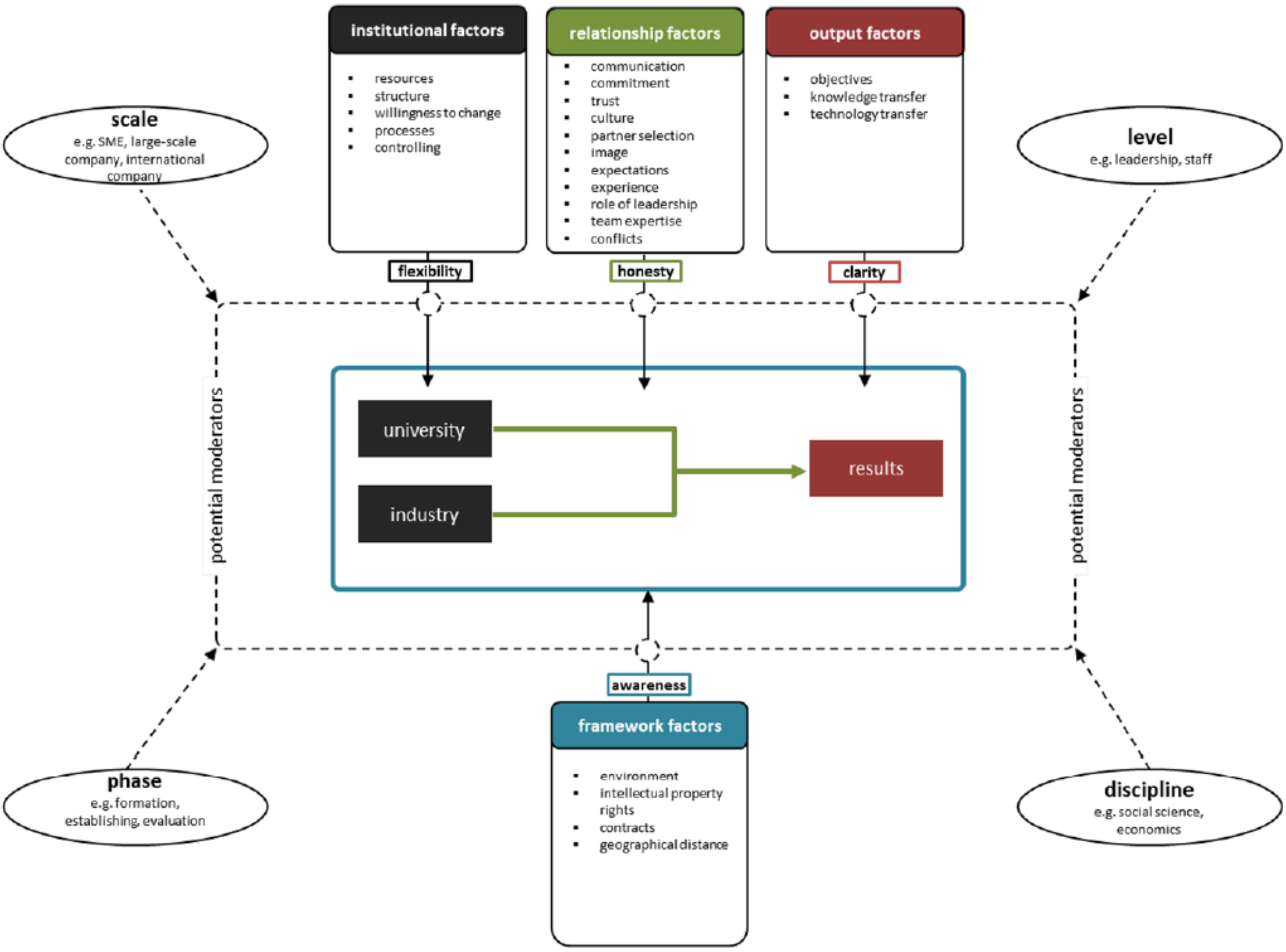


Figure 3.6 *Conceptual model of successful business and university collaboration (Rybnicek and Königsgruber, 2019), p229*

3.4 Overarching Research Limitations

3.4.1 Standing: how much is too much?

This body of work focuses on the detrimental impact of standing throughout the working day. However, there is a similar body of research suggesting that prolonged sitting is as bad for the health. Prolonged sitting is most frequently associated with office workers. Paper 2 found office workers spent 70.8% of their time at work sitting, similar to the 66-69% reported in larger cohorts (Oliver *et al.*, 2010; Ryan *et al.*, 2011). Excessive time spent in sedentary behaviour like sitting are associated with detrimental health outcomes and chronic diseases such as cardiovascular disease, diabetes and obesity (Rezende *et al.*, 2016), even when physical activity guidelines are met (Hamilton *et al.*, 2008). As with those undertaking prolonged standing tasks, prolonged sitting is also associated with musculoskeletal disorders of the lower back (Thorp *et al.*, 2014; Karakolis *et al.*, 2016). Indeed, one study that assessed both sitting and standing found the average lower back discomfort increased at a similar rate for both tasks (Karakolis *et al.*, 2016).

In the same way that breaking periods of standing up with sitting or walking can be beneficial for discomfort, the reverse is true for sitting. These individuals are actively encouraged to break up periods of sitting such as through the use of standing desks, or even treadmill desks (MacEwen *et al.*, 2015). In overweight and obese individuals, introducing periods of standing reduced low back pain by 32% (Thorp *et al.*, 2014). Thus, standing itself can be a beneficial activity when it is not the primary posture.

Therefore, the negative factors associated with prolonged occupational standing reported in this thesis are a result of the high exposure time in the discussed occupations. Standing itself can evidently be beneficial for musculoskeletal discomfort when used to break up other activities and in much lower doses than reported here. Any activity-based solution to reducing musculoskeletal disorders would likely not be to adapt workplaces to promote sitting, but would be about adopting a mixture of activities, or being ‘just right’ dubbed the ‘Goldilocks Principle’ by Straker, Mathiassen and Holtermann (2018). The differing responses observed by individuals to standing would also likely mean the optimum balance of activity may well be dependent on the individual.

3.4.2 Is a footwear solution enough?

These works were geared to a footwear solution as a result of the commercial nature of the project and although the impact that footwear alone could have on musculoskeletal disorders is unknown, it is unlikely to provide a full solution by itself.

Despite identifying the benefits of focusing on footwear in comparison to flooring earlier on, it is necessary to realise that they are not independent of one another, particularly when considering cushioning. It is the combined effect of the insole, shoe and flooring in series (i.e. any surface between the foot and ground) that creates the overall characteristics of the system (Goonetilleke, 1999). Thus, Paper 5 was really assessing the comfort of the test shoes on the specific flooring present in the laboratory, which may well have differed if, for example, a largely different flooring such as a soft carpet was used. Furthermore, if a shoe with a different midsole was used to identify insole preferences in paper 6, this would also impact the system and perhaps an individual's insole preference. The importance of workplace flooring for musculoskeletal disorders has been emphasised in a study that found variations in workplace flooring impacted musculoskeletal disorders in the long term regardless of the footwear used (Wahlström *et al.*, 2012). Therefore, although footwear arguably offers more opportunities to make beneficial change, the flooring should not be dismissed both in regard to musculoskeletal disorders and footwear comfort or preference. Likewise, when exploring the impact of insoles, the type of shoe the insole is being used in should be a consideration.

Any physical solution, flooring or footwear, might need to be combined with other concepts for a more complete solution, such as exercises to strengthen or activate muscles. Work considering lower back pain has demonstrated some evidence suggesting co-contraction of the gluteus medius muscles (Nelson-Wong *et al.*, 2008), hip abductor strength and endurance (Marshall *et al.*, 2011) or hip range of motion can contribute to pain development. Furthermore, there is an initial indication that using targeted exercises can improve tolerance to standing, resulting in a significant reduction in low back pain (Ingerson *et al.*, 2019). A randomised controlled trial reported the greatest reduction in musculoskeletal disorders of the lower back and limbs in standing workers over 8 weeks was seen in individuals given both insoles and exercises, compared to either condition alone (Mousavi *et al.*, 2019). Of course, the impact of exercises will be largely a result of the muscles targeted and the aim of the exercises (e.g. strengthening vs stretching) but this does suggest that a combination of approaches would be beneficial.

3.5 Recent research and future directions

3.5.1 Activity and musculoskeletal disorders

Within paper 2 standing was divided into three more precise movements and suggested that these may help to link musculoskeletal disorders with activity. Recently, two papers confirmed this theory with a focus on static standing. Defining static standing as an inclination of the thigh below 45 and no movement of the thigh (very similar to our definition), a relationship between time spent static standing and musculoskeletal disorders of the hip, knee and lower back was found (Locks *et al.*, 2018, 2019). Going one step further and dividing continuous periods of static standing into short (<5 minutes), medium (5-10 minutes) or long bouts (>10 minutes), it was also identified that the length of these bouts was important, with longer periods worse for low back pain (Locks *et al.*, 2018).

The works presented here did not consider activity outside of work in detail, but recent research identifies the importance of including this. Standing bouts in leisure time have been related to a greater risk of lower back pain (Locks *et al.*, 2018). On the other hand, dynamic physical activity in leisure time could reduce the impact of prolonged standing and has been shown to lower long-term sickness absence (Gupta *et al.*, 2020). Qualitatively, nurses have also identified dynamic sports activities in their leisure such as walking, jogging and cycling to be a beneficial way to counter the static standing performed at work (Stolt *et al.*, 2018).

Thus, determining a link between activity and musculoskeletal disorders requires further investigation, and should include a range of standing activities, the length of standing bouts and ideally activity outside of work too. While previous work has considered static standing, including our definitions of shuffling and weight shifting would provide a more complete overview of workplace activity and an understanding of the impact of these more dynamic standing movements. This information could be important for identifying exposure-based risk factors, identifying differences between job roles and specific individuals (e.g. male vs female) and eventually for developing health and safety guidelines.

3.5.2 The effect of time (footwear and participants age)

More work should be done to consider the longer-term impacts of standing, especially given the alterations in footwear comfort over a day (Paper 6). This includes changes to both the body and footwear. For example, how much goes the foot shape change over a working day in shape and size? Does the arch lower over the day as seen in running (Mei *et al.*, 2018)? How does the shoe change shape over the working day and how long does it take the material to recover after use (i.e. should it be worn every two days rather than every day to allow recovery)? Considering these factors and how the interaction between the shoe and foot change as well could lead to solutions to improve comfort over time, even if it is as simple as having a shoe that adjusts in size slightly or switching shoes half way through the day.

These changes should then be further considered over the lifetime of the individual. The foot changes with age: it gets wider and longer, fat pads under the foot get thinner, the foot arch gets flatter, range of motion at the ankle reduces and foot sensitivity is lowered (Scott *et al.*, 2007; Ansuategui *et al.*, 2016). These factors can alter an individual's biomechanics and therefore likely impact comfort when standing, for example modelling studies have shown that thinner heel pads are associated with greater plantar pressures (Chatzistergos *et al.*, 2015). Investigating the impact of a career in a standing occupation on these factors is important as it could alter the rate of these changes. Furthermore, some of these factors, namely foot arch height and foot sensitivity, impact footwear comfort meaning there is potentially an impact of age on footwear comfort or preference.

The lifetime of the shoe is also of interest. It was identified from the questionnaires that the length of time a shoe is worn for by workers varies largely. In running, it is known that the age of footwear is related to injury risk (Taunton *et al.*, 2003) and changes in biomechanics (Kong *et al.*, 2009). One of the most used running midsole foams, ethylene vinyl acetate or EVA, is also frequently used for the midsole of work shoes. Therefore, it is likely there is a maximum time footwear should be worn for in the workplace before it potentially becomes a risk factor for musculoskeletal disorders. Asides from the comfort, slip resistant is also reduced with time and is important to workers, particularly those in kitchens, so assessing when a shoe becomes unsafe to wear should also be reviewed.

3.5.3 Further concepts not considered in this thesis

The studies presented here considered a huge range of variables, but it was not possible to explore every related theme and concept. However, there are a few further concepts that have the potential to develop this research in the future and warrant a mention within this thesis.

The first of these concepts is the consideration of the tissue properties on the plantar foot surface. As discussed in section 3.4.2 above, it is the combined effects of insole, shoe and flooring that creates the overall cushioning effects of the system (Goonetilleke, 1999). However, the work presented here did not consider the impact that the plantar tissue itself, such as the heel pad, had in this system. This is particularly pertinent given that research has shown that differences in the tissue properties and thickness of the heel pad influence plantar pressure and loading (Chatzistergos *et al.*, 2015; Behforootan *et al.*, 2017). Given the link we reported between comfort and plantar pressure, this is something that has the potential to impact comfort. Heel pad properties have been shown to change in association with conditions such as diabetes and plantar heel pain (Hsu *et al.*, 2002; Rome *et al.*, 2002) and as with any biological factors, natural variability in the heel pad can be seen in studies that have measured it (Taş and Bek, 2018). This variation suggests that heel pad properties could have an impact on individual comfort and thus be another factor relating to footwear preference. Furthermore, it has been shown that confining the heel pad with the aid of a heel counter could reduce stress in the region during static standing (Spears *et al.*, 2007) suggesting that footwear design can be used to assist or alter the function of the heel pad. Despite this, one modelling study did not report an impact of heel pad properties on the optimum insole properties (Chatzistergos *et al.*, 2015). Given the variation in heel pad properties, its relationship to the cushioning system between the body and foot, it is certainly a variable that warrants future exploration in relation to standing.

Foot temperature and humidity are two factors that we know influence footwear comfort (Irzmańska *et al.*, 2014; Anderson *et al.*, 2017). This is particularly important in environments like kitchens that are very warm, combined with the fact that many kitchen shoes are made from easy to clean materials such as EVA that are not breathable. Although identified by workers in our interview study as impacting footwear comfort (paper 4), this was not chosen as a route to investigate. This was mostly because it was a known issue that was under consideration by the footwear developers at the company in terms of footwear material selection. Furthermore, there was no equipment readily available for measuring in shoe conditions and removing the foot from the shoe would have impacted the in-shoe conditions and likely comfort. Alterations in the shoe microclimate (temperature and humidity) have also been shown to predispose to foot problems such as blisters and reductions in foot health (Kirkham *et al.*, 2014; West *et al.*, 2019). This would be particularly important to include as a variable if measuring footwear comfort in workplace settings over prolonged periods and it would be interesting to determine If objective and subjective measures of the foot microclimate aligned.

A more recent technique that is used in lower limb research is infrared thermography. This allows the measurement of infrared light or heat being radiated from the skin surface (Astasio-Picado *et al.*, 2018). It has been used commonly to assess the foot temperature and could be used for this alone, but it also has uses when looking at disease progression. Changes in skin temperatures are associated with changes in the peripheral blood flow as blood circulation is the regulator of peripheral temperature (Tattersall, 2016; Astasio-Picado *et al.*, 2018). Blood flow changes can be linked to inflammation and tissue damage or degeneration. It is thought to be useful from a clinical perspective, particularly in diabetes and peripheral arterial disease, where it can be useful for the early identification of tissue damage (Ilo *et al.*, 2020). Infrared thermography has more recently been used to determine regions of pain in diseases that are hard to diagnose, including lower back pain (Polidori *et al.*, 2018; Alfieri *et al.*, 2019). Thermography could therefore be a novel tool to further understand the known changes in blood flow to the foot discussed throughout this thesis, but also a tool that is worth investigating as a potential objective measure of musculoskeletal disorders.

3.5.4 Footwear comfort

Footwear comfort remains a topic of interest, including a drive towards finding solutions for specific groups of people. A recent paper considering safety shoes for workers, assessed differences in safety footwear opinions between men and women (Janson *et al.*, 2021). Although both men and women reported discomfort associated with their work shoes, this was greater in women and corresponded to a reduced wear time, potentially due to the previously male-dominated industries and therefore likely the male foot that the safety shoes were designed for. This emphasises the need for future research to consider differences in footwear needs between genders and how having shoes designed for each gender is important.

The VAS, Likert or Ranking scales are the scales used for assessing footwear comfort. It has recently been suggested that these methods have not been developed in a robust systematic way that assesses footwear factors that are meaningful to end-users (Bishop *et al.*, 2020). This paper went on to develop a running shoe comfort assessment tool prospectively in three stages: an online questionnaire to identify meaningful running shoe factors to users, testing of shoe models using draft questionnaire to refine questions, testing the reliability and discriminative ability of the method as well as identifying meaningful changes. In the future, a similar approach to develop a tool for standing workers could be useful in improving comfort ratings surrounding specific footwear design features. As already discussed, it is also important to consider methodological factors such as the number of shoes that can be reliably assessed at any one time and the length of time that each shoe should be worn for before being assessed.

Continuing to develop tools to identify comfortable footwear is also going to remain important while purchasing habits are unchanged. While Paper 6 identifies simplistic questions to find the preferred shoe, there remains room for improvement. A larger study looking at end-user’s ability to assess their own arch height is warranted based on its relationship to footwear comfort. It might also be possible to develop physical tools to help this process, such as print outs with height guides.

3.5.5 Footwear for standing

The works presented here focused on footwear cushioning, but work should continue to assess other footwear factors in relation to comfort over prolonged standing. First, as medial midfoot plantar pressure was identified as a key factor relating to footwear comfort, contouring of the insole, particularly under the medial arch could also be important. In fact, one study reported contouring to be more important than cushioning for comfort (Mills *et al.*, 2011). It is likely that there is a relationship between hardness and contouring under the medial arch in which changing one will impact the preference for the other, so this must also be considered in any future works.

When considering aspects aside from the insole that can be altered, heel height could also impact comfort. A sloped surface has been tested as a means to reduce lower back musculoskeletal disorders. There was a preference for a downward slope, for which you could get a similar effect by raising the heel. A slope has been shown to reduce lower back pain in pain developers by an average 60% on a VAS and 88% of participants said they would use the slope if they stood for a prolonged time at work. (Nelson-Wong and Callaghan, 2010b). Having a sloped floor might work under a desk or in a factory setting, but in more dynamic environments, if the same effect can be made by altering heel height, then that would be highly beneficial given lower back has the highest prevalence of musculoskeletal disorders in the populations reported in these works.

3.5.5 Education

To ensure the use of good, comfortable footwear in standing workers, it is also important to make information readily available and promote it in an efficient way to educate workers. The need for this education is highlighted in Paper 4 with the identification that some workers did not think that footwear could impact aches and pains they were feeling. There is emerging evidence that education can impact behaviour in relation to foot health and footwear selection. An education module on footwear altered the perceptions of almost two thirds of runners, with over half indicating their shoe selection methods would be altered (Dhillon *et al.*, 2020). An education module on foot health was developed for nurses, and it was reported that they particularly valued the information regarding footwear and socks (Stolt *et al.*, 2020). Therefore, one part of future research should include the identification of methods to disseminate information to workers and their employers. Unless end users understand how to choose footwear and look after their feet and the associated advantages of doing so, then the developed products and knowledge will not be effectively translated into the real world.

3.6 Conclusion

The six peer-reviewed papers presented and the associated critique in this thesis provide a novel insight into the effects of prolonged standing and the research-led development of a footwear solution. The mixed methods approach enabled the consideration of the wearer as well as the biomechanical effects of prolonged standing and footwear. The completed research starts to fill gaps in the knowledge of this previously under researched area and has identified specific topics that require investigation in the future. The impact of the research on the footwear company was large, resulting in a new product, developing internal staff knowledge and creating marketing and sales tools. Furthermore, a number of footwear recommendations were developed for the company and user.

The main take away points from this body of work are:

- Musculoskeletal disorders are very high in the two standing populations investigated in this thesis (operating theatre workers and kitchen workers), with feet the second most prevalent region of pain despite being previously overlooked.
- Prolonged 'standing' is complex and can be broken down in to a range of tasks, that has enabled more recent research to ascertain links with activity and musculoskeletal disorders.
- One shoe will not work for everyone and a range of shoes should be offered to workers. The hardness underneath the medial arch is a key factor for which preference between individuals varies.
- Footwear comfort should be tested over a working day, if not longer, as it changes with time. If it is not possible to test footwear for a working day prior to selection by workers, then other methods such as the development of questionnaires as in paper 6 part 2 should be invested in by the sellers to identify the shoe that will provide the greatest long-term comfort. This would be beneficial for the businesses too as it would likely increase product satisfaction and resales.

While these works provide an initial indication of a relationship between footwear comfort and time, this needs to be extended to consider why this happens and extended to investigate the age of the individual and the age of the shoe. Further work should be done to understand footwear comfort and to identify if there are different ways that it can be assessed. Much remains to be investigated in relation to footwear for standing workers, including other design factors such as heel height and insole contouring, the use of novel research techniques and finally, the translation of this information to the real world must also be considered to ensure the research findings resultantly benefit those that need it.

Overall, these works identify the large impact that prolonged standing has on the body, particularly in relation to musculoskeletal disorders, including the feet that have been previously disregarded. It identifies a role of footwear in reducing musculoskeletal disorders in these workers that could reduce the loss of workforce including absenteeism, improve quality of life for workers and have financial implications.

Chapter 4 : Appendices

Appendix 1 Co-authors statement on contributed work

Associated table on page vii

Professor Chris Nester (papers 1-6)

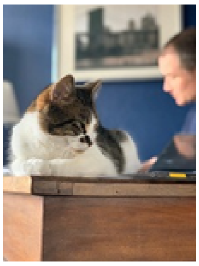
RE: paper JFAR and prima facia paperwork

Christopher Nester
To Jennifer Anderson; Anita Williams

Yes for me

Thanks (and stay in and safe everyone)

Chris



WORKING AT HOME
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SCHOOL OF HEALTH & SOCIETY

EPSRC Centre for DOCTORAL TRAINING PROSTHETICS & ORTHOTICS

great foundations Taking strides in children's foot health

From: Jennifer Anderson <J.R.Anderson1@salford.ac.uk>
Sent: 11 May 2020 10:03
To: Christopher Nester <C.J.Nester@salford.ac.uk>; Anita Williams <A.E.Williams1@salford.ac.uk>
Subject: RE: paper JFAR and prima facia paperwork

Hi Chris,

Thanks for that, I have edited the table to include all of these now.

I haven't specified contribution from yourself and Anita individually, so 'joint contribution' refers to areas from everyone.

If this looks okay now, then if you could just confirm this on email then I can screen grab it into the paperwork.

Thanks,
Jenny

Dr Anita Williams (papers: 1-6)

RE: paper JFAR and prima facia paperwork

Anita Williams
To Jennifer Anderson

Hi Jenny

I can confirm that the information provided in your Prima Facia report regarding your contribution to the works is accurate

Kind regards
Anita

Dr Anita Williams
Reader in Qualitative Health Science Research
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Professor Malcolm Granat (paper: 1)

RE: phd by publication - work contribution

MG Malcolm Granat
To Jennifer Anderson

Dear Jenny,

Thank you for passing on the information regarding you including your paper *"Exploring occupational standing activities using "accelerometer-based activity monitoring"* for your PhD.

I confirm that the table you sent me, which gives details of your independent contribution, is accurate.

Best wishes,

Malcolm

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Appendix 2 - Commercial use of research

Research on web page:
https://www.wearertech.com/about/wearer-innovation-loop/
https://www.toffeln.com/comforttech

Marketing video links

Wearer Innovation Loop – collaboration with Salford (Project Overview)
https://www.youtube.com/watch?v=jHwiTzxK7_Y

Why do chefs experience pain during the working day?
https://www.youtube.com/watch?v=JScZg24bDiU

What's one of your most interesting findings?
https://www.youtube.com/watch?v=DM_hEJ4s-hI

Why is it so important to focus on people standing on their feet all day?
https://www.youtube.com/watch?v=est-ioiXZ30

How have wearers guided research?
https://www.youtube.com/watch?v=9YCEI_oPet4

Find out why research is key when it comes to pain relief – full interview
https://www.youtube.com/watch?v=3aNl5YsrP2A

Marketing blog posts

Creation of the customer panel
https://www.wearertech.com/blog/customer-panel/

What it's like to spend all day on your feet
https://www.wearertech.com/blog/what-its-like-to-spend-all-day-on-your-feet/

The science of comfortable shoes
https://www.wearertech.com/blog/the-science-of-comfortable-shoes/

New Research on Prolonged standing at work
https://www.wearertech.com/blog/new-research-on-prolonged-standing-at-work/

The science behind our custom pro range
https://www.wearertech.com/blog/the-science-behind-our-custom-pro-range/

Appendix 3 - Insole selection tool

Insole selection tool available on the WearerTech website. https://www.wearertech.com/vitalise/ [Accessed 14/06/2121]

		What type of foot arch do you have when standing?		
		Low Arch	Medium Arch	High Arch
How do you prefer a shoe to feel under the arch of your foot?	Soft material with less support	Medium Insole	Soft Insole	Soft Insole
	Medium firmness with some support	Firm Insole	Medium Insole	Soft Insole
	Firm material for more support	Firm Insole	Firm Insole	Medium Insole

www.wearertech.com

Appendix 4- Conference Abstract 1: Footwear Biomechanics Symposium. Gold Coast, Australia. 20th-22nd July 2017

Reference: Anderson, J. R., C. J. Nester, and A. E. Williams (2017). The effect of prolonged standing on the body and the impact of footwear hardness. *Footwear Science* 9.sup1: S67-S68.

Appendix 5 - Conference Abstract 2: **Footwear Biomechanics Symposium. Calgary, Canada. 28th-30th July 2019.**

Reference: Anderson, Jennifer, Anita Williams, and Christopher Nester (2019). The development of a multi-insole shoe for occupations requiring prolonged standing. *Footwear Science* 11.sup1: S139-S140.

Appendix 6 - Questionnaire (Paper 3)

Page 2: Footwear

1 What footwear do you currently wear to work?

- Washable clog
- Standard clog
- Dress shoe
- Flat dolly shoe/pump
- Trainer
- Heeled boots
- Flat boots
- Safety shoe (with toe cap)
- Safety boot (with toe cap)
- Other

1.a If you selected Other, please specify:

2 Where do you normally purchase or receive your footwear from?

- Supermarket (e.g. Asda, Tesco, Sainsbury's)
- High street shoe store (e.g. Schuh, Office, Clarks, Hotter, Crocs)
- High street department or clothing store (e.g. Marks and Spencers, Topshop, House of Fraser)
- Specialist Orthopaedic Shoe Shop (e.g. Ken Hall)
- Specialist work shoe company (e.g. Toffeln, Oxypas)
- Other

2.a If you selected Other, please specify:

2.b What is the make of shoe you usually wear to work?

3 Do you own multiple pairs of work shoes that you regularly rotate between wearing?

- Yes - I have multiple pairs of the exact same shoe (always the same make and model)
- Yes - I have multiple pairs of the same type of shoe
- Yes - I have multiple pairs of shoes that are different in type
- No - I wear the same pair of shoes each day

2 / 22

4 Do you use insoles/ orthotics that you have added inside your shoe?

- ☐ Yes - I use shop bought insoles
- ☐ Yes - I wear insoles I was prescribed by a professional (e.g. podiatrist)
- ☐ No - I don't use insoles or orthotics

4.a If yes, what features do the insoles/ orthotics have?

- ☐ Cushioning
- ☐ Shock absorbing
- ☐ Arch support
- ☐ Heel raise
- ☐ Lateral wedge
- ☐ Rocker
- ☐ Other

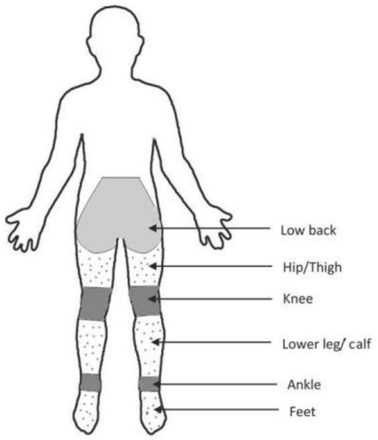
4.a.i If you selected Other, please specify:

5 Do you normally (day-to-day basis) wear socks with your shoes at work?

- ☐ Yes, I normally wear socks
- ☐ No, I do not normally wear socks

Page 3: Pain

Using the picture below as a rough guide, please answer the following questions.



Lower back

6 Have you at any time in the last 12 months had trouble (ache, pain, discomfort) in your lower back?

- ☐ Yes
- ☐ No

6.a If yes, have you at any time during the last 12 months been prevented from doing your normal work (at home or away from home) because of this trouble (ache, pain or discomfort) in your lower back?

- ☐ Yes
- ☐ No
- ☐ NA (I don't have pain)

6.b Approximately how much time off from work have you had to take as a result of the trouble (ache/ pain/ discomfort) in your lower back in the last 12 months?

- ☐ No time off work
- ☐ Under a week
- ☐ Up to a month (4 weeks)
- ☐ More than a month
- ☐ NA (I don't have any aches, pain or discomfort)

6.c Have you had any low back trouble (ache, pain or discomfort) at any time during the last 7 days?

- ☐ Yes

- No
- NA (I don't have any trouble)

6.d Have you been seen by a doctor, physiotherapist, chiropractor or other such person because of low back trouble (ache, pain or discomfort) during the last 12 months?

- Yes
- No
- NA (I don't have trouble)

6.e Please select a word that best describes the pain you feel in your lower back.

6.f Are there any particular tasks or movements that you associate with the aches, pains or discomfort in your lower back?

Hip/ Thigh

7 Have you at any time in the last 12 months had trouble (ache, pain, discomfort) in your hips/thighs?

- Yes - in the right hip/ thigh
- Yes - in the left hip/thigh
- Yes - in both the hips/thighs
- No

7.a If yes, have you at any time during the last 12 months been prevented from doing your normal work (at home or away from home) because of the trouble (ache, pain or discomfort) in your hips/thighs?

- Yes
- No
- NA (I don't have pain)

7.b Approximately how much time off from work have you had to take as a result of the trouble (ache/ pain/ discomfort) in your hip/ thighs in the last 12 months?

- No time off work
- Under a week
- Up to a month (4 weeks)
- More than a month
- NA (I don't have any aches, pain or discomfort)

7.c Have you had any trouble (ache, pain or discomfort) in your hips/thighs at any time during the last 7 days?

- ☐ Yes
- ☐ No
- ☐ NA (I don't have pain)

7.d Have you been seen by a doctor, physiotherapist, or other such person because of trouble (ache, pain or discomfort) in your hips/thighs during the last 12 months?

- ☐ Yes
- ☐ No
- ☐ NA (I don't have pain)

7.e Please select a word that best describes the pain you feel in your hip/thighs.

7.f Are there any particular tasks or movements that you associate with the aches, pains or dicomfort in your hip/ thigh?

Knee

8 Have you at any time in the last 12 months had trouble (ache, pain, discomfort) in your knee?

- ☐ Yes - in the right knee
- ☐ Yes - in the left knee
- ☐ Yes - in both the knee
- ☐ No

8.a If yes, have you at any time during the last 12 months been prevented from doing your normal work (at home or away from home) because of the trouble (ache, pain or discomfort) in your knee?

- ☐ Yes
- ☐ No
- ☐ NA (I don't have any trouble)

8.b Approximately how much time off from work have you had to take as a result of the trouble (ache/ pain/ discomfort) in your knee in the last 12 months?

- ☐ No time off work

- Under a week
- Up to a month (4 weeks)
- More than a month
- NA (I don't have any aches, pain or discomfort)

8.c Have you had any trouble (ache, pain or discomfort) in your knee at any time during the last 7 days?

- Yes
- No
- NA (I don't have any aches, pain or discomfort)

8.d Have you been seen by a doctor, physiotherapist or other such person because of trouble (ache, pain or discomfort) in your knee during the last 12 months?

- Yes
- No
- NA (I don't have any aches, pain or discomfort)

8.e Please select a word that best describes the pain you feel in your knees.

8.f Are there any particular tasks or movements that you associate with the aches, pains or discomfort in your knee(s)?

Lower leg/calf

9 Have you at any time in the last 12 months had trouble (ache, pain, discomfort) in your lower leg/calf?

- Yes - in the right lower leg/calf
- Yes - in the left lower leg/calf
- Yes - in both the lower legs/calfs
- No

9.a If yes, have you at any time during the last 12 months been prevented from doing your normal work (at home or away from home) because of the trouble (ache, pain or discomfort) in your lower leg/calf?

- Yes
- No
- NA (I don't have any aches, pain or discomfort)

9.b Approximately how much time off from work have you had to take as a result of the trouble (ache/ pain/ discomfort) in your lower leg/ calf in the last 12 months?

- ☐ No time off work
- ☐ Under a week
- ☐ Up to a month (4 weeks)
- ☐ More than a month
- ☐ NA (I don't have any aches, pain or discomfort)

9.c Have you had any trouble (ache, pain or discomfort) in your lower leg/calf at any time during the last 7 days?

- ☐ Yes
- ☐ No
- ☐ NA (I don't have any aches, pain or discomfort)

9.d Have you been seen by a doctor, physiotherapist or other such person because of trouble (ache, pain or discomfort) in your lower leg/calf during the last 12 months?

- ☐ Yes
- ☐ No
- ☐ NA (I don't have any aches, pain or discomfort)

9.e Please select a word that best describes the pain you feel in your lower leg/calf.

9.f Are there any particular tasks or movements that you associate with the aches, pains or discomfort in your lower leg/ calf?

Ankle

10 Have you at any time in the last 12 months had trouble (ache, pain, discomfort) in your ankle?

- ☐ Yes - in the right ankle
- ☐ Yes - in the left ankle
- ☐ Yes - in both the ankles
- ☐ No

10.a If yes, have you at any time during the last 12 months been prevented from doing your normal work (at home or away from home) because of the trouble (ache, pain or discomfort) in your ankle?

- [ ] Yes
- [ ] No
- [ ] NA (I don't have any aches, pain or discomfort)

10.b Approximately how much time off from work have you had to take as a result of the trouble (ache/ pain/ discomfort) in your ankle in the last 12 months?

- [ ] No time off work
- [ ] Under a week
- [ ] Up to a month (4 weeks)
- [ ] More than a month
- [ ] NA (I don't have any aches, pain or discomfort)

10.c Have you had any trouble (ache, pain or discomfort) in your ankle at any time during the last 7 days?

- [ ] Yes
- [ ] No
- [ ] NA (I don't have any aches, pain or discomfort)

10.d Have you been seen by a doctor, physiotherapist or other such person because of trouble (ache, pain or discomfort) in your ankle during the last 12 months?

- [ ] Yes
- [ ] No
- [ ] NA (I don't have any aches, pain or discomfort)

10.e Please select a word that best describes the pain you feel in your ankles.

10.f Are there any particular tasks or movements that you associate with the aches, pains or discomfort in your ankle(s)?

Feet

11 Have you at any time in the last 12 months had trouble (ache, pain, discomfort) in your feet?

- [ ] Yes - in the right foot
- [ ] Yes - in the left foot
- [ ] Yes - in both the feet

- [ ] No

11.a If yes, have you at any time during the last 12 months been prevented from doing your normal work (at home or away from home) because of the trouble (ache, pain or discomfort) in your feet?

- [ ] Yes
- [ ] No
- [ ] NA (I don't have any aches, pain or discomfort)

11.b Approximately how much time off from work have you had to take as a result of the trouble (ache/ pain/ discomfort) in your feet in the last 12 months?

- [ ] No time off work
- [ ] Under a week
- [ ] Up to a month (4 weeks)
- [ ] More than a month
- [ ] NA (I don't have any aches, pain or discomfort)

11.c Have you had any trouble (ache, pain or discomfort) in your feet at any time during the last 7 days?

- [ ] Yes
- [ ] No
- [ ] NA (I don't have any aches, pain or discomfort)

11.d Have you been seen by a doctor, physiotherapist, podiatrist or other such person because of trouble in your feet during the last 12 months?

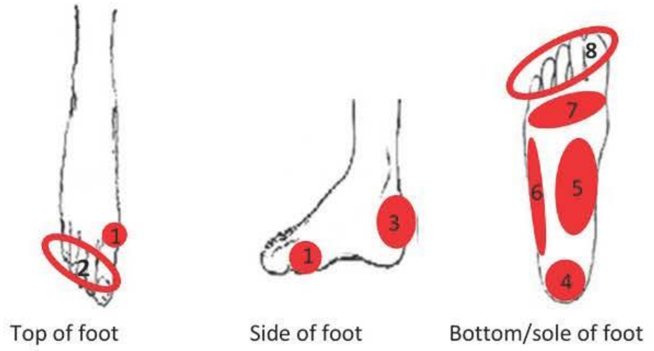
- [ ] Yes
- [ ] No
- [ ] NA (I don't have pain)

11.e Please select a word that best describes the pain you feel in your feet.

11.f Are there any particular tasks or movements that you associate with the aches, pains or discomfort in your feet?

Page 4: Foot problems

12 Using the below diagram as a rough guide, can you identify any area in your foot that you feel pain during the



working day (select all that apply)?

- ☐ 1 - Inside of big toe
- ☐ 2 - top of toes
- ☐ 3 - back of heel
- ☐ 4 - bottom of heel
- ☐ 5 - arch area under foot
- ☐ 6 - outside edge of foot
- ☐ 7 - ball of feet
- ☐ 8 - underside of toes
- ☐ 9 - between toes
- ☐ NA - no pain in the foot

13 Do you suffer from any known foot conditions?

- ☐ No
- ☐ Blisters
- ☐ Corns
- ☐ Calluses
- ☐ Plantar fasciitis
- ☐ Bunions
- ☐ High arch
- ☐ Low arch
- ☐ Hammer toe
- ☐ Claw toe
- ☐ Yes - other

13.a If you selected Other, please specify:

13.b Was this foot condition diagnosed by a professional (e.g. podiatrist)?

- ☐ Yes
- ☐ No
- ☐ NA

14 Do you suffer from any medical condition that could increase your pain?

- ☐ No
- ☐ Osteoarthritis
- ☐ Rheumatoid arthritis
- ☐ Yes - Other

14.a If you selected Other, please specify:

Page 5: Important footwear characteristics

15 Rank the following footwear characteristics in order of importance for you (1 being the most important and 11 the least important). Please select each number only once.

Please don't select more than 1 answer(s) per row.

Please don't select more than 1 answer(s) in any single column.

	1	2	3	4	5	6	7	8	9	10	11
Good fit	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Supportive	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cushioned	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Durable	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Lightweight	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Waterproof	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Breathable	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Slip resistant	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Washable	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Flexible sole	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Style	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

15.a Are there any other important characteristics you look for in footwear?

16 Please answer the following by marking one box.

Please don't select more than 1 answer(s) per row.

	Not at all important	Slightly important	Important	Fairly important	Very important
In work footwear, how important is comfort to you?	☐	☐	☐	☐	☐

17 In relation to footwear, what does the word **comfortable** mean to you? (Please be as detailed as possible in your description)

18 Rate your current work footwear comfort on a scale from 1-10 (1 = the most uncomfortable shoe you can imagine, 10 = the most comfortable footwear you can imagine)

Please don't select more than 1 answer(s) per row.

	1	2	3	4	5	6	7	8	9	10
Current footwear comfort	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

19 How could your current work footwear be improved?

Page 6: Job Information

20 Are you a health care worker?

Please select no more than 1 answer(s).
- ☐ Yes
- ☐ No

21 What is your job title?

22 What is your main work site?

Please select no more than 1 answer(s).
- ☐ Wards
- ☐ Operating rooms
- ☐ Kitchens
- ☐ Office
- ☐ Shop/Cafe
- ☐ Lab
- ☐ Other

22.a If you selected Other, please specify:

23 How many hours do you work in an average week?

Please select no more than 1 answer(s).
- ☐ 0-10 hours
- ☐ 10-20 hours
- ☐ 20-30 hours
- ☐ 30-40 hours
- ☐ 40-50 hours
- ☐ 50+ hours

24 How many years have you been working in your current profession for (including training time on the job)?

Please select no more than 1 answer(s).

- less than 1 year
- 1-5 years
- 6-10 years
- 11-15 years
- 16-20 years
- 21-25 years
- 26-30 years
- 31-35 years
- 36-40 years
- 41 years +

25 Approximately what percentage of your time at work is spent doing the following activities? Please put one mark in each row.

Please don't select more than 1 answer(s) per row.

	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Sitting (including work and break time)											
On your feet (including standing and walking)											
Standing											
Walking											

Page 7: Social factors

Previous research has shown that certain psychosocial factors also contribute to aches and pains at work. Therefore, to allow us to assess the problems associated with the physical work load, we would really appreciate you answering the following as accurately as possible. Remember, all information submitted is completely anonymous. Thank you in advance for your help.

26 Please answer the following by marking one box in each row.

Please don't select more than 1 answer(s) per row.

	Always	Often	Sometimes	Seldom	Never/ hardly ever
Do you get behind your work?	☐	☐	☐	☐	☐
Do you have enough time for your work tasks?	☐	☐	☐	☐	☐
Is it necessary to keep working at a high pace?	☐	☐	☐	☐	☐
Do you work at a high pace throughout the day?	☐	☐	☐	☐	☐
Does your work put you in emotionally disturbing situations?	☐	☐	☐	☐	☐
Do you have to relate to other people's personal problems as part of your work?	☐	☐	☐	☐	☐
Do you have a large degree of influence concerning your work?	☐	☐	☐	☐	☐
Can you influence the amount of work assigned to you?	☐	☐	☐	☐	☐

27 Please answer the following by marking one box in each row.

Please don't select more than 1 answer(s) per row.

	To a very large extent	To a large extent	Somewhat	To a small extent	To a very small extent
Is your work recognised and appreciated by the management?	☐	☐	☐	☐	☐
Are you treated fairly at your workplace?	☐	☐	☐	☐	☐

28 Please answer the following by marking one box in each row.

Please don't select more than 1 answer(s) per row.

	Always	Often	Sometimes	Seldom	Never/ hardly ever
How often is your nearest superior willing to listen to your problems at work?	☐	☐	☐	☐	☐
How often do you get help and support from your nearest superior?	☐	☐	☐	☐	☐

29 Please answer the following by marking one box.

Please don't select more than 1 answer(s) per row.

	Very satisfied	Satisfied	Unsatisfied	Very satisfied
Regarding your work in general. How pleased are you with your job as a whole, everything taken into consideration?	☐	☐	☐	☐

Page 8: Personal Information

To help us classify your answers and to enhance the analysis, we would really appreciate you to answer the following.

30 What is your age?

- ☐ Under 20
- ☐ 20-29
- ☐ 30-39
- ☐ 40-49
- ☐ 50-59
- ☐ 60-69
- ☐ 70+

31 What is your gender?

- ☐ Male
- ☐ Female

32 What is your height (in metres)?

33 What is your weight (in kg)?

34 Outside of work, how many times a week do you exercise?

- ☐ 0
- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7
- ☐ 7+

35 What are your usual forms of exercise outside of work?

- ☐ Walking
- ☐ Running
- ☐ Cycling
- ☐ Exercise classes
- ☐ Weights/ resistance training
- ☐ Racket sport
- ☐ Football
- ☐ Rugby
- ☐ Cricket
- ☐ Martial arts
- ☐ Swimming
- ☐ Netball
- ☐ Dancing
- ☐ Other

35.a If you selected Other, please specify:

Page 9

Thank you very much for taking the time to fill in the questionnaire. Your answers will be very helpful in future product development.

To be in with a chance of winning the prize draw, click the following link and enter your details:

https://salford.onlinesurveys.ac.uk/healthcare-footwear-prize-draw

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Key for selection options

6.e - Please select a word that best describes the pain you feel in your lower back.

Throbbing
Shooting
Stabbing
Sharp
Cramping
Gnawing
Hot-burning
Aching
Heavy
Tender
Splitting
Tired-exhausting
NA - I don't feel pain

7.e - Please select a word that best describes the pain you feel in your hip/thighs.

Throbbing
Shooting
Stabbing
Sharp
Cramping
Gnawing
Hot-burning
Aching
Heavy
Tender
Splitting
Tired-exhausting
NA - I don't feel pain

8.e - Please select a word that best describes the pain you feel in your knees.

Throbbing
Shooting
Stabbing
Sharp
Cramping
Gnawing
Hot-burning
Aching
Heavy
Tender
Splitting
Tired-exhausting
NA - I don't feel pain

9.e - Please select a word that best describes the pain you feel in your lower leg/calf.

Throbbing
Shooting
Stabbing
Sharp
Cramping
Gnawing
Hot-burning
Aching
Heavy
Tender
Splitting
Tired-exhausting
NA - I don't feel pain

10.e - Please select a word that best describes the pain you feel in your ankles.

Throbbing
Shooting
Stabbing
Sharp
Cramping
Gnawing
Hot-burning
Aching
Heavy
Tender
Splitting
Tired-exhausting
NA - I don't feel pain

11.e - Please select a word that best describes the pain you feel in your feet.

Throbbing
Shooting
Stabbing
Sharp
Cramping
Gnawing
Hot-burning
Aching
Heavy
Tender
Splitting
Tired-exhausting
NA - I don't feel pain

Appendix 7 - Ethical approval

Interview/Activity Monitoring

University of Salford
MANCHESTER

Research, Innovation and Academic Engagement Ethical Approval Panel

Research Centres Support Team
G0.3 Joule House
University of Salford
M5 4WT

T +44(0)161 295 2280

www.salford.ac.uk/

27 May 2016

Dear Jenny,

RE: ETHICS APPLICATION HSCR 16-09 – Footwear biomechanics – development of footwear for standing occupations.

Based on the information you provided, I am pleased to inform you that application HSCR16-09 has been approved.

If there are any changes to the project and/ or its methodology, please inform the Panel as soon as possible by contacting Health-ResearchEthics@salford.ac.uk

Yours sincerely,

Sue McAndrew
Chair of the Research Ethics Panel

University of Salford
MANCHESTER

Research, Innovation and Academic Engagement Ethical Approval Panel

Research Centres Support Team
G0.3 Joule House
University of Salford
M5 4WT

T +44(0)161 295 2280

www.salford.ac.uk/

10 March 2017

Dear Jenny,

RE: AMENDED ETHICS APPLICATION–HSCR16-09 – 'Footwear biomechanics – development of footwear for standing occupations.'

Based on the information you provided I am pleased to inform you that amended application HSCR16-09 has been approved.

If there are any changes to the project and/or its methodology, then please inform the Panel as soon as possible by contacting Health-ResearchEthics@salford.ac.uk

Yours sincerely,

Sue McAndrew
Chair of the Research Ethics Panel

Questionnaire

University of Salford
MANCHESTER

Research, Innovation and Academic Engagement Ethical Approval Panel

Research Centres Support Team
G0.3 Joule House
University of Salford
M5 4WT

T +44(0)161 295 2280

www.salford.ac.uk/

11 January 2016

Dear Jenny,

RE: ETHICS APPLICATION HSCR 15-132 – An investigation into lower limb problems associated with the health care workplace and footwear

Based on the information you provided, I am pleased to inform you that application HSCR15-132 has been approved.

If there are any changes to the project and/ or its methodology, please inform the Panel as soon as possible by contacting Health-ResearchEthics@salford.ac.uk

Yours sincerely,

Sue McAndrew
Chair of the Research Ethics Panel

NHS
Health Research Authority

Miss Anderson (C/O Dr Anita Williams – office PO29)
University of Salford
Brian Blatchford Building
M6 6PU

Email: hra.approval@nhs.net

06 June 2016

Dear Miss Anderson,

Letter of HRA Approval for a study processed through pre-HRA Approval systems

Study title:	**An investigation into lower limb problems associated with prolonged standing and footwear in surgical staff.**
IRAS project ID:	**192183**
Sponsor:	**University of Salford**

Thank you for your request for HRA Approval to be issued for the above referenced study.

I am pleased to confirm that the study has been given **HRA Approval.** This has been issued on the basis of an existing assessment of regulatory compliance, which has confirmed that the study is compliant with the UK wide standards for research in the NHS.

The extension of HRA Approval to this study on this basis allows the sponsor and participating NHS organisations in England to set-up the study in accordance with HRA Approval processes, with decisions on study set-up being taken on the basis of capacity and capability alone.

If you have submitted an amendment to the HRA between 23 March 2016 and the date of this letter, this letter incorporates the HRA Approval for that amendment, which may be implemented in accordance with the amendment categorisation email (e.g. not prior to REC Favourable Opinion, MHRA Clinical Trial Authorisation etc., as applicable). If the submitted amendment included the addition of a new NHS organisation in England, the addition of the new NHS organisation is also approved and should be set up in accordance with HRA Approval processes (e.g. the organisation should be invited to assess and arrange its capacity and capability to deliver the study and confirm once it is ready to do so).

Participation of NHS Organisations in England

Please note that full information to enable set up of participating NHS organisations in England is not provided in this letter, on the basis that activities to set up these NHS organisations is likely to be underway already.

Amendment Notification Form

Please complete this form and submit it to the Health Research Ethics Panel that reviewed the original proposal: Health-ResearchEthics@Salford.ac.uk

Title of Project:
An investigation into lower limb problems associated with the health care workplace and footwear

Name of Lead Applicant:	*School:*
Chris Nester	**School of Health Sciences**

Are you the original Principal Investigator (PI) for this study? ***NO*** *(delete as appropriate)*

If you have selected 'NO', please explain why you are applying for the amendment:
The previous principal investigator does not work for the University any more.

Date when original approval was obtained:	*Reference No:*
11/1/16	**HSCR 15-132**

Please outline the proposed changes to the project. ***NB.*** *If the changes require any amendments to the PIS, Consent Form(s) or recruitment material, then please submit these with this form highlighting where the changes have been made:*

- **Recruitment is for hospitality, not health care**
- **Most questions remain the same (musculoskeletal disorders questions, psychosocial, individual characteristics) but some questions have been added to reflect the different footwear demands of the job (do you use a toe cap, questions regarding slip resistance of the footwear, job title list). Some questions have been removed that did not end up being used for analysis in the last questionnaire, due to issues with results (e.g. 4 questions regarding different postures at work have been cut to 1).**
- **The software has been changed from BOS to Survey Monkey.**
- **Questionnaire will still offer a prize draw, but for £150 amazon vouchers. Each participant will also receive a 20% off voucher for WearerTech footwear.**
- **Recruitment will be done through the mailing lists of WearerTech Ltd (100 hospitality staff), the chefs forum (email database of 4500 chefs) and other restaurants and chains will be approached if necessary.**
- **End date will be 31st December 2019**
- **The two recruitment emails will be sent out 2 weeks apart, rather than 1, as this is expected to give those on annual leave a greater opportunity to complete the questionnaire.**
- **Recruitment emails have been updated (see below)**
- **The company associated with the research has updated their company name from Toffeln to WearerTech.**

Please say whether the proposed changes present any new ethical issues or changes to ethical issues that were identified in the original ethics review, and provide details of how these will be addressed: **No further ethical issues have been identified**

Amendment Approved: ✓

Date of Approval: ***29.10.18***

Chair's Signature: 

Note: this application (HSCR15-132) has now been transferred to Chris Nester's name from Jenny Anderson's, and the amendment has been approved with Chris as PI.

Paper 5

University of Salford MANCHESTER

Research, Innovation and Academic Engagement Ethical Approval Panel

Research Centres Support Team
G0.3 Joule House
University of Salford
M5 4WT

T +44(0)161 295 2280

www.salford.ac.uk/

12 July 2016

Dear Jenny,

RE: ETHICS APPLICATION HSCR 16-64 – Biomechanical testing and optimisation of footwear for the work place.

Based on the information you provided, I am pleased to inform you that application HSCR16-64 has been approved.

If there are any changes to the project and/ or its methodology, please inform the Panel as soon as possible by contacting Health-ResearchEthics@salford.ac.uk

Yours sincerely,

Sue McAndrew
Chair of the Research Ethics Panel

Paper 6 part 1

Research, Innovation and Academic
Engagement Ethical Approval Panel

Research Centres Support Team
G0.3 Joule House
University of Salford
M5 4WT

T +44(0)161 295 2280

www.salford.ac.uk/

30 June 2017

Dear Jenny,

RE: ETHICS APPLICATION–HSR1617-145–'Insole preference and the relation to individual and biomechanical parameters.'

Based on the information you provided I am pleased to inform you that application HSR1617-145 has been approved.

If there are any changes to the project and/or its methodology, then please inform the Panel as soon as possible by contacting Health-ResearchEthics@salford.ac.uk

Yours sincerely,

Sue McAndrew
Chair of the Research Ethics Panel

Paper 6 part 2

Research, Enterprise and Engagement
Ethical Approval Panel

Doctoral & Research Support
Research and Knowledge Exchange,
Room 827, Maxwell Building,
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28 September 2018

Dear Carina,

RE: ETHICS APPLICATION–HSR1819-001 – 'Predicting insole comfort in workers standing for long periods of time.'

Based on the information that you have provided, I am pleased to inform you that ethics application HSR1819-001 has been approved.

If there are any changes to the project and/or its methodology, then please inform the Panel as soon as possible by contacting Health-ResearchEthics@salford.ac.uk

Yours sincerely,

Professor Sue McAndrew
Chair of the Research Ethics Panel

Chapter 5 References

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