School of Physiotherapy and Exercise Science

The Impact of Prolonged Sitting and Alternate Work Positions on Musculoskeletal Discomfort and Cognitive Performance

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Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made. This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

The research presented and reported in this thesis was conducted in accordance with the National Health and Medical Research Council National Statement on Ethical Conduct in Human Research (2007) – updated March 2014. The proposed research study received human research ethics approval from the Curtin University Human Research Ethics Committee (EC00262), Approval Numbers: PT018/2014 and RDHS-266-15.

Results of this thesis have been presented in part by the candidate, in the following publications and at the following scientific meetings:

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Lee, J.Y., Baker, R., Coenen, P. & Straker, L., 2018. Use of a footrest to reduce low back discomfort development due to prolonged standing. *Applied Ergonomics*, 67, 218-224

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Abstract

Aim

Excessive sedentary behaviour is an important health issue. For some workers, such as office workers, high levels of sitting can be accumulated through their work. Interventions, such as alternate work positions which reduce the amount of time spent sitting while still allowing workers to remain productive, have been explored as a potential solution. There is limited understanding however, of how alternative work positions may influence acute discomfort and cognitive functions. Further, there is a lack of evidence based guidance available to inform industry on use of alternate work positions, potential impact on work performance and how to avoid introducing new risks to the workplace. The aim of this thesis was to investigate the impact of prolonged sitting and three alternative work positions on musculoskeletal discomfort and cognitive function. The specific objectives of the thesis were:

- To determine the impact of prolonged just-sitting, under-desk cycling, just-standing and standing-with-movement on musculoskeletal discomfort over a two hour period while normal healthy adults perform clerical tasks .

- To determine the impact of prolonged just-sitting, under-desk cycling, just-standing and standing-with-movement on cognitive function (problem solving and sustained attention) over a two hour period.

- To determine the impact of prolonged just-sitting, under-desk cycling, just-standing and standing-with-movement over a two hour period on muscle fatigue, posture, pelvis movement and mental state, and lower limb swelling for the standing conditions.

- To explore correlations between discomfort and cognitive function during prolonged just-sitting and just-standing.

- To evaluate musculoskeletal and cognitive changes during prolonged just-sitting, under-desk cycling, just-standing and standing-with-movement to inform work posture policy, practice and research.

- To analyse participant perceptions of feasibility of alternatives to prolonged sitting.

Methods

Two laboratory studies were conducted. In Study 1, participants undertook two hours of prolonged sitting and two hours of under-desk cycling while seated. In Study 2 participants undertook two hours of prolonged standing and two hours of standing-with-movement. Twenty adults were recruited to participate in each of the two studies, with different participants across the two studies. The inclusion criteria were: participants aged between 18 – 65 years, English and computer literate, and with anticipated physical ability to undertake light activity over two hours. Those with a known pain response to prolonged positions were excluded.

Each study had a repeated measures design. Dependent variable measurements were taken at baseline, then every 30 minutes until 120 minutes when the final measurement was taken (five measures in total). The independent variables were the work position and time spent (two hours) in the work position and dependent variables were discomfort, cognitive function (creative problem solving and sustained attention), muscle fatigue, low back angle, pelvis movement and mental state. For the standing conditions an additional dependent variable of calf swelling was added, along with qualitative feedback. Participants visited the laboratory prior to participation in the study to be familiarised with the procedure and tests. Participants undertook the respective conditions in Study 1 and Study 2 in a random order, approximately one week apart, at a similar time of day.

During the two hours, participants undertook self-directed computer or paper based activity. For the seated conditions in Study 1, a desk was adjusted to allow optimal desk height for under-desk cycling (lowest level possible whilst still allowing acceptable knee clearance) and then used across both conditions. A standard adjustable office chair with backrest was used. A height adjustable footrest was used by all participants to allow 90 degrees knee flexion when not cycling. During under-desk cycling the cycle was set at the lowest resistance level and participants were instructed to cycle at a comfortable slow pace (no control over cadence was implemented). For the standing conditions in Study 2, a height adjustable desk was set to 5cm below standing elbow height. Participants stood within a couple of centimetres of the desk edge, and were asked not to lean on the desk surface. During the just-standing condition participants continuously stood with both feet on the floor but were free to move their feet and shift their weight at will. Participants were instructed to stand in their usual manner but were not instructed, nor otherwise constrained, in foot position and wore flat shoes for both conditions. For standing-with-movement participants rotated every five minutes between right foot raised on a 100mm footrest followed by left foot, then both feet on the floor.

Musculoskeletal discomfort was measured using an electronic (modified) Nordic Musculoskeletal Questionnaire (NMQ) which required participants to rate intensity of musculoskeletal discomfort. The Ruff Figural Fluency Test (RFFT) was used to measure creative problem solving. The RFFT requires production of as many unique designs as possible, using a dot pattern, without repeating any designs (which would be considered as errors). Sustained attention was measured using the Sustained Attention to Response Test (SART) which requires withholding a response on an infrequent basis. A scale of five visual analogue items based on the Visual Analogue Scale for Fatigue, was used to measure mental state. For Study 1 muscle activity was collected using surface electromyography (EMG) of upper trapezius, external oblique, lumbar erector spinae, rectus femoris and biceps femoris. While for Study 2 muscle activity was collected for lumbar erector spinae, rectus femoris, biceps femoris and tibialis anterior. Kinematics of low back angle (sagittal plane) and pelvis movement (traverse plane displacement at S2) were measured using Space Fastrak. For Study 2 calf circumference was measured in three locations using a non-stretch tape with spring tension. Finally, for Study 2 participants completed a questionnaire of their perception of feasibility of the work positions.

Results

Each of the work positions resulted in significant increases in discomfort with time across all body areas. Further, each of the work positions had at least one body area which reached clinically meaningful levels of discomfort. Participants under-desk cycling reported higher total body discomfort than just-sitting. Participants just-standing reported higher total body discomfort than standing-with-movement. At 120 minutes, participants under-desk cycling reported four body areas with clinically meaningful levels of discomfort compared to two areas for just-sitting. At 120 minutes, participants standing-with-movement had five body areas with clinically meaningful levels of discomfort compared to four areas for just-standing. For the low back, discomfort reached clinically meaningful levels for all conditions. For the lower limb, during under-desk cycling, participants had greater discomfort of hip/thigh/buttock, knee and ankle/foot areas than just-sitting with each also reaching clinically meaningful levels. For the standing conditions, all of the lower limb areas (hip/thigh/buttock, knee and ankle/foot) reached clinically meaningful levels for both conditions. In contrast, for the upper limb no body areas reached clinically meaningful levels for any condition.

Cognitive functions had no clear substantial decrement or improvement of any measure for each of the alternate work positions. Individual cognitive function variables though had both trends and statistically significant differences. However, as there is currently no threshold to determine clinical significance, it is not known what real-world importance the observed differences have, nor implications for industry. In Study 1, there may have been a dual task cost during under-desk cycling for sustained attention with a speed-error trade-off. While reaction time was able to be maintained over the two hours for under-desk cycling, reaction time sped up for just-sitting with a statistically significant effect for condition. However, percentage success deteriorated for participants under-desk cycling while just-sitting had a more stable percentage success over time. For the standing conditions, participants' sustained attention percentage success had no significant difference between conditions. Reaction time got significantly slower with time for both standing conditions. For creative problem solving, there was a non-significant trend for an increase in unique designs for participants under-desk cycling, with just-sitting remaining more stable over time. The standing conditions had no difference in participants' number of unique designs. There was a non-significant trend for a reduction in number of errors during under-desk cycling compared to just-sitting. For participants just-standing, creative problem solving errors had a trend for increased errors over time while for standing-with-movement errors tended to be reduced.

There were no significant correlations between total body discomfort and cognitive measures for either just-sitting or just-standing. Investigation of potential mechanisms was not able to provide a clear explanation for the discomfort and cognitive findings. Mental state deteriorated with time for all conditions. Participants rated under-desk cycling higher (mental state deteriorated more) than just-sitting, and standing-with-movement higher than just-standing. Based on qualitative feedback obtained for Study 2, including acceptability and feasibility, participants preferred standing-with-movement to just-standing.

Conclusions

Excessive sitting is a recognised health risk. However, the current studies showed that alternative work positions to reduce prolonged sitting also carry risks of acute musculoskeletal discomfort for users. The current studies found clinically meaningful acute musculoskeletal discomfort when alternate work positions were used continuously over two hours, even with healthy individuals. Use of alternative work positions for shorter durations of less than two hours has potential for benefit, in particular under-desk cycling which resulted in delayed onset of clinically meaningful levels of body discomfort, compared to sitting. The use of standing alternatives for full work days should only occur in combination with seated options, given the considerably higher and earlier onset of discomfort compared to sitting during the two hour laboratory sessions and other known health risks from excessive standing. Educating industry about the risks, and how to reduce these through strategies such as timing for changes of position, is required. The cognitive functions evaluated in the current studies did not have any clear short term decrement. However, implications for real world work performance over the longer term are unknown. Use of alternate work positions in the workplace are not without issues suggesting they are likely to form only part of the solution to addressing excessive workplace sedentary behaviour.

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List of Abbreviations

A: Amplitude

C: Under-desk cycling (in tables)

CI: Confidence Interval

EMG: Electromyography

IRR: Incident Rate Ratio

MF: Median Frequency

S: Just-sit

exception: in Chapter 6 '*S'* was used to represent '*just-stand'* (in tables)

St: Just-stand

SWM: Standing-with-movement

List of Key Terms

Cognitive functions	Subcomponents which together result in execution of cognition.
Just-sitting	Condition used in Study 1 whereby participants only sat for the duration.
Just-standing	Condition used in Study 2 whereby participants only stood for the duration.
Mental state	Global cortical activation level
Position	Used to describe overall work position of participants
Posture	Used to describe low back angle
Standing permissive desk	Desk which has height adjustable capability to allow use in either a sitting or standing position
Standing-with-movement	Condition used in Study 2 whereby participants stood for the duration while using a footrest to raise alternating foot (every five minutes).
Under-desk cycling	Condition used in Study 1 whereby participants used a portable cycle placed under a standard office desk.

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Chapter 1 Introduction

1.1 Sedentary behaviour as an important health issue

For many adults, time spent being sedentary makes up a large proportion of waking hours (Chau *et al.* 2013, Straker *et al.* 2016). Sedentary behaviour is defined as any waking behaviour with a low energy expenditure (≤1.5 metabolic equivalents), while in a sitting, reclining or lying posture (Tremblay *et al.* 2017). Sedentary behaviour, both total volume and prolonged bouts, has been linked to negative health outcomes (van der Ploeg *et al.* 2012, Wilmot *et al.* 2012, de Rezende *et al.* 2014, Chau *et al.* 2015a, Zhai *et al.* 2015, O'Donoghue *et al.* 2016, Tigbe *et al.* 2017) including increased risk of mortality, cardiovascular disease (Katzmarzyk *et al.* 2009, Thorp *et al.* 2011, Biswas *et al.* 2015), diabetes (Dunstan *et al.* 2012, Ahmad *et al.* 2017), some cancers (Biswas *et al.* 2015) and musculoskeletal disorders (Straker *et al.* 2016). There are suggestions that sedentary behaviour can also impact negatively on cognitive functions (Voss *et al.* 2014, Falck *et al.* 2017). High levels of sitting is an increasing health problem for many countries, such as Australia where many adults sit for up to 11 hours per day (Chau *et al.* 2013) across the domains of leisure, transport and work (Brown *et al.* 2009). Further, occupational exposure to sitting is high for many workers (Chau *et al.* 2010) with the percentage of those employed in sedentary occupations increasing (Church *et al.* 2011, Ng and Popkin 2012).

1.2 Contribution of work to sedentary exposure

Excessive sitting is reported to be a health hazard and, given the high levels accumulated through work for some, is now also recognised as an occupational hazard (Dunstan *et al.* 2012, Straker *et al.* 2016). Office workers are particularly at risk with some evidence suggesting over 80% of work hours is sedentary (Parry and Straker 2013). In addition, during work time prolonged bouts of sedentary time have been found to be higher than during non-work time for some workers (Parry and Straker 2013). Employers have a duty of care to manage risks in the workplace and are therefore looking to understand the risks and controls available for excessive occupational sitting (Straker *et al.* 2014).

There has been an increasing number of studies over the last decade which have investigated how to reduce occupational sitting. Interventions to date have generally focussed on protocols to interrupt sitting, to reduce the length of bouts and/or to use alternate work positions to reduce the total volume of sitting (Healy *et al.* 2012, Neuhaus *et al.* 2014a, Chu *et* *al.* 2016, Shrestha *et al.* 2018). Some interventions which have interrupted sitting at regular intervals have introduced movement or a rest break which, while addressing sedentary behaviour, also impacts ability to work. Typically these interventions have been investigated in laboratory studies with protocols such as interrupting sitting every 30 minutes with bouts of walking (three minutes) (Wennberg *et al.* 2016) or breaks away from a workstation (Sheahan *et al.* 2016). Use of such protocols are likely to face feasibility concerns due to a potential negative impact on productivity (De Cocker *et al.* 2015b) and thus have had limited field based research undertaken. Interventions involving alternate work positions have demonstrated the capacity to reduce the volume of sitting yet maintain participants' ability to work (Alkhajah *et al.* 2012, Pronk *et al.* 2012). Field studies such as Alkhajah *et al.* (2012) and Pronk *et al.* (2012) have implemented a standing permissive desk, allowing a work position of sitting or standing, among office workers and demonstrated reduction in overall sitting time. While standing permissive desks are the most common type of alternate work position design used to reduce overall volume of sitting, desks which allow walking or cycling while working have also been trialled (Huysmans *et al.* 2015, Torbeyns *et al.* 2017). Of concern though in using these alternate work positions, is whether discomfort will increase, particularly with standing (Callaghan *et al.* 2015). It is also unclear what impact there may be on cognitive functions when using an alternate work position to sitting (Bantoft *et al.* 2016), which is important for productivity in knowledge based workers. It is therefore not yet clear what amount of time in an alternate work position should be recommended (Callaghan *et al.* 2015).

1.3 Research to address prolonged sitting at work

A recent review found no current national legislation, regulations and/or codes of practice specifically addressing sedentary behaviour in the workplace (Coenen *et al.* 2017a). Workplaces, and professionals guiding those workplaces, require good evidence to inform decision making. Interventions which interrupt work, such as breaks or performing non-work based movement, in addition to requiring behaviour change, are expected to have implementation issues given the expected impact on productivity and therefore require further investigation (Cooley and Pedersen 2013, De Cocker *et al.* 2015a, De Cocker *et al.* 2015b). Another approach which may have greater capacity for implementation is finding ways for workers to remain productive while using an alternate work position to sitting (Huysmans *et al.* 2015). There is a limited understanding of how alternative work positions may influence acute musculoskeletal discomfort and long-term musculoskeletal conditions, and avoid introducing new risks to the workplace (Marshall and Gyi 2010, Davis and Kotowski 2015). Further where there is discomfort associated with prolonged use of a work position, the mechanisms responsible are unclear (Coenen *et al.* 2018). While the evidence base is increasing, it is also not yet known how use of an alternate work position may impact cognitive functions (Torbeyns *et al.* 2014, Russell *et al.* 2016). It has been postulated that alternate work positions may influence cognitive functions as a result of dual task demands, increased energy expenditure (Tudor-Locke *et al.* 2014), impact on mental state (Hasegawa *et al.* 2001, Thorp *et al.* 2014) and/or due to discomfort (Drury *et al.* 2008, Ebara *et al.* 2008), however further research is required to understand how these factors may play a role. For office based workers any impact of using an alternative work position on cognitive functions is likely to be important for their employers (Huysmans *et al.* 2015). The cognitive functions include higher order cognitive functions (such as problem solving) as well as lower order cognitive functions (such as sustained attention). Alternative work position interventions need to be tested rigorously (Owen *et al.* 2010) and risks to musculoskeletal discomfort and impact on work performance examined (Ojo *et al.* 2018). Evidence from such investigations will support guidance to industry, making implementation of alternatives to sitting feasible and safe for workers.

1.4 Study aim

The aim of this thesis was to investigate the impact of prolonged sitting and alternate work positions on musculoskeletal discomfort and cognitive functions. Two studies were conducted. In the first study participants undertook two hours of prolonged sitting and two hours of under-desk cycling.

The primary aims of Study 1 were as follows:

- To determine the impact of prolonged just-sitting and under-desk cycling on musculoskeletal discomfort over a two hour period while performing clerical tasks at a standard seated workstation in normal healthy adults.
- To determine the impact of prolonged just-sitting and under-desk cycling on cognitive functions (problem solving and sustained attention) over a two hour period.

The secondary aims of Study 1 were:

- To determine the impact of prolonged just-sitting and under-desk cycling over a two hour period on muscle fatigue, posture, pelvis movement and mental state.
- To explore correlations between discomfort and cognitive functions during prolonged just-sitting.
- To evaluate musculoskeletal and cognitive changes during prolonged just-sitting and under-desk cycling to inform work posture policy, practice and research.

A second study which considered alternate work positions of standing and standing-with-movement, each for two hours, was also undertaken.

The primary aims of Study 2 were as follows:

- To determine the impact of prolonged standing and standing-with-movement on musculoskeletal discomfort over a two hour period while performing clerical tasks at a standard standing workstation in normal healthy adults.
- To determine the impact of prolonged standing and standing-with-movement on cognitive functions (problem solving and sustained attention) over a two hour period.

The secondary aims of Study 2 were:

- To determine the impact of prolonged standing and standing-with-movement over a two hour period on muscle fatigue, posture, pelvis movement, lower limb swelling and mental state.
- To explore correlations between discomfort and cognitive functions during prolonged standing.
- To evaluate musculoskeletal, lower limb swelling and cognitive changes during prolonged standing to inform alternative work posture policy, practice and research.
- To analyse participant perceptions of feasibility of alternatives to prolonged sitting.

1.5 Thesis structure

The structure for this thesis includes this introduction, a literature review (Chapter 2), four chapters describing the two studies (Chapter 3-6), an overall discussion (Chapter 7) and a conclusion (Chapter 8). Chapter 3 considers prolonged sitting and addresses the research objectives for Study 1 for sitting only. Chapter 4 considers a movement alternative, under-desk cycling, and reports findings addressing the objectives for Study 1 concerning both sitting and under-desk cycling. Chapter 5 considers prolonged standing and addresses the research objectives for Study 2 for standing only. Chapter 6 considers a movement alternative during prolonged standing, use of a footrest to alternate raising a leg, and reports findings addressing the research objectives for Study 2 concerning prolonged standing both with and without use of a footrest. Chapters 3 to 6 contain text from papers published/accepted for publication in leading peer-reviewed journals. Chapter 7 is a discussion of the synthesis of the two studies and provides recommendations for future research and workplace practice. Chapter 8 provides a conclusion and is followed by the appendices which include copies of conference abstracts and documentation relating to the studies (copies of forms and key documents). Appendix N includes a sub-study led by an honours student which involved the author.

Chapter 2 Literature Review

2.1 Sedentary behaviour exposure and health outcomes

It is important to distinguish between being sedentary and being inactive. Not meeting recommended levels of moderate-to-vigorous intensity activity is being 'inactive', whereas low intensity energy expenditure in a sitting posture is being sedentary (Tremblay *et al.* 2010). Evidence suggests that the risks associated with sedentary behaviour are partially independent of engagement in moderate-to-vigorous physical activity (Ekelund *et al.* 2016). A recent systematic review found those with high levels of sitting (>8 hours per day) combined with lower levels of moderate-to-vigorous physical activity were at higher all-cause mortality risk than those with less sitting at the same level of moderate-to-vigorous physical activity (Ekelund *et al.* 2016). Moderate-to-vigorous intensity activity is generally a proportionally small component of an individual's waking hours. For instance, Healy *et al.* (2007) found only 4% of waking hours were spent in moderate-to-vigorous level activity in a study of 173 Australian adults. As a result of the minimal proportion of time while awake spent in moderate-to-vigorous level physical activity, the primary variance when studied across populations appears to be the extent to which sedentary time displaces light activity (Dunstan et al. 2012). Where light activity is replaced with sedentary behaviour, the overall proportion made up by sedentary behaviour can increase considerably (Wilmot et al. 2012). Given this, replacing sedentary behaviour with light activity movement is a potentially attractive health strategy.

Excessive sedentary behaviour can have negative consequences due to both the overall amount and the manner in which sedentary time is accumulated. Sedentary behaviour has a dose-response relationship with health outcomes which appears to be non-linear. The non-linear findings suggest that an additional hour of sitting may not have the same consequence at low levels compared to high levels of sedentary behaviour. Further, where an individual undertakes primarily standing or walking activity, some sitting may provide rest and recovery (Straker *et al.* 2016). In contrast, at excessive sitting levels health risks increase considerably (van der Ploeg *et al.* 2012, Wilmot *et al.* 2012). The temporal pattern of exposure to sedentary behaviour may also play a role in influencing health outcomes (Dunstan et al. 2012). Breaks in sitting time have been found to influence blood glucose levels which has implications for type two diabetes risk (Healy et al. 2008). Further, a higher number of interruptions to sedentary time has been beneficially associated with adiposity measures such as body mass index and waist circumference (Owen et al. 2010).

2.2 Metabolic mechanisms which may influence sedentary behaviour health outcomes

Light activity, or interruptions to prolonged sitting, are postulated to impact health through metabolic mechanisms (Tremblay et al. 2010). The mechanisms linking sedentary behaviour to health and other outcomes are not yet well understood (Buckley *et al.* 2015), however there is evidence from human and animal studies to suggest likely mechanisms (Hamilton *et al.* 2008, Lynch 2010, Owen *et al.* 2010, Dunstan *et al.* 2012, Saunders *et al.* 2014). The reduced level of skeletal muscle contractile activity during sedentary behaviour, compared to higher intensity physical activity, is postulated as one of the mechanisms influencing health outcomes (Hamilton *et al.* 2004, Owen *et al.* 2010, Tremblay *et al.* 2010). While muscle contractions act as a mechanical pump to increase circulation of the blood, they also exert a vasodilatory influence which assists blood flow. A subsequent increase to the surface area of the blood vessels improves nutrient delivery for muscle uptake (John et al. 2015). The strongest evidence of health risks of sedentary behaviour to date is linked to type two diabetes (Henson *et al.* 2016). Skeletal muscles have a large role in reducing blood glucose levels (Healy et al. 2008). Sedentary behaviour, with the associated reduction in skeletal muscle contractions, impacts on the ability to reduce glucose levels compared to activity with a higher energy expenditure (Dempsey et al. 2016). Research on rats suggests sedentary behaviour is linked with lower levels of lipoprotein lipase activity and that as a result there is low lipid uptake (Bey and Hamilton 2003). Low levels of lipoprotein lipase have been linked with hypertension, metabolic issues and coronary artery disease (Hamilton et al. 2007). These changes to metabolic activity may provide some explanation for how sedentary behaviour is related to chronic diseases.

2.3 Occupational sitting and health and cognitive functions

2.3.1 Sedentary behaviour and health risk

A substantial body of literature clearly supports a longitudinal relationship between sedentary behaviour and negative health implications including all-cause, cardiovascular-related and other-causes mortality risk (Thorp *et al.* 2011). A meta-analysis undertaken by Chau *et al.* (2013) of studies published from 1989 to 2013 involving data of more than 500,000 adults, estimated there was a 34% higher mortality risk for adults who sat for 10 hours or more per day, in combined occupational and leisure time, even after taking into account physical activity. In addition, a subsequent meta-analysis by Ekelund *et al.* (2016) which reviewed studies up to 2015 covering over 1 million individuals (with follow-up of up to 18 years) found mortality rates were higher for those with low levels of physical activity and high levels of sitting time. Only those with the highest category of physical activity (60-75 minutes of moderate intensity activity per day) did not have an increased risk of early mortality from sitting. This seminal paper highlighted that only those individuals (approximately 25%) who undertake the highest category levels of moderate activity are protected from the ill effects of sedentary behaviour.

2.3.2 Occupational sitting and health risk

While high overall levels of sedentary behaviour have been identified as a health risk for most adults, the evidence relating to *occupational* sitting suggests that the association is less clear. Sedentary occupations have been linked with negative health outcomes since the 1950s. Morris and Crawford (1958) found the more sedentary clerks had higher rates of mortality from cardiac infarction than the postmen who were less sedentary. More recently a systematic review by van Uffelen *et al.* (2010), which examined epidemiological studies from 1980 to 2009, concluded that there was insufficient evidence to support a positive relationship between occupational sitting and health risks of increased body mass index, cancer, cardiovascular disease, diabetes mellitus and mortality. Of the 43 papers that met the inclusion criteria, 22 found evidence for a positive association between occupational sitting and body mass index and diabetes mellitus from a cross-sectional design; and cancer, cardiovascular disease and mortality from case-control design. A lack of adjustment by a number of the studies for levels of physical activity (exercise) and other important confounders (such as smoking, alcohol and energy intake) is however a potential bias. The authors highlighted the need for more research specifically measuring sitting time and how this was accumulated (for instance leisure versus occupation) to assist in determining a dose-response relationship.

There has been limited literature focussing specifically on the relationship between occupational sitting time and negative health outcomes. While early studies did not collect domain specific data for time spent sitting during work, school and home; to allow additional analysis of the relationship between health outcomes and the domain of only work (Katzmarzyk *et al.* 2009), evidence is emerging to address this gap (Saidj *et al.* 2016, Wanner *et al.* 2016). Results are thus inconclusive of whether sitting during work is different to sitting during other domains, including leisure or travel. One epidemiological study has recently examined the relationship between self-reported occupational sitting time and all-cause mortality (van der Ploeg *et al.* 2015). Data was collected over the period of 1990 to 2010 of the Danish working population (n=149,773 person-years). The proportion of workers who sat for at least 75% of their work time, which increased over the data collection period, was found not to have a statistically significant association with all-cause mortality. The increase in occupational sitting occurred in the cohort of workers categorised as high socioeconomic status. Although the study does not provide clarification, this may reflect an increase in workers employed in white collar occupations. Arguably, individuals of higher socioeconomic status may have healthier habits including diet, smoking and alcohol which would influence mortality findings (van der Ploeg *et al.* 2015).

A recent analysis of the literature in a report developed to provide guidance to industry, concluded there was mixed evidence for an association between occupational sitting and cardiovascular risk, obesity and cancer (Straker *et al.* 2016). Recent studies also suggest the relationship of health outcomes and occupational sedentary behaviour may be complex. Stamatakis *et al.* (2013) in a smaller sample than those above (5380 women and 5788 men in England and Scotland with follow-up over 12.9 years) found an increased risk in all-cause and cancer mortality for women in sitting occupations, but not for men. Further there was no association between cardiovascular mortality, in men or women, and sitting occupations. In this study, workers were classified into a main occupational activity group of standing, walking or sitting during work-time based on their self-reported activities. A considerable limitation of the study was the activity classification approach rather than a specific dose-response approach. In an epidemiological study of Japanese workers (n=99 447), Kikuchi *et al.* (2015) found there was evidence of a significant association between occupational sitting duration and mortality for some occupational groups. For those employed in a secondary or tertiary industry (defined as salaried workers, home business, professional and other), there was no association between occupational sitting and mortality. For those employed in primary industry (agriculture, forestry and fishing), longer sitting was associated with higher mortality. Measurement of sitting time was by self-report and the authors acknowledge it may have been under reported based on additional unpublished data of 102 workers in secondary or tertiary industry. These findings remained substantially unchanged when adjusted for confounders.

2.3.3 Occupational sitting and musculoskeletal symptoms

In addition to the effects of excessive sedentary time on cardiometabolic and cancer health, workers may also face a risk to the musculoskeletal system due to insufficient physical stress (Straker and Mathiassen 2009). The low physical demand of sedentary behaviour may have detrimental effects on muscle strength and endurance (Straker and Mathiassen 2009). Tissues are not being challenged and thus tissue-stress-tolerances are postulated to reduce, resulting in more susceptibility to symptoms and pathology (Le and Marras 2016). From a musculoskeletal perspective the evidence linking occupational sitting and discomfort is inconclusive with a lack of focus on acute musculoskeletal impact in research to date (Marshall and Gyi 2010, Straker *et al.* 2016). Studies have however found discomfort for some individuals in the low back, lower limb and upper limb with prolonged sitting (da Costa and

Vieira 2010, Sondergaard *et al.* 2010, Madeleine 2012, Sheahan *et al.* 2016, Agarwal *et al.* 2018).

Studies examining potential associations between occupational sitting and musculoskeletal implications have included constructs of discomfort and pain in addition to diagnosed conditions. Discomfort has been defined as a state of the human body which is unpleasant and which occurs in reaction to the physical environment (Vink and Hallbeck 2012). While discomfort is a subjective measure, it has been linked with objective measures such as pressure distribution (de Looze *et al.* 2003). It is debatable whether all individuals see discomfort and pain as one construct (two ends of one continuum with no discomfort at one end and maximum pain at the other) or discomfort and pain as separate constructs which may overlap. Authors such as Karakolis and Callaghan (2014) have suggested discomfort may be a predictor of future pain, suggesting discomfort to have a lower threshold than pain. Those studies which have used the terminology 'discomfort' with participants are therefore expected to have captured a lower threshold of symptoms than those who have used the construct of 'pain'. The majority of studies outlined throughout this thesis have not provided definitions of what constitutes discomfort compared to pain and rather this was left to participants' interpretation. This may account for some differences in study results. In some, but not all, epidemiological studies where symptoms are reported, a clinical assessment has occurred to identify whether there was a diagnosable condition. Participants in well-designed studies have kept a diary of symptoms along with work positions and tasks to allow dose-response consideration. Unfortunately, this is not the case for all studies and thus gaps remain in the literature.

2.3.4 Occupational sitting and cognitive functions

From a cognitive functions perspective, limited research has investigated the potential impact of occupational sitting both from an acute and chronic perspective. A considerably greater number of studies have explored the relationship between cognitive functions and sedentary behaviour (across various domains including leisure) particularly with samples of older adults. As a result there are limitations on the ability to apply findings from the current research base to working-age adults. Hamer and Stamatakis (2014) conducted a cohort study with a two year follow-up period of community dwelling older adults (n=6359). The study categorised individuals by most recent occupation (noting some were retired) and explored cognitive function and self-reported sedentary behaviours of television time, reading and use of the internet. Measurement of sedentary time was only objectively measured for selected domains (for instance travel or socialising) however occupational sedentariness was not one of the domains identified. Those from manual occupations reported higher television time than those from professional/managerial occupations. Television viewing time had a linear inverse relationship with global cognitive score, meaning increased television time resulted in reduced cognitive function, while internet use had a positive relationship with cognitive function. This is suggestive that the type of activity being undertaken while sitting may play a role in long-term effects on cognitive functions. A limitation of this study was that although the impact of sedentary behaviour by occupational category was conducted, the number of individuals who were still working versus retired was not described and nor were the accumulation of the computer time (during work or free time) or the cognitive demand of the computer based tasks (potentially higher during work than leisure). This level of data would have provided richness to the analysis of long-term effects to cognitive functions and allow greater applicability in an occupational context.

A further study by Puig-Ribera *et al.* (2015) investigated work productivity and sitting time (total and domain specific) of Spanish university employees (n=557, with mean age 42 years). The self-report questionnaire identified time spent sitting both at work and travelling. The authors found those who undertook higher levels of physical activity tended to sit less at work and had better self-reported work performance and mental well-being (based on the Warwick-Edinburg Mental Wellbeing Scale). Further, as levels of physical activity increased, the amount of productivity loss reduced. While the aforementioned study found an association with amount of time sitting-at-work, physical activity and work productivity levels for some cohorts, for others (such as the inactive cohort) higher sitting time was not found to be linked to work productivity. While this study measured a broader construct of work productivity rather than cognitive functions, the evidence is suggestive of a relationship between reduced sitting time and improved cognitive function for some cohorts. These results should be regarded with caution given the self-reported nature of sitting time and lack of adjustment for other variables (such as frequency of interruptions to sitting) which may play a role.

Thus, from the limited studies able to be located, occupational sitting may negatively affect health or cognitive functions outcomes. Seated work can however contribute considerably to overall sedentary time for some occupations, including office work. Workplaces which do not offer alternatives to prolonged sitting therefore need to consider whether they are providing a safe system of work (Straker *et al.* 2014). Alternatives to prolonged sitting in an office environment which have been trialled include working in a different position both with and without movement options. These alternatives include standing permissive desks to alternate between sitting and standing, and movement oriented options such as a walking or cycling workstation. Opportunities for dynamic sitting such as use of a stability ball or dynamic chairs have also been considered. Where alternative work positions are provided, there is a need to consider musculoskeletal issues including discomfort and the impact on cognitive functions, such that work productivity is not adversely impacted. The remainder of Section 2.3 and Section 2.4 reviews the literature on musculoskeletal and cognitive functions outcomes and the potential mechanisms linking occupational sitting and these outcomes.

2.3.5 Occupational sitting and low back discomfort

The link between occupational sitting and low back discomfort is unclear, with epidemiological evidence not conclusive. Many studies in this area have not measured duration or volume of occupational sitting, and discomfort or pain which would enable a dose-response analysis. Further, for those studies which have collected data on overall time spent sitting, it is not always described whether this was constrained sitting or allowed for intermittent changes in work position.

In a systematic review, Hartvigsen *et al.* (2000) found only one of 35 studies published between 1985 and 1997 supported an association between occupational sitting and low back pain. Dose-response relationships were only reported in three of those studies, and separation of occupational exposure from sitting during leisure time (for instance watching television or use of a computer) was not viable. The single study which found an association did not have a strong design (Lee and Chiou 1994). The variable used was self-reported understanding of low back care health as it related to various postures. For sitting, this understanding of low back care health (and self-reported postural habits) was then analysed to allow identification of those with 'poor' sitting habits and the correlation with back pain. There was no independent verification of whether individuals had poor posture and the extent of sitting time at work. Further, clarification of time spent undertaking other more strenuous tasks, including patient manual handling, was not available. While this study found an association between sitting and back pain, the conclusion was based on low quality evidence.

Lis *et al.* (2007) conducted a systematic review, of studies published between 1990 and 2004 which examined sitting exposure, of occupational groups who sat for more than half of their working time. The authors concluded that occupational sitting when independent of other risks, such as whole body vibration and/or awkward postures, was not associated with the risk of developing low back pain. It was not identified however whether the occupational sitting reported in the studies was constrained to the extent it minimised changes in posture. Tissot *et al.* (2009) in a subsequent study also found no evidence that sitting was a risk factor for chronic low back pain based on data from the Quebec Health and Social Survey 1998 (with a population of over 3000 sitting workers). Again, a limitation of the research was the inability to determine the amount of movement undertaken by the sample when sitting, however it was suggested that few of the workers sat in a fixed position (without the option of movement).

Finally, in a summary of eight systematic reviews by Kwon *et al.* (2011), of 23 high quality epidemiological studies, found there was insufficient evidence of causality to suggest occupational sitting was causative of low back pain. It was acknowledged that the studies available had limitations which impacted the ability to form conclusions regarding causality. Limitations included lacking an experimental aspect and temporality which did not allow a dose-response causal relationship inference. Kwon *et al.* (2011) acknowledged that while there was insufficient evidence for causality, this did not rule out a potential association. Kwon *et al.* (2011) suggested there may not be a distinct pain generator for the low back and rather a number of factors may contribute. A further systematic review by Janwantanakul *et al.* (2012) explored broader risk factors for onset of nonspecific long-term low back pain for office workers, over three cohort studies. Even when considering individual, work-related physical and work-related psychosocial factors, there was only limited evidence to predict onset of low back pain. Posture was not a clear risk factor. The findings of Janwantanakul et al's (2012) review were limited by the methodological limitations of the respective studies which were included in the systematic review.

Based on the gaps in the available evidence on the amount of sitting and pattern in which this was accumulated, it is perhaps not surprising that causality between occupational sitting and low back pain has not been established (Roffey *et al.* 2010a). Laboratory evidence however suggests prolonged sitting is a short term risk factor for acute onset of low back discomfort (Sondergaard *et al.* 2010, Karakolis *et al.* 2016, Sheahan *et al.* 2016). On this basis further examination of prolonged sitting appears warranted to better understand the factors which may lead to discomfort. Prolonged postures are acknowledged to lead to static loading of soft tissues which in turn is postulated to cause discomfort (Pope *et al.* 2002). This, together with a number of changes associated with the seated posture including low back angle and extensor musculature contractions have also been postulated as potential mechanisms (McGill 1997). These potential mechanisms are discussed in more detail in the subsequent Sections.

2.3.5.1 Low back angle as a potential mechanism for low back discomfort

Prolonged sitting, and the resultant biomechanical changes, have potential to impact the structures of the lumbar spine (Howarth *et al.* 2013). Understanding the behaviour of the lumbar spine in sitting and how this changes when undertaking periods of prolonged sitting requires further research (Morl and Bradl 2013). In a study of asymptomatic participants (n=50) who undertook only 10 mins of sitting (without a backrest) the spontaneous (unprompted) lumbar posture assumed was flat or kyphotic (Claus *et al.* 2016). Sitting, which results in the pelvis rotating backward and a subsequent reduction in lumbar lordosis can exceed 50% of an individual's active lumbar spine range of motion (Dunk and Callaghan 2005). This reduction in lordosis impacts the relative orientation of adjacent vertebrae and alters the pattern of stress distribution on zygapophyseal joints and intervertebral discs (Adams and Dolan 2005), increasing strain on posterior passive elements of the spine (Harrison *et al.* 1999, O'Sullivan *et al.* 2006). Increased loading of the passive tissues, including ligaments and intervertebral disc, may induce micro-damage and be a factor in low back pain onset (Lord *et al.* 1997, Le and Marras 2016). Compression on intervertebral discs is postulated to induce spinal shrinkage through viscoelastic deformation (Toussaint 1993, Karakolis *et al.* 2016). Slumped posture, i.e. kyphotic lumbar spine, has been found to increase over time which may further alter the passive loading pressure distribution (Le and Marras 2016) and may be problematic if sustained (Claus *et al.* 2016).

Reduced lumbar lordosis has been hypothesised by some authors to result in an increase in load on the muscles compared to a more lordotic posture (Harrison *et al.* 1999). Others suggest there is reduced trunk muscle activity and passive tissues assume responsibility for a greater load with forward flexion of the lumbar spine (slump) (Howarth *et al.* 2013, Morl and Bradl 2013). A third alternative mechanism is that with prolonged sitting, sustained contractions of the trunk muscles will result in muscle fatigue and thus increase passive tissue loading over time (O'Sullivan *et al.* 2006, Le and Marras 2016).

Maintaining lumbar lordosis during sitting has been suggested as having a beneficial effect (De Carvalho et al. 2010), however it is not known what the ideal posture is to prevent tissue damage and manage discomfort (O'Sullivan *et al.* 2012b). A range of 'ideal' sitting postures have been suggested including: a flat lower thoracic and lumbar spine, a lordosis at lower thoracic and lumbar spine and thirdly thoracic kyphosis and lumbar lordosis (Claus *et al.* 2009). A number of authors have advocated for a 'neutral' lumbar spine posture and avoidance of end-range positions, however what constitutes a neutral spine posture remains widely debated (O'Sullivan *et al.* 2006, O'Sullivan *et al.* 2012a, O'Sullivan *et al.* 2012b). Panjabi (1992) defined a neutral position as a posture where the internal stresses of the spinal column and the muscular effort required to maintain that position are minimal. Greater understanding of lumbar posture during prolonged sitting and its relationship with discomfort is required.

Another factor which may influence lumbar posture is tension of muscles around the pelvis such as hamstrings, gluteal, iliopsoas and erector spinae (Bridger 2003). Le and Marras

(2016) suggest the hip-thigh angle and support of the upper limb will also influence the load on the spinal column. Early work by Keegan (1953) suggested neutral position of the lumbar spine occurred at a thigh-trunk angle of 135 degrees, which while based on a study of only 4 subjects, has been frequently cited (Bridger *et al.* 1989, Corlett 1999, Harrison *et al.* 1999). Keegan (1953) radiographed subjects in a range of positions including sitting to consider changes in the lumbar spine (viewed laterally) while also considering muscle tension. A decrease in the hip-thigh angle was postulated to result in reduced lordosis (flattening) and be causative of low back pain.

Whilst in the studies mentioned in the above paragraphs authors have recommended maintaining lumbar lordosis to reduce likelihood of pain, not all studies have supported this. A small study (n=9) where participants were seated for 96 minutes (Sondergaard *et al.* 2010) found discomfort increased over time despite a shift toward more lordosis and increased variability in the lumbar curvature. In explaining these differences it is important to note participants did not have access to a backrest. As a result it is anticipated that without use of a backrest an increase in trunk muscle activity was required compared to when using a backrest (Harrison *et al.* 1999), and the spinal load would thus be higher (Le and Marras 2016). Greater clarity of the interaction between posture and muscle activity including trunk muscle fatigue is thus also important to understand as this may have contributed to discomfort. Overall, the evidence currently suggests that mechanics for low back pain are complex and the relationship between lumbar posture and discomfort is multifaceted. Further, other evidence suggests that low back angle may be less important than the small movements undertaken to avoid sustained positions (Madeleine 2012) thus allowing relief of passive tissue loading.

2.3.5.2 Trunk movement as a potential mechanism for low back discomfort

When experiencing discomfort, a strategy which may be used to alleviate or prevent discomfort is to move while sitting. Laboratory studies of prolonged sitting have found both the amount and type of movement can change over time. The amount of movement has a tendency to increase with time (Fenety et al. 2000) while the type of movement has a tendency towards larger postural shifts (Vergara and Page 2002a). In a study of sitting over 90 minutes participants moved (fidgeted) on average every 40-50 seconds (Dunk and Callaghan 2010). However, those who were pre-identified with low back pain had a significant increase in the frequency of shifts (step-like lumbar angular change) compared to those without low back pain. Further, for shifts and fidgets (small rapid changes in lumbar angle) the movements were of a larger magnitude in the low back pain group (Dunk and Callaghan 2010).

A study by Madeleine (2012) found the magnitude of movement (centre of pressure and lumbar curvature) did not change after a period of prolonged sitting, however the amount and temporal pattern of the movement (regularity of movement) did. The amount of movement increased while the regularity of movement decreased. In this study, participants (n=9) had data collected for five minutes, before and again after 96 minutes of sitting. There was no categorisation of participants into those who went on to develop pain and those who did not. Participants did not have access to a backrest and sat on a force platform without cushioning. While the study has limited generalisability to office workers given the seating equipment, the findings do provide insight about movement changes. It is postulated the more frequent variation in lumbar curvature, together with pelvis movement, may provide pressure relief to the ischial tuberosities and other passive tissues including ligaments (Madeleine 2012).

Individuals have been reported to adopt varying strategies when undertaking prolonged sitting. Callaghan and McGill (2001) found some individuals will adopt more static positions over longer duration while others will use many different postures over shorter durations. Interestingly, those who undertook more static sitting used less than 10% of total lumbar flexion range of motion while those who used a number of positions tended to also use a greater degree of range of motion (up to 50%) (Callaghan and McGill 2001). Therefore, not only was the position less static but also a greater range of postures were assumed. Unfortunately the study by Callaghan and McGill (2001) did not have measures of discomfort. Liao and Drury (2000) in a study of six college students found the rate of postural shift gave a good indication of discomfort. While their results showed discomfort and postural shifts were highly correlated, this was apparent for the neck, shoulders, right upper arm, buttock and thighs but not the back.

The relationship between movement and discomfort appears to be complex and the evidence is not yet conclusive on how movement influences low back discomfort. Movement has been hypothesised to nourish structures (such as the intervertebral disc), provide periodic rest to muscles and relief to passive tissues by alleviating static loading (Callaghan and McGill 2001). Movement does not however appear to be a stand-alone approach to manage discomfort. O'Sullivan et al. (2012a) in a systematic review, found dynamic sitting with spinal micro-movement did not provide effective discomfort or pain relief. Other variables mentioned earlier, such as lumbar posture and influence on muscle fatigue, may also play a role. Investigation of these variables simultaneously may help to better understand mechanisms underlying low back discomfort during prolonged sitting.

2.3.5.3 Trunk muscle fatigue as a potential mechanism for low back discomfort

Another factor which has been postulated to contribute to low back discomfort is muscle fatigue although currently the evidence is inconsistent (de Looze *et al.* 2003). An indicator of muscle fatigue is the increase in electromyography (EMG) amplitude and/or a decrease in signal frequency (Hostens and Ramon 2005, Luttmann *et al.* 2010). Changes in amplitude and/or frequency, indicative of muscular fatigue, are likely to vary with a number of factors including: the specific muscle (likely related to characteristics of that muscle including fibre type) (Mathur *et al.* 2005), the position in range of motion (Mathiassen *et al.* 1995), and the nature of the contraction (dynamic or isometric (Cifrek *et al.* 2009)). Some authors have also suggested that field based studies examining muscle fatigue need to take into account any change in muscle force production in addition to EMG amplitude and frequency (Luttmann *et al.* 2010), which can be challenging in non-standardised conditions.

Muscle fatigue can result from high force contractions or low load sustained contractions (Blangsted *et al.* 2005). The linkage between discomfort and muscle fatigue resulting from low load sustained contractions has been postulated to be due to interference with muscle blood circulation (de Looze *et al.* 2003). In the trunk, sustained activity as low as 2% of maximum voluntary contraction has previously shown fatigue related changes via EMG measurement (van Dieën *et al.* 2009).

Findings from laboratory studies of the effect of prolonged sitting on trunk muscle fatigue are mixed. Sheahan *et al.* (2016) found no effect on trunk muscle fatigue (by means of amplitude of rectus abdominus and erector spinae muscle activity) based on EMG amplitude during four sessions of one hour periods of sitting with variations in rest breaks. Kingma and van Dieen (2009) had 10 participants sit on a stability ball and an office chair and compared muscle activation over one hour for each condition. There was no effect of time on erector spinae EMG activity. Interestingly participants verbally advised the researchers that after 1 hour on the stability ball their low back 'felt fatigued'. The levels of muscle activation were assessed as 1.8 to 3% of maximum voluntary contraction. In contrast, other laboratory evidence suggests that low level muscle activation levels (2% of maximum voluntary contraction) can result in trunk muscle fatigue after as little as 30 minutes (van Dieën *et al.* 2009). It is therefore arguable whether participants were actually describing muscle fatigue or more generalised 'discomfort'. A limitation of the cited studies is that it was not established whether the lumbar posture naturally assumed by participants (lordosis, flat or kyphotic) impacted the level of muscle activation (Morl and Bradl 2013) and thus fatigue.

It is acknowledged that low back posture and the subsequent load on muscles, in addition to the task being performed, can influence EMG results (Balasubramanian *et al.* 2009, Cifrek *et al.* 2009, Antle and Côté 2013). From an acute perspective, Makhsous *et al.* (2009) undertook a study to monitor paraspinal muscle activity with a seat design which increased anterior pelvic tilt and provided enhanced lumbar support. The result of this seat design was a reduction in acute paraspinal muscle activity. This design could be postulated to reduce likelihood of muscle fatigue. Other evidence suggests a kyphotic posture to have very low or no activity of lumbar muscles (Morl and Bradl 2013). Should low muscle activation be shown to occur, a potential consequence of long-term sitting could be deconditioning due to habitually reduced muscle activation, with additional load on passive tissues (Morl and Bradl 2013). Further investigation of muscle activity, and fatigue, during prolonged sitting and association with discomfort is required.

Gap: Prolonged sitting has been linked to acute low back discomfort, however there is a lack of clarity of the mechanisms responsible. Exploration of potential mechanisms could include low back angle changes over time, movement and whether fatigue is a factor.

2.3.6 Occupational sitting and lower limb discomfort

There is a lack of strong epidemiological evidence to understand the potential impact of occupational sitting on lower limb discomfort. In a systematic review of six longitudinal studies, da Costa and Vieira (2010) found the risk factors for work related lower limb (non-specified, hip and knee) musculoskeletal disorders included frequent stair climbing and heavy physical work, but not prolonged sitting. In examining the studies which were included in the systematic review it is evident that there was a bias toward long-term conditions rather than acute discomfort. Further, in some of the studies, occupational sitting exposure was either not one of the risks evaluated, or was categorised in a way that application to some occupational groups would be inappropriate. For instance, with categories for sitting of nil, <15 mins or >15 mins per day the sensitivity of findings for occupational groups such as office workers is debatable. Recall bias was also a considerable issue across some studies with participants of up to 93 years old advising of previous occupational history and exposure. Thus, the lack of dose-response clarity and non-acute focus provides limited understanding of how prolonged sitting may impact acute discomfort.

A cohort study of industrial and service workers (n=5,604) by Andersen *et al.* (2007) also found no association between occupational sitting (for more than 30 mins per hour) and lower limb severe musculoskeletal pain. Of note in that study, was the measurement of severe pain rather than discomfort, which would be expected to have a considerably lower threshold. More recently a study of office workers found occupational sitting resulted in a reduction of lower extremity musculoskeletal symptoms over a work day (Coenen *et al.* 2018). The authors found a 28% lower prevalence of lower limb symptoms, per hour spent sitting. In that study, 69% of the sample reported presence of symptoms in the three months prior to the study. Whilst the nature and resolution (or not) of the symptoms by the start of the study is not described, if on-feet activities resulted in increased symptoms, having the ability to sit would explain this finding. Underlying chronic conditions can also lead to a bias of workers who self-select office based work due to inability to perform more physically demanding work. Greater understanding of confounders, such as underlying conditions, appears important in clarifying the impact of occupational sitting on lower limb discomfort.

In contrast, other evidence suggests there may be an association between occupational sitting and lower limb discomfort. A review paper by Reid *et al.* (2010), examining 'chair sitting', acknowledged there was a lack of research in this area but suggested discomfort due to sitting was evident in the hip, knee, lower leg and foot in occupational settings. This is supported by recent field-based research of a sample with high workplace sitting (77% of time) which found participants (n=44) reported musculoskeletal discomfort for hips/thighs/buttocks, knees and ankles/feet (Neuhaus *et al.* 2014b). The study assessed use of a standing permissive workstation compared to a sitting work position. In the group who only sat, there was an increase in the number of participants who reported an increase in hips/thighs/buttocks and knees discomfort (initially three participants and then six at follow-up after three months). It is not evident why a greater number of participants reported discomfort with the sitting only work position, than the standing permissive work position, during the three month measurement period, however the results do suggest sitting is not without discomfort. Finally, Sondergaard *et al.* (2010) undertook a laboratory study over 96 minutes and also found lower limb discomfort with sitting. The study protocol required participants to keep legs and feet still for blocks of five minutes after which there was a 'break' for 20 seconds and participants could move their legs and feet freely. While the protocol may have helped to reduce the impact of potential confounders, the study may not be representative of the real world where sporadic and unconscious movements are expected to occur and may influence discomfort. Therefore, whilst inconclusive it does appear that discomfort is an issue for some individuals with prolonged sitting, particularly where the legs and feet are inactive.

2.3.6.1 Tissue pressure as a potential mechanisms for lower limb discomfort

The aetiology of lower limb discomfort with sitting has been suggested to be multifactorial and include physical factors and but also psychosocial factors (Janwantanakul *et al.* 2009). From a physical perspective the evidence supports lower limb discomfort arising from two main factors. Firstly, pressure on buttock and thigh areas with passive loading of tissues and secondly, venous pooling resulting in lower limb swelling (de Looze *et al.* 2003, Makhsous *et al.* 2009, Reid *et al.* 2010).

Pressure on the buttock and thigh tissues when sitting may be influenced by a number of factors. The impact of seat design on buttock and thigh pressure is expected to differ between individuals based on their stature and body shape and suitability to the equipment made available. Equipment factors include the seat pan size and contours and the subsequent effect on distribution of body weight (Harrison *et al.* 1999). Other seat design factors such as lumbar support may also influence sitting posture resulting in more or less loading on the ischial tuberosities (Makhsous *et al.* 2009). Laboratory studies have previously used seating designs which limited generalisability. For example participants have sat for prolonged periods on force platforms without cushioning (Sondergaard *et al.* 2010, Madeleine 2012), which not unexpectedly resulted in buttock pressure and discomfort. Further research which uses more realistic equipment such as office chairs rather than force platforms, and takes into account support for the lower limb (such as via foot rests) to address thigh pressure (Harrison *et al.* 1999, Reid *et al.* 2010) is required. Each of these factors has potential to influence pressure and thus potentially discomfort.

2.3.6.2 Venous pooling as a potential mechanisms for lower limb discomfort

The mechanism for venous pooling when sitting has been researched extensively for prolonged sitting across various domains (including work and travel). The semi upright position of sitting is hypothesised to impact return of venous blood flow (Winkel and Jorgensen 1986b) and result in an increase in interstitial fluid volume. The volume increase is thought to be caused by elevated hydrostatic pressure in the distal vasculature and the lack of muscle pump secondary to little or no leg movement (Winkel and Jorgensen 1986a, Reid *et al.* 2010). Sitting has also been found to negatively affect venous flow velocities at the popliteal and femoral veins (Mittermayr *et al.* 2007). Studies of prolonged sitting have found swelling significantly increases during the first four hours (Winkel and Jorgensen 1986b, Mittermayr *et al.* 2007) reaching a maximum after 10 hours (Mittermayr *et al.* 2007). Swelling has also been found to have a pattern of early (first 45 minutes) exponential increase and then linear increase over time with prolonged sitting (Vena *et al.* 2016). Sitting with little or no leg movement was suggested in the review by Reid *et al.* (2010) to be associated with venous pooling (swelling) in the lower legs and feet discomfort. Laboratory research has identified a potential link of discomfort with lower limb swelling (Winkel and Jorgensen 1986a, Seo *et al.*

1996, Chester *et al.* 2002). Chester *et al.* (2002) found both calf volume and circumference increased when participants (n=18) sat in an office chair for 90 minutes. Calf volume increased by 38cm^2 while circumference increased by 2%. The laboratory-based study restricted natural foot movement and participants were only permitted to undertake minor movement of the lower limb for one minute every 15 minutes. Seo *et al.* (1996) had previously also found leg swelling was evident after one hour of laboratory-based sitting (9.7%) compared to baseline (n=12). The differences in the amount of swelling increase between the studies is postulated to be partially related to the type of chair used. Whilst no photographs are provided in Seo *et al.* (1996), comments made by Chester *et al.* (2002) suggest the width of the chair used by Seo *et al.* (1996) and the lack of padding may have influenced findings. Therefore, lower limb swelling during prolonged sitting, with little or no leg movement, may increase discomfort.

Psychosocial factors have also been raised as a variable which may impact self-reported lower limb musculoskeletal disorders in the context of occupational sitting. Janwantanakul *et al.* (2009) conducted a cross sectional survey of 2,000 Thai office workers and found significant associations between mental demands, work repetitiveness, perception of air circulation and frequency of feeling frustrated with lower limb disorders. Other non-psychosocial factors were also explored and were found to have significant associations. These included perception of ergonomics of the work area such as desk set up and office space. The mechanism by which psychosocial factors influence lower limb discomfort is not yet clear, however, it may be related to mental stress and subsequent increase in muscle activity and load, or negative impact on perception of pain (Janwantanakul *et al.* 2009).

In summary, the evidence linking lower limb discomfort and occupational sitting and potential mechanisms is not conclusive. However, there is research to support a potential association between discomfort and prolonged sitting across domains (e.g. sitting during non-occupational time such as leisure and travel time). The mechanisms to explain discomfort may also be influenced by individual differences in body composition and psychosocial factors. The amount of incidental movement of the legs and feet when sitting (such as fidgeting) may also play a role. The applicability of some studies to a real world setting is limited due to the constrained laboratory or field-based study protocol selected. This should be taken into account when assessing study findings and giving guidance to industry.

Gap: There is a lack of clarity of the association between prolonged sitting and lower limb discomfort as well as how movement of the trunk and lower limb may influence potential mechanisms including pressure (on buttocks and thighs) and lower limb swelling.

2.3.7 Occupational sitting and upper limb discomfort

For office workers sitting is often coupled with computer based tasks. The majority of identified studies did not focus on potential associations between prolonged sitting and upper limb discomfort and rather have focused on *computer use* and upper limb discomfort. Anderson et al. (2008) however did consider the potential association between occupational sitting and upper limb musculoskeletal pain. The cohort study undertaken in Denmark used self-report questionnaire with follow-up after 24 months. A range of occupations were included from administrative to service oriented occupations (including nursing, cleaners and kitchen assistants). Two categories of sitting were used; sitting for more than 30 minutes per hour and sitting for less than 30 minutes per hour. Occupational sitting was not associated with neck/shoulder pain or elbow/forearm/hand pain, even when sitting for more than 30 minutes per hour. For office workers though, sitting is likely to be considerably greater than 30 minutes per hour. It is not specified in Anderson et al's (2008) study how much time was spent sitting in total and how that sitting was accumulated as this may have effected results. Further, some of the occupations may have had considerable physical demands in positions other than sitting (such as pushing/pulling while standing) and this may have been a confounder.

In reviewing the broader literature of upper limb discomfort and computer use, evidence of a potential association is mixed. A complication in comparing studies is that some have used a measure of self-reported discomfort or pain while others have used disorder or diagnoses. The differing levels of symptoms and acute through to chronic presentation of such symptoms needs to be taken into account in interpreting and comparing results. A systematic review by Wærsted *et al.* (2010) which explored computer work and musculoskeletal disorders concluded there was limited epidemiological evidence of a moderate or strong association between computer work and the clinical diagnoses considered. These included tension-neck syndrome, shoulder tendonitis, epicondylitis and wrist tendonitis (Wærsted *et al.* 2010). Studies explored by Wærsted *et al.* (2010) date back to 1981. Studies undertaken in the previous century studied workplaces with equipment to that used currently, while the tasks performed would have also varied across the decades. For instance, a study from 1995 which assessed computer use acknowledged that a mouse was not used. This would be uncommon in more recent workplaces where use of both a mouse and keyboard would be more typical. Further, in comparing results across studies there may also be differences in workstation characteristics internationally, for example in the level of adherence to accepted physical workstation setup principles.

In a systematic review of 63 studies da Costa and Vieira (2010) also examined computer work-related musculoskeletal disorders although with contrasting findings. The review was of more contemporary studies from 1998 to 2007. The review found there was reasonable evidence that prolonged computer work was a risk for wrist/hand disorders, however there was a lack of conclusive evidence linking computer work for shoulder and elbow disorders. The use of disorders as a variable by da Costa and Vieira (2010) may have been affected by diagnostic criteria used in the studies examined within the review and led to the different conclusion for wrist disorders risk compared to Wærsted *et al.* (2010) conclusion. One of the field-based studies included in da Costa and Vieira's (2010) systematic review, by Gerr et al. (2002), found more than 50% of computer users (n=632) had upper limb musculoskeletal symptoms in the first year after starting a new job. The study by Gerr et al. (2002) was of high quality with follow-up for three years and data which included a daily diary completed by users regarding the amount of computer use and symptoms. Any reports of symptoms were followed up with assessment rather than relying only on self-report. Similarly, a systematic review by Ijmker et al. (2007) of nine articles also found moderate evidence for a positive association between the duration of mouse-use and hand-arm symptoms. All studies reviewed by Ijmker *et al.* (2007) used self-report measures for duration of computer use and associations were explored between total computer use, mouse use and keyboard use but not sitting time. A factor which may have affected these results was the inconsistent criteria used to diagnose the musculoskeletal disorders across the studies. Developing agreed criteria for classification of upper limb disorders is important to be able better comparison of results and potentially aggregate data for meta-analysis in the future.

Roelofs and Straker (2002) conducted a field study which compared work positions of just-sit, just-stand and sit-stand for bank tellers. Greatest discomfort was found in the upper limbs during just-sit work position. It was hypothesised that the constrained sitting impacted discomfort as a result of task demands. When sitting, there was greater periods where the tellers' arms were unsupported and shoulders abducted. This finding was supported in a laboratory study by Kar and Hedge (2016) with higher discomfort rating in the upper body in sitting than standing. In this study, the upper body variable was made up of head and neck, shoulder and arm, lower back, elbow and forearm, wrist and hands. As a result the extent the upper limb contributed to this outcome is not known. A further study by Sondergaard *et al.* (2010) (n=9) found discomfort increased over time in the shoulders and neck where participants sat (without a backrest or armrests) over 96 minutes. Again, there were limitations in interpreting the impact of prolonged sitting on the upper limb as the body areas of elbows, wrists and hands were not measured.

2.3.7.1 Posture and muscle fatigue as potential mechanisms for upper limb discomfort with prolonged sitting

The mechanisms which have been postulated to explain the increased discomfort in the upper limb have included work position related issues and muscle fatigue. Constrained and static postures have been proposed as a risk for discomfort which further increase if the work posture is awkward (Marshall and Gyi 2010). To combat this, neutral joint positions have been promoted to manage musculoskeletal related discomfort and pathology. However even these positions, if assumed for long periods, may not be effective in reducing discomfort (Davis and Kotowski 2014). Wahlstrom (2005) proposed prolonged low static muscle effort when using a keyboard and mouse to be a factor which may lead to discomfort. Other postulated risk factors for neck and upper limb discomfort include the repetitive movements required when using computer equipment, lack of upper limb support (with lack of armrests or ability to rest on desk surface), periods of sustained work with limited rest/break opportunities or requirement for high levels of precision (Wærsted *et al.* 2010). Psychosocial issues have also been raised as a factor which may contribute to self-report of upper limb musculoskeletal symptoms (Wærsted *et al.* 2010). Perception of job demand, decision latitude, time and workload pressure and associated stress have been considered risk factors (Wærsted *et al.* 2010).

The relationship between prolonged sitting and upper limb discomfort particularly in the occupational context is complicated by the use of the upper limb for work tasks. In other words, the tasks of the occupation are a confounder which is difficult to separate from the overall work position of sitting. In many studies the association between upper limb discomfort and computer use rather than between upper limb discomfort and prolonged sitting has been examined. In non-occupational contexts such as laboratory studies there appears to be some evidence supporting an increase in acute discomfort in the upper limb with sitting time. The mechanisms are also unclear with a number of potentially contributing factors. Further investigation is required to understand the risk for workers and provide guidance to prevent discomfort.

Gap: The impact of prolonged sitting on upper limb discomfort is inconclusive. The impact of movement (fidgets) and the presence or not of muscle fatigue require further investigation.

2.4 Sedentary behaviour and cognitive functions

As outlined in Section 2.3.4 there is limited research on occupational sitting and the potential association with cognitive function. The potential impact of sedentary behaviour on cognitive functions also has had limited research within the healthy adult population. The evidence available, which has primarily focussed on long-term effects, suggests there may be a negative association between long-term sedentary behaviour and cognitive functions, however a causal link remains unproven (Voss *et al.* 2014, Falck *et al.* 2017). Studies which have investigated the acute effects of prolonged sitting on cognitive functions are limited and inconclusive.

Evidence on the effect of sedentary behaviour on cognitive functions over the longer term, and whether reducing sedentary behaviour, or increasing physical activity is important (Falck *et al.* 2017), is still emerging. A systematic review of eight epidemiological studies (three cohort design with up to 21 years follow-up periods, two case control and three cross sectional studies) by Falck *et al.* (2017) found increased sedentary behaviour was associated with lower cognitive performance. The studies used a range of measures of sedentary behaviour and included sitting, lying, sleeping and time spent watching television, however occupational exposure was not captured. It is unclear how time spent watching television may influence cognitive functions differently to time sitting at work. Further, the measures of cognitive functions varied, with the studies using 13 different measures of cognitive functions and few measuring similar domains of cognitive functions to allow comparison. Based on this review it was inconclusive whether sedentary behaviour may be linked to specific cognitive functions, or more globally to cognitive functions overall. A subsequent cross-sectional study of over half a million United Kingdom participants (Bakrania *et al.* 2017) found negative associations between only some sedentary behaviour and cognitive functions. Television and driving were inversely related to cognitive functions while computer use had a positive association with cognitive functions. Despite identifying time spent using a computer, no analysis of correlation with occupational sitting (57% were in paid employment) was undertaken. A limitation of this study was the self-report of sedentary behaviour levels and the lack of reporting on the type of computer use (passive such as watching video content, or more cognitively active as would be expected through work). Further only 9% of participants reported computer use of three or more hours per day. This amount of computer use would be considerably lower than an average day's use for an office worker.

The majority of studies on acute effects of prolonged sitting on cognitive functions have been laboratory studies undertaken over relatively short durations. With some studies undertaken for only up to one hour (Schraefel *et al.* 2012, Russell *et al.* 2016), conclusions for any acute effect of prolonged sitting on cognitive functions should be made with caution. Other studies have compared sitting to another work position, with assessments between conditions only made at the end of a trial period without also comparing to baseline measures (Bergouignan et al. 2016). For example Thorp *et al.* (2014) compared just-sitting to sit-stand over five days in a simulated office setting but did not undertake baseline measures. Results showed concentration was higher for just-sitting however there was a trend towards better subjective work productivity in sit-stand. Baseline measures in this instance would have been valuable to reduce confounders such as participants adjusting to working in a standing position. In addition, understanding whether the transitions in work position (for example from sitting to standing) impacted concentration both at the time of transition and for overall work performance would also be beneficial for workplace implementation.

In a longer field based study over 14 days, the association between college students' daily activity behaviour (measured with accelerometers) and perceived cognitive abilities was assessed (Fitzsimmons *et al.* 2014). While the authors concluded sedentary behaviour was negatively associated with perceived cognitive abilities, it was not identified whether it was the nature rather than quantity of sedentary behaviour which influenced results. Consideration of other study designs of longer duration, with baseline measures while controlling sedentary behaviour characteristics (volume, breaks) may help to provide greater clarity. It is acknowledged however that studies of longer duration particularly in workplace settings are challenging to undertake and thus use of well-designed laboratory studies to assist in addressing gaps in knowledge remains important.

2.4.1.1 Sedentary behaviour and mental state

The ability to process information, measured through the various cognitive functions, can be impacted by activation levels of the cerebral cortex (Oken *et al.* 2006). Terms which are commonly used to describe the activation levels include arousal, alertness, vigilance and attention (Oken *et al.* 2006). The terms are however somewhat broad and may be perceived to have overlap depending on the context of use. As a result 'mental state' will be used to cover cortical activation levels more globally throughout this thesis.

It has been postulated that non-sitting work positions have the potential to increase arousal as a result of changes in the autonomic nervous system in particular the sympathetic nervous system (Knight and Baer 2014). A laboratory study by Ebara *et al.* (2008) which measured heart rate variability as an index of sympathetic nerve activity, found alternating between sitting and standing resulted in arousal levels remaining steadily high compared to uninterrupted sitting. The results of a more recent laboratory study by Wennberg *et al.* (2016)

was aligned with this finding. Uninterrupted sitting resulted in an increase in perceived fatigue (which included measures of alertness and energy levels) while for light activity there was a trend for improved cognitive performance. A further laboratory study of interventions which found improved performance for conditions which interrupted sitting, also postulated their findings may have been linked to changes in levels of arousal (Mullane *et al.* 2017).

Task monotony has been found to result in reduction of sustained attention which can be common in occupations such as pilots, air traffic controllers, radar operators and security screeners where there are periods of little mental activity for the worker (Thomson *et al.* 2015). The mindlessness hypothesis suggests tasks which are monotonous and under stimulating result in a withdrawal of attention (Thomson *et al.* 2015). It has been argued that the lack of postural change with prolonged sitting (thus monotony of posture rather than task) may contribute to a reduction in arousal while interrupting sitting may increase arousal (Russell *et al.* 2016).

2.4.1.2 Habitual physical activity level and brain function

Higher levels of habitual physical activity have been associated with increased brain volume (Voss *et al.* 2014). Impact on grey and white matter density and integrity has been found with radiological investigations supporting this conclusion (Voss *et al.* 2014). The short and long term effect of exercise on the central nervous system is suggested to be mediated by multiple mechanisms including: acute increases in event related potential and changes in cortical activation (Loprinzi et al. 2013), and ability to influence brain plasticity over the longer term through neurogenerative, neuroadaptive and neuroprotective processes (Dishman et al. 2006).

Studies of more physically fit (and thus potentially more physically active) older adults have shown greater brain connectivity, white matter integrity and more efficient brain activity and better executive functions (Erickson et al. 2015). Studies of rats and mice with higher activity levels have found enhanced choline uptake, increased cerebellar capillary density, dopamine receptors, brain derived neurotrophic factor and number of new cells in the hippocampus (Colcombe and Kramer 2003). Wheeler *et al.* (2017) outlines a potential mechanism between sedentary behaviour and brain health may be the deleterious effect of glycaemic variability, which occurs in the absence of activity. Even at rest the brain requires considerable energy (~20% of total body requirements). With both hypoglycaemia and hyperglycaemia, energy supply to the brain can impact on cognition (Wheeler *et al.* 2017). With ongoing variability in glycaemic levels over time it is proposed that a negative feedback loop develops altering physiology and results in accumulating damage to the brain (Wheeler *et al.* 2017). With better understanding of how habitual movement such as light intensity physical activity may provide some protection against cognitive decline, informed recommendations around sedentary behaviour (Dishman et al. 2006) then have potential to impact health outcomes.

2.4.1.3 Acute physical activity level and brain function

As outlined previously in Section 2.1 only a small percentage of waking hours are typically attributed to moderate-to-vigorous activity. For most, it is light activity which is displaced by sedentary behaviour, and thus reducing sedentary behaviour by reinstituting light activity (Dunstan *et al.* 2012, Wheeler *et al.* 2017) is perceived to be a more achievable strategy to increase movement and energy expenditure (Tremblay *et al.* 2010). From an acute standpoint a large body of evidence has considered the impact of exercise, often moderate-to-vigorous, on brain function. Research to date though has not been able to clarify if the pathways which influence brain and cognitive health for sedentary behaviour compared to physical activity are overlapping or parallel pathways (Voss *et al.* 2014).

In recent decades a considerable body of research has investigated the short term impact of higher intensity activity on cognition, primarily by considering moderate-to-vigorous activity or 'exercise'. In a meta-analysis considering the effects of acute exercise on cognitive performance Chang *et al.* (2012) concluded there was a small positive effect, and for particular cognitive outcomes where specific exercise parameters were used larger effects were evident. Colcombe and Kramer (2003) in an earlier meta-analysis concluded the largest area of cognitive functions to benefit from increased activity levels was executive control. This finding was supported by Chang and Etnier (2009) who also concluded that the largest effects of exercise programs were reflected in executive performance, with a smaller but still positive impact on non-executive cognitive processes.

Exercise has previously been postulated to have an inverted U effect on acute cognitive performance (Brisswalter *et al.* 2002). In this model, moderate exercise (below lactate threshold <70% maximal oxygen uptake) has been found to lead to improved cognitive performance while high intensity exercise results in a decrease in cognitive performance (Brisswalter *et al.* 2002). Low levels of activity such as sitting (the low end of the U) are by extension anticipated to have lower cognitive performance than the optimal moderate exercise. With increasing metabolic intensity there is initially a proportionate increase in cerebral blood flow, however, at vigorous levels of activity the blood flow to the cerebrum will be reduced due to muscle blood flow demands (Rooks *et al.* 2010). This relative reduction in blood flow at high intensity activity levels may play a role in the deterioration in cognitive performance.

Further to this, exercise intensity has been associated with changes in arousal of the central nervous system (Brisswalter *et al.* 2002). Identifying the activity level where complex cognitive performance is optimal is difficult. In considering the mechanisms for cognitive functions improvement via central nervous system arousal it has been postulated that the rate of elevation of catecholamines and levels of adrenaline may play a role (Brisswalter *et al.* 2002).

Other authors suggest the exercise intensity is one of many moderators which can influence cognitive functions (Chang et al. 2012). Other moderators include fitness of the person, duration of the exercise and timing of cognitive testing (for example during or after exercise, if after then what amount of time after) (Tomporowski 2003, Chang et al. 2012, Bailey and Locke 2015). It is postulated that these factors will influence heart rate and physiology (e.g. catecholamines and brain derived neurotrophic factor) (Chang et al. 2012). A more recent hypothesis is the reticular activation hypofrontality theory (McMorris and Hale 2012), which suggests that during moderate exercise the reticular system is activated resulting in increased arousal which in turn is anticipated to improve performance of well learned / habitual tasks. In contrast, when undertaking higher intensity activity, poorer cognitive performance is anticipated due to premotor and supplementary motor activation requirements (McMorris and Hale 2012).

While evidence suggests physical activity can positively affect cognitive performance, it remains unclear what type and how much activity is necessary. Work positions that are alternatives to sitting are typically of light intensity activity in most instances (Beers *et al.* 2008, Barone Gibbs *et al.* 2016). However, these alternative work positions will have variance in activity level. When considering alternatives to prolonged sitting, further investigation of the changes in arousal level which may result from increased movement or changes in work position is required. Further, if arousal changes are evident, it is important to understand what impact there may be on cognitive functions.

Gap: The acute effects of prolonged sitting on cognitive functions and mental state are not clear.

2.5 Interventions to address excessive occupational sitting

Given the potential association of excessive occupational sedentary behaviour with health and cognitive performance, a range of interventions to address excessive sedentary behaviour for office workers have been developed. The impact these interventions have had on the amount of time spent sitting in the short and longer term has varied, with sustainability of any interventions also being raised as an important issue (Wilks *et al.* 2006, Chau *et al.* 2010, Straker *et al.* 2013, Neuhaus *et al.* 2014a, Huysmans *et al.* 2015). Interventions which require workers to interrupt their work (Davis and Kotowski 2015) have negatively impacted productivity to varying degrees (Dunstan *et al.* 2012) and may have influenced uptake. Standing to read a document or while on the telephone may be considered to be less of an interruption to work productivity and may therefore have higher uptake. In contrast, other strategies such as adding light activity by increasing the amount of time spent walking within the office, such as going to speak to a colleague rather than emailing may be perceived to result in less efficiency (Straker *et al.* 2016) and result in less adoption. In situations of work pressure, strategies which impact productivity may not sustainable for individuals or industry.

In more recent times a considerable amount of research has focussed on the use of alternative workstations. The perceived benefit of many of these workstations is the ability for workers to continue their work while using an alternative work position to sitting. Selecting an appropriate alternate position is not straightforward, with a number of different options available, each with benefits and limitations. The options also vary in amount of movement and type of movement.

2.5.1 Taxonomy of workstation alternatives

A number of different taxonomies have been used for categorising the types and amount of movement which occur when using sitting work positions and viable alternatives. In sitting, authors have distinguished between smaller and larger movements in an effort to understand how this may be associated with discomfort. Fenety *et al.* (2000) suggested categorising as either small radius movements (which overlap previous movements) considered to represent postural sway or large radius movements which could be considered to be a postural shift (Fenety *et al.* 2000). Alternatively Vergara and Page (2002) described movement while sitting to be either macro-movements for gross changes of posture, or micro-movements for those around an earlier stable posture.

In standing, Duarte and Zatsiorsky (1999) defined three types of movement; fidget (fast movements with a large displacement of centre of pressure which returned to the starting point), shift (fast displacement from one location to another) and drift (slow continuous displacement). Gallagher et al. (2011) expanded on the above definitions to indicate fidget, shift and drift were all unconscious movements. An additional category of conscious movement to shift body weight between right and left leg was added.

Tudor-Locke *et al.* (2014) took a broader approach to categorise the movement available across the various work position alternatives considering both type and amount of movement. Primary alternatives to just-sitting were classified as static or active, reflecting the amount of movement expected. Static included those positions where a standard office chair was replaced with an exercise ball or a desk height was altered to accommodate an alternative to sitting such as intermittent (sit-stand) or continuous standing. In the static category, movement was incidental and sporadic (eg weight shift or postural transitions). In contrast, the active category included altered desk height to accommodate use of a treadmill for walking, or the use of an under desk device to pedal, step or perform elliptical movement. Movement in the active category was described as low intensity rhythmic movement.

Other alternatives not included in the above include promoting movement while standing. Movement when standing has been achieved with the use of varying equipment. This has included use of a footrest (alternate raising a foot) requiring weight shift, and the use of soft mats and shoes (Rys and Konz 1994, Hansen *et al.* 1998, Cham and Redfern 2001, Reid *et al.* 2010, Karimi *et al.* 2016) which facilitate smaller but more frequent movements. See Table 2.1 below:

Table 2.1: Workstation alternatives and categorisation of movement

Workstation alternative	**Design**				
	Movement			**Work position**	
	Incidental/ sporadic	Intentional low intensity rhythmic	Intentional non-rhythmic	Seated	Upright
Sitting on stability ball	√			√	
Treadmill desk		√			√
Sit-stand	√			√	√
Standing desk	√				√
Pedal desk		√		√	
Standing-with-movement (footrest)			√		√
Standing-with-movement (mats/shoes)	√				√

Adapted from Tudor-Locke *et al.* (2014).

For the purposes of this thesis the following 3 categories of movement have been adopted: sporadic, intentional and rhythmic. Sporadic would include unintentional movement such as categorised by Duarte and Zatsiorsky (1999) as fidget, shift and drift. Intentional movement would include intentional weight shift as defined by Gallagher *et al.* (2011) and rhythmic movement would include low intensity near-to continuous movement as described by Tudor-Locke *et al.* (2014).

2.5.2 Barriers to implementation of sitting workstation alternatives

The introduction of alternate work positions for office workers currently faces a number of barriers including: limited evidence of long-term efficacy in reducing sitting time, feasibility issues, limited evidence on impacts on cognitive functions and thus work productivity, and limited evidence of the potential impact of musculoskeletal discomfort on cognitive functions. The varying alternatives outlined in Table 2.1 above each have unique issues for implementation related to these limitations and are outlined in Section 2.5.3 below.

Evidence to guide which alternatives to prolonged sitting should be implemented and how, is important to minimise risks (Huysmans *et al.* 2015). The various alternatives to sitting have considerably different amounts of research to date. Research has predominantly focussed on stand-permissive desks which allow an alternating sit-stand work position, while other alternatives, such as pedal or treadmill desks which allow rhythmic movement, have had comparatively little research. Large gaps remain in scientific understanding of the implications of use of the various alternative work positions and how policy should therefore respond (Tudor-Locke *et al.* 2014).

2.5.2.1 Long-term efficacy issues

Workplace interventions to reduce sitting time have had varying levels of effectiveness (Chau *et al.* 2010, Neuhaus *et al.* 2014a). Multiple factors seem to influence effectiveness of behaviour change. Factors which may contribute include the level of instruction and education provided at implementation and thereafter (Wilks *et al.* 2006, Huysmans *et al.* 2015), intrinsic motivation of participants (Grunseit *et al.* 2013), having a supportive organisational culture (Chau *et al.* 2015b, Pronk 2015), worker preferences or likes/dislikes, discomfort, and impact on work performance (Neuhaus *et al.* 2014a). Interventions to reduce sitting may be less effective when workers are paid based on work productivity and the intervention is perceived to interrupt workflow and therefore income (Straker *et al.* 2013).

Organisations which were early adopters of the use of alternative workstations, such as sit-stand, have found sustainability of changes in workplace sitting time to have been problematic. Straker *et al.* (2013) assessed Swedish call centre operators' sitting and standing time (where sit-stand desks were available) together with the operators' awareness of postural change recommendations. The authors showed a very modest decrease in sitting time (of 19 minutes over a six hour shift) for those with access to a sit-stand desk compared to those who used a sit-only desk. Having awareness of posture recommendations did not appear to be associated with sedentary behaviour. An important aspect of this research is that in this organisation sit-stand workstations were provided for office workers as a standard office work position before recent mainstream acknowledgment of concerns about excessive sedentary behaviour. As a result, the novelty effect of using an alternative work position was not expected to be a confounder. Many studies introducing alternative work positions are of relatively short duration (such as laboratory studies which are usually hours or days in duration, and field studies which are usually weeks or months). Thus, the ability to assess an effect of conditioning and potential influence of novelty will vary. Based on the study by Straker *et al.* (2013) providing sit-stand workstations, even with education for workers on ergonomic recommendations, may only have a modest effect on reducing sedentary time.

Longitudinal studies on the use of alternative work positions are lacking. The majority of study durations are up to 3 months, with less frequent studies up to 9 months and rarely 12 months or longer (Neuhaus *et al.* 2014a). If sitting time at work is to be successfully reduced, deeper understanding is required of feasibility issues in the short term but also importantly over the longer term. The lack of reduction in sitting time when alternatives have been provided is concerning because despite considerate cost to organisations the reduction in the risk of excessive sitting was not achieved.

2.5.2.2 Feasibility issues

The barriers to wide scale implementation of alternative office workstations are considerable especially for some types of alternative workstations. Feasibility issues include the inability to accommodate large equipment (such as treadmills) in existing office design (McAlpine *et al.* 2007), practical aspects such as users still having access to their full desk surface and storage (Huysmans *et al.* 2015), noise (McAlpine *et al.* 2007), the need to change footwear and having suitable clothing to use some alternatives (Tudor-Locke *et al.* 2014) and equipment suitability for all users from an anthropometric perspective (Huysmans *et al.* 2015). Industry has also raised concerns about risks of falls, cost, equitable access (if not able to provide for all employees) and portability of some alternatives if required to be shared across users or with intra-office movements (Wieczer 2013, Tudor-Locke *et al.* 2014).

Other feasibility issues include workers' subjective experience within the workplace. A qualitative study of Australian government office workers following an office refurbishment, where sit-stand desks were installed, was undertaken by Grunseit *et al.* (2013). The workers advised their pattern of use was influenced by peer use (or not), having a manual mechanism to raise the desk and a preference to perform some tasks in only sitting (for example avoiding typing while standing).

In some workplaces, interventions have been provided as a shared resource so that change of work location to use the workstation or equipment is required. This can be perceived positively (opportunity to stand up and walk/move) or negatively (interrupting work). Where only shared resources are available workers need to make more of effort to use the device (Tudor-Locke *et al.* 2014, Torbeyns *et al.* 2017, Schellewald *et al.* 2018) which may result in reduced usage.

The majority of sitting intervention studies have been with healthy populations. Some studies have included participants with low back conditions (Son *et al.* 2018) or those known to develop pain with prolonged positions (Gallagher *et al.* 2011, Nelson-Wong and Callaghan 2014, Karakolis *et al.* 2016). Recommendations to manage individuals using alternate work positions who have pre-existing health conditions or advancing age are yet to be provided (Torbeyns *et al.* 2014, Tudor-Locke *et al.* 2014). Without such guidance there may be a considerable risk of detrimental effects with some work positions for some workers, such as those with compromised gait, motion related imbalance, or joint pain with weight bearing (Tudor-Locke *et al.* 2014).

2.5.2.3 Work productivity issues

Work performance when using an alternative work position is important to individuals and industry. Ojo *et al.* (2018) in a recent systematic review (n=7 studies) concluded alternative work positions did not appear to reduce work performance. The studies included interventions of one day up to 52 weeks with varying levels of participant use (starting at 30 mins, work position used once). The methods by which performance was measured across the studies varied from standardised tests to workplace specific performance measures. One of the studies in the systematic review was a three month field study by Alkhajah *et al.* (2012) which sought subjective feedback about productivity. One-third of participants agreed the work position (sit-stand) had improved their productivity. A further field study by Carr *et al.* (2012) found participants believed neither their productivity nor quality of work had declined, when using an under-desk cycle over a four week period. Despite participant feedback suggesting productivity had not declined in Carr et al's (2012) study, the under-desk cycle was not used by all participants while accessing the computer and there was an option of positioning the pedalling device adjacent to the desk. It is not specified what work tasks, if any, the participants engaged in where the device was placed adjacent to the desk and if cycling was undertaken over longer durations what impact this may have had on productivity.

One reason the use of an alternate work position may impact performance is as a result of dual task performance. Dual tasks result in additional physical and/or cognitive load and may impact performance of one or both of the tasks if capacity is exceeded (Woollacott and Shumway-Cook 2002). For alternative work positions the dual task commonly includes the combination of the physical task (posture) potentially affecting motor performance (balance and/or muscle coordination) and the diversion of attention to perform the additional cognitive task. Even a habitual activity such as walking has potential for dual task implications. Walking requires complex processes to integrate visual stimuli, proprioceptive and vestibular information despite being performed daily (Beurskens and Bock 2012). When considering the impact of a dual task, factors which may influence the impact include the individual, the nature of the task (simple/complex), and the physical coordination required (Brisswalter *et al.* 2002).

It is argued that there is an optimal zone which balances physical and cognitive system demand, specific to the individual (Brisswalter *et al.* 2002). Performance of dual tasks will be impacted by the complexity of the physical task (Woollacott and Shumway-Cook 2002). Those positions which are more habitual are likely to result in less demands (Ruffieux *et al.* 2015) and are thus less likely to compromise the second task. As a result not all alternative work positions are anticipated to be equal in regard to dual task implications. For example cycling, which is less habitual and automatic than standing may result in a greater dual task effect due to the higher level of information processing required (Tudor-Locke *et al.* 2014). Further, alternate work positions with extraneous movement may impact physical task performance, such as fine motor activities (Tudor-Locke *et al.* 2014).

It is assumed that any decrement in productivity when a dual task is present is the result of both tasks competing for information processing resources (Husemann *et al.* 2009) and/or that these resources are limited (Klingberg 2000). One of the more widely accepted theories which have been used to describe this phenomenon is capacity sharing theory (Pashler 1994). Capacity sharing theory suggests there are finite resources and when performing dual task activities, both tasks must share the resources and as a result performance is affected (Pashler 1994, Tombu and Jolicœur 2003). The theory suggests that detriment will become evident if one or both of the tasks becomes more difficult. Individuals have the ability, however, to consciously choose which task they will place more focus on and therefore which task will consequently decline, although this will also depend on the tasks involved (Pashler 1994, Tombu and Jolicœur 2003). Where movement is required, it has also been suggested that both the initiation and maintenance of movement will draw attentional resources away from other areas of the brain including the pre-frontal cortex and, depending on the type of motor activity, it may result in decline in complex cognitive functions (Dietrich 2006).

Given the small number of studies which have included analysis of cognitive functions whilst using an alternative workstation, and that in some studies participants only used the alternate work position for a limited duration, further research is required to provide robust evidence on work performance interference. Understanding which alternate work positions impact work performance and to what extent will aid implementation and provide guidance on strategies to minimise negative impact.

2.5.2.4 Discomfort and work productivity issues

Some trials of alternate work positions have resulted in reported increases in discomfort (Neuhaus *et al.* 2014a). This finding is a concern for organisations in managing worker health however it may also be a concern for work performance. Studies which have measured the impact of discomfort on work productivity, but not discrete cognitive functions, have suggested there is a complex relationship. The studies outlined below found an impact on productivity was not apparent, despite increases in discomfort.

Liao and Drury (2000) investigated the relationship between posture, discomfort and performance and found some evidence to support a relationship between the three constructs. Typing accuracy was found to decrease marginally with higher levels of discomfort although a greater sample size (n=6) would be required for generalisability of these findings. It was also suggested that typing may not be a sensitive measure upon which to draw conclusions. It is postulated that as typing is a habitual skill the threshold for impacting performance may be higher than for other measures. Another study, although not among office workers, used a baggage screening task and work positions of sitting, high sitting (use of a raised office chair) and standing, together with measures of discomfort (Drury *et al.* 2008). While discomfort varied between the conditions, there was no measureable effect on performance. The authors concluded that, given the lack of correlation between discomfort and performance in this study, responses to discomfort may be task specific (Drury *et al.* 2008).

Hagberg *et al.* (2002) conducted a cross sectional questionnaire study (n=1,283) across a number of Swedish workplaces with office based workers. Musculoskeletal discomfort was found to be common, with self-report of discomfort in at least one body part for 87% of females and 76% of males over the preceding month. However, only 9.9% reported reduced productivity in undertaking computer work. The authors suggested persistent and/or frequent discomfort may have a greater impact on productivity. Other factors not included in the Hagberg et al. (2002) study, but raised by the authors as potentially important in explaining the relationship, included whether the discomfort was work-related, exacerbated by work activities, interfered with work performance, and/or the severity of the condition.

Expanding on the earlier study, Hagberg *et al.* (2007) conducted further follow-up over 10 months and found the presence of discomfort in the neck and upper limb did not always result in a self-reported reduction in productivity. The risk factors for reported reduction in productivity, related to musculoskeletal symptoms, included individual factors such as obesity and levels of exercise in addition to organisational factors such as job demands. A limitation of the studies by Hagberg *et al.* (2002) and Hagberg *et al.* (2007) was the subjective measurement of productivity. Further, as results in the second study were collected at the end of the month, recall bias is also a concern. Importantly, these studies suggest that perception of discomfort will be influenced by a range of factors, not just perceived severity of musculoskeletal symptoms. It is noted though that if discomfort is considered to capture lower level symptoms than pain, the impact on performance may differ (Moore *et al.* 2017). Studies which have explored pain (not discomfort) have found a detrimental effect on some cognitive functions including attention and working memory (Attridge *et al.* 2015) with the magnitude of the effect postulated to result in greater impact where there is a complex dual task (Moore *et al.* 2017). Individual factors such as work ethic, stress at work and psychosocial issues have also been raised as potential confounders impacting perception of the impact of discomfort on cognitive performance (Wahlström *et al.* 2004).

Cognitive functions have been defined as the subcomponents which together result in execution of cognition (Fitzsimmons *et al.* 2014) and contribute to work productivity. Assessment of cognitive functions is complex and also not easily undertaken in a workplace setting. The specificity of which cognitive functions is impacted by discomfort is important for office workers. Often, an office worker's performance may utilise a single cognitive function such as working memory. Therefore, cognitive function testing needs to be highly specific and not global, as global testing may not be sensitive to deficits in critical cognitive domains. The ability to implement a reliable and valid testing regime including performing test-retest to examine acute effects is challenging (Mullane *et al.* 2017).

Given the range of options available and the risks associated both collectively and uniquely to each alternative work position, to ensure risks are appropriately managed industry requires guidance on the various alternative work positions (Huysmans *et al.* 2015). The following Sections 2.5.3 to 2.6.3 review the specific evidence on issues likely to be important for implementation of various alternative work positions, including those considered in this thesis.

Gap: Comprehensive investigation of discomfort when using alternative work positions and the impact on specific cognitive domains is yet to be reported.

2.5.3 Issues with specific alternative work positions

2.5.3.1 Stability ball

A stability ball provides an opportunity for sporadic movement. Stability balls, also known as swiss, gym, balance or physio balls (Jackson *et al.* 2013), include those which are used simply as a ball and others which have a ball which is inserted into a base with castors. Evidence suggests a stability ball may only result in a minimal increase in energy expenditure (Tudor-Locke *et al.* 2014). Benefits are claimed by product suppliers, but musculoskeletal impacts are mixed, cognitive functions impacts are largely unknown, and feasibility concerns have been raised.

The use of a stability ball is hypothesised to increase the use of trunk muscles to remain upright and leg muscles to maintain balance (Beers *et al.* 2008). It is suggested the increase in trunk muscle activity, through core muscle activation and improved endurance (Gregory *et al.* 2006), in addition to constant small movements will assist to release muscle tension (Jackson *et al.* 2013). However, evidence from laboratory based studies suggests that considerable low back muscle activity was not evident in using a stability ball, being assessed at or below 5% of maximum voluntary contraction (Gregory *et al.* 2006, Kingma and van Dieen 2009, Jackson *et al.* 2013). Further, a study by Kingma and van Dieen (2009) did not find movement increased significantly when using a stability ball compared to sitting on an office chair.

A laboratory study of the use of a stability ball for one hour found trunk muscle activity did not differ from sitting on a standard office chair, however whole body discomfort was significantly greater (Gregory *et al.* 2006). Further, pressure around the ischial tuberosities and gluteal region was an issue when using the stability ball. In a separate study of 30 minutes duration, there were no beneficial effects in trunk stability or spinal load, however the study found greater buttock and posterior thigh pressure when using a stability wall compared to sitting on an office chair (McGill *et al.* 2006). Jackson *et al.* (2013) used a study design (n=12, six females, six males) which provided opportunity for gradual increase in use of the stability ball over nine days. The study found discomfort in the low back and buttock decreased for females, but not for males, however there was no effect on muscle activation (erector spinae and abdominal muscles). Should use of a stability ball be considered for wider implementation in offices as an alternative to sitting, further investigation of whole body discomfort appears warranted.

The studies outlined above did not have cognitive functions as a dependent variable. No studies regarding the use of a stability ball which assessed cognitive functions were able to be located, and thus it is unknown how work performance may be affected (Davis and Kotowski 2015). This is a considerable gap in the literature which would be important to understand should more wide scale use of stability balls in offices be considered.

As has been found with other alternatives which reduce truck stability (such as treadmills) there may also be impact on fine motor function, such as using a keyboard and mouse. If a stability ball was used over long periods, fine motor function impairments may have considerable impact on productivity and influence sustainable implementation. Searching revealed only one short duration study which evaluated work productivity while using a stability ball. The study by Beers *et al.* (2008) (n=24) found there was no significant decrement in typing performance compared to sitting for 20 minutes. In a study by Kingma and van Dieen (2009) of 10 females who undertook typing over one hour, participants were found to lean forward more on a stability ball compared to sitting on an office chair and this increased with time. While typing performance was not measured, it is postulated the postural findings may impact performance and/or discomfort over longer durations and needs to be further investigated. As outlined above, further research would be important for industry given the implications on worker productivity.

The use of stability balls as an alternate work position has had criticism from industry for number of reasons. Concerns have been raised that a stability ball is a hazard in the workplace with some industry bodies recommending against the use of stability balls due to the risk of falls, unstable base and lack of low back support (WorkSafe 2018). While it does not appear there is any scientific evidence of falls to validate the above concerns further guidance for use of stability balls appears necessary for both regulators and industry.

2.5.3.2 Walking

Walking workstations are typically a treadmill together with a height adjustable desk or a specialised design which incorporates both. Usually the treadmill will be set at a slow speed and without a slope in the walking surface. A walking work position increases energy expenditure through the use of large leg muscles via rhythmic movement (Tudor-Locke *et al.* 2014). Consequently this work position has shown promise of ability to impact other health measures (such as cholesterol and obesity) although further studies are required (MacEwen *et al.* 2015). Available evidence of the impact on musculoskeletal and cognitive functions outcomes is limited, and feasibility concerns have been raised.

Walking at a slow pace while working is also postulated to have benefits for musculoskeletal health through increased spinal movement, impacting intervertebral disc nutrition and spinal shrinkage, and reduction in lower limb swelling (Straker *et al.* 2009). However, when using a walking work position there may be changes to usual gait, such as a slower cadence and a reduction in arm swing, to accommodate the task at hand thus reducing anticipated benefits. Callaghan *et al.* (1999) has previously found altered gait and associated biomechanical changes to result in increased compressive joint loading and muscular activation levels in the lumbar spine. Thompson *et al.* (2008) assessed use of a treadmill over four weeks (n=25). For those with back pain (number of participants with pain not provided) the treadmill reportedly assisted in reducing pain. Thus, although preliminary evidence suggests there may be benefit, greater understanding of the impact of walking on discomfort while concurrently performing office work is needed.

From a cognitive perspective Oppezzo and Schwartz (2014) found walking increased creativity. The study did not isolate potential mechanisms, although suggested circulatory or chemical mediators may play a role. It was acknowledged that walking with a non-natural stride demands more cognitive control. Thus, different types of walking equipment and design may impact cognitive results (Oppezzo and Schwartz 2014). Other evidence suggests there may be potential for improvement in memory and attention (Labonté-LeMoyne *et al.* 2015). A small study (n=2) of radiographers using a treadmill whilst reading images found case detection rates were increased compared to original interpretation (undertaken without a treadmill) (Fidler *et al.* 2008). The authors acknowledged potential influence from increased alertness, however also a possible Hawthorn effect. The treadmill condition resulted in a lower number of cases being read and was undertaken in a different work environment (with a quiet room for use of treadmill). It was suggested however, that use of a treadmill may be feasible to implement on a wider scale and further investigations should explore this. Other studies have found no difference in cognitive functions tasks. Bantoft *et al.* (2016) (n=45) found no significant difference in cognitive functions between walking and sitting (or standing) over one hour across memory, attention and information processing domains. Larson *et al.* (2015) also found no difference between walking and sitting for conflict adaptation and sustained attention. The study randomised participants to sitting (n=35) or walking (n=34) conditions, again with duration of one hour. Walking was at a fixed speed of approximately 2.4 kilometres per hour (1.5 miles per hour). The degree to which this matched the natural stride of individuals in the walking group may have affected results. Having an intra-participant study design would have strengthened the results from this study. Alderman *et al.* (2013) also compared sitting and walking on a treadmill with 27 participants and found no difference in attention and reading comprehension.

A number of studies have examined work productivity when using a walking work position. A study by Koepp *et al.* (2013) found the use of a treadmill over a one year period did not result in reduced work performance. Questionnaires were completed by the participant and their supervisors each week to measure performance which focussed on qualitative self-reported measures. The results suggested participants had a minor reduction in performance over the first three months, however overall performance was unaffected over the full 12 months. Reduction in sedentary time (across the entire day, not just work) was 43 minutes (on average) compared to baseline. An earlier study by Thompson and Levine (2011) of transcription typists found no difference in errors when comparing sitting to use of a walking work position, however they found a trend for transcription to take longer when walking. The task was undertaken over two sessions of four hours then repeated a month later. The authors acknowledged there was an order effect, however given the difference between conditions was 23%, there may also be other factors which impacted performance. The authors did not hypothesise what these factors may be, however, a possible explanation is that learning to use new transcription equipment while sitting was easier than walking (given the limited opportunity to practice before the study commenced). There were mixed responses in regard to perceived productivity considering both quality (errors) and productivity (time taken). Participants reported they would use a walking work position regularly if available (two participants anticipated 25% use while nine indicated they would use at least 50% of their work time).

Working while walking has been found to impair fine motor performance such as undertaking mouse and keyboard activities (John *et al.* 2009, Straker *et al.* 2009, Funk *et al.* 2012, Commissaris *et al.* 2014, Neuhaus *et al.* 2014a, Tudor-Locke *et al.* 2014, MacEwen *et al.* 2015). Commissaris *et al.* (2014) found mouse pointing speed deteriorated (23%) and mouse pointing errors increased (121%) while walking at 2.5 kilometres per hour (test duration for mouse approximately five minutes). Further typing speed also reduced (9%) although typing errors did not change compared to sitting (test duration for typing approximately five minutes). Funk *et al.* (2012) assessed a range of walking speeds with 24 participants and found walking 2.25 kilometres per hour did not result in detriment to typing speed compared to sitting. However, typing speed while walking at both 1.3 kilometres per hour and 3.2 kilometres per hour was slower than while sitting. The assessment of typing for each condition was also brief at approximately four minutes. The less stable upper body compared to static positions (sitting or standing) is postulated to be the at least partially responsible for these differences. In each of the above studies, participants were not familiar with working while using a walking workstation. If the walking workstation was used over a longer period it may result in less deficits in productivity.

Given the above findings of potential impact on typing, mouse use and productivity it is perhaps not surprising that walking while working, such as using a treadmill, has had issues with industry acceptance (Tudor-Locke *et al.* 2014, Davis and Kotowski 2015). The concerns also extend to risk of falls and injuries, cost and feasibility (Wieczer 2013). From a practical perspective, in many cases a larger office area is required to accommodate the walking equipment thus impacting office design and this is also likely to affect ease of implementation.

2.5.3.3 Alternating sit-stand

A sit-stand workstation allows change of work height such that work in either sitting or standing is permissible. Some desks require manual operation to change the work height while others are electric. The typical types of movement while using of a sit-stand workstation are a combination of sporadic (while in the sitting or standing position) and intentional (when transitioning). The change in energy expenditure will vary depending on the frequency of transitions however, previous research had found a modest 7.8% increase compared to just sitting (Barone Gibbs *et al.* 2016). There is a rapidly growing evidence base of the impact of sit-stand workstations on musculoskeletal and cognitive functions outcomes, along with evidence regarding its feasibility for implementation within workplaces.

Postural variation over the course of a work day, as is possible with a sit-stand workstation, has been reported to assist in managing discomfort (Tudor-Locke *et al.* 2014). However, concern has been raised that use of a sit-stand workstation results in replacing one relatively static position (sitting) with another (standing) (Callaghan *et al.* 2015). A considerable number of studies have investigated sit-stand workstations and the result of alternation of sitting and standing to reduce discomfort particularly related to the low back. A systematic review of studies which had a sit-stand condition concluded that sit-stand work positions resulted in lower levels of discomfort than just-sit (Karakolis and Callaghan 2014). Field studies have also reported reduced discomfort from sit-stand workstation use (Roelofs and Straker 2002, Hedge and Ray 2004, Pronk *et al.* 2012, Garrett *et al.* 2016). Unfortunately, these studies have not always clarified how frequent the transitions occurred and how much time was spent in each position.

In studies where sit-stand has improved discomfort levels, compared to just-sit or just-stand, it is not identified why this was the case to allow generalisation of these findings (Husemann *et al.* 2009, Davis and Kotowski 2014, Karakolis *et al.* 2016). Factors which may have had an influence are the durations in each work position, a novelty effect, or a lack of blinding. A meta-analysis by Agarwal *et al.* (2018) evaluated low back discomfort and use of a sit-stand work station. At a pooled level, the results indicated a reduction in low back discomfort for use of a sit-stand workstation. However, when further analysed by use (freely or constrained) there were different outcomes. With ability to alternate posture between sitting and standing freely, low back discomfort decreased, yet when set parameters for use were required low back discomfort did not decrease. Therefore the different results reported may be differences in the pattern and overall dose of sit-stand, as well as conditioning.

Greater understanding of the factors which may influence discomfort for the low back is required to assist with guiding implementation of workstation alternatives including sit-stand. Clarity of how the use of a sit-stand approach changes lumbar posture in each position and the loading on joints and passive tissue and resultant influence on low back discomfort (Karakolis *et al.* 2016) can assist in providing guidance on use. Further, understanding the impact of greater activation of stability muscles and implications for muscle fatigue (Davis and Kotowski 2014) would assist industry to provide guidance on timeframes for alternating between sitting and standing. A promising study by Bao and Lin (2018) found all muscles measured (bilateral trapezius and erector spinae) showed signs of fatigue by the end of participants' work day. The study had varying durations of standing and standing alternation and also found there was a trend for less muscle fatigue with longer bouts of standing (60 minutes compared to 15, 30 or 45 minutes). Discomfort was reported to be low for all conditions and to vary between participants. However, the condition with the most sitting was also the least preferred. It could be postulated that the alternate position (standing) or movement to perform the transitions may have impacted static muscle loading (Barone Gibbs *et al.* 2016). Larger movements by way of positional transitions may also play an important role in influencing discomfort through attenuation of static passive tissue loading, and the increased muscle use resulting in altered blood flow, oxygenation, nutrient delivery to muscles and potentially assistance in removal of waste products (Davis and Kotowski 2015, John *et al.* 2015, Barone Gibbs *et al.* 2016).

Discomfort in other body regions is also important to consider when using a sit-stand workstation. Prolonged sitting and prolonged standing have been linked with lower limb swelling (Winkel and Jorgensen 1986a, Seo *et al.* 1996, Chester *et al.* 2002, Lin *et al.* 2012b). Given this, the impact of use of sit-stand workstations and positional change on foot swelling has also been investigated. Use of a sit-stand workstations over a work day with four different alternation patterns was studied by Bao and Lin (2018). The authors found swelling increased over the work day however there were no difference between conditions, regardless of the sit-stand alternation timing. However, the authors found those participants who undertook greater amounts of movement by being active during work breaks had less foot swelling. The positional change which occurs through use of a sit-stand workstation may not be sufficient to impact foot swelling. Further research which established if more or different movement was able to successfully mediate swelling would address this health concern.

There has been limited research which has examined cognitive functions when alternating between sitting and standing compared to just sitting or just standing. Rather the majority of the research has compared just sitting and just standing (Schraefel *et al.* 2012, Commissaris *et al.* 2014, Bantoft *et al.* 2016) or has used industry measures rather than cognitive function measures (Robertson *et al.* 2013, Chau *et al.* 2015b). From a cognitive perspective some evidence suggests the transition (from sitting to standing or vice versa) may negatively affect short term concentration (Thorp *et al.* 2014) and thus have implications broadly for cognitive functions. In contrast, a laboratory study by Schwartz *et al.* (2018) with 45 participants, compared sitting only to alternating sit-stand and found no significant difference in attention, concentration or working speed with a 30 minute alternation pattern.

Use of a sit-stand desk in the workplace has been researched more extensively than any other alternative work position. Productivity has been evaluated in a number of studies. Chau *et al.* (2015b) compared two groups of Australian workers (total of 31 workers across both groups); one group who only sat and the other with a stand permissive desk and thus ability to alternate between sitting and standing. Productivity measures, which were based on company (call-centre) specific metrics, showed no difference between the two groups over a 19 week period. Sitting at work reduced by 1.5 hours per day over the 19 weeks, although based only on self-report. Another workplace-based study among office workers in the United States by Dutta *et al.* (2014) also found no difference in self-reported productivity. The study was conducted over four weeks with a crossover design study (n=28). Self-reported productivity was also used by Pronk *et al.* (2012) in a workplace sit-stand based intervention. Participants (66%) reported feeling more productive when using the sit-stand desk over a four week period. Sitting reduced by 66 minutes per day for the intervention group compared to the just sit group based on experience-sampling methodology (participants confirmed their current work position in response to a text message at random times). In a separate study undertaken as part of an office refurbishment, qualitative feedback obtained from 13 workers (who completed a questionnaire and attended a group interview after three months) suggested that for some participants there was a certain task preferred to undertake when sitting which differed to standing (Grunseit *et al.* 2013). This may impact usability in some occupations or for some individuals.

There is potential for a Hawthorn effect in use of the sit-stand work positions. Objective evidence confirming any effect on productivity levels in future studies, would be important for industry to support wider implementation. Another bias which is evident in a number of studies is the use of workers in office environments who are related to a university health faculty/or public health facility. Further, a limitation of a number of studies is that accurate measures of time spent sitting compared to standing and durations have not been captured.

A challenge for industry in considering implementation of sit-stand desks is that research to date, including both field and laboratory studies have failed to give specific recommendations for the amount of time to be spent in each posture before alternation (Callaghan *et al.* 2015). Varying durations of sitting versus standing have been assessed through laboratory studies. Ratios of sitting and standing have varied from 1:1 to 3:1 however have not been able to provide clear direction (Callaghan *et al.* 2015). Concurrent repeat measures of discomfort and productivity have not been undertaken in some studies while others have tested this across only one ratio (Karakolis and Callaghan 2014). In addition, complicating generalisability of the laboratory studies is that some have a lack of transferability to the workplace due to the study design. For example, studies have used equipment not suitable for an office such as an office chair without a backrest during sitting (Karakolis *et al.* 2016). As a result there are no standards available to guide industry to minimise or prevent musculoskeletal discomfort (Callaghan *et al.* 2015) thus presenting a considerable workplace risk. Concerns by participants have also been raised in regard to perceived productivity impact, practical requirements to make transitions (especially if the desk is not electric and manual adjustments are required) and managing pre-existing musculoskeletal issues (Grunseit *et al.* 2013). These areas are important to research further given previous studies have found limitations in participants' willingness to change their behaviour and adopt the alternate work position (which is usually standing) both acutely and longer term (Wilks *et al.* 2006, Straker *et al.* 2013, Callaghan *et al.* 2015, Davis and Kotowski 2015).

As outlined in Section 2.5 above, a range of alternative work positions have been trialled. In summary, stability balls have resulted in increases in discomfort and concerns about falls. Walking workstations require increased space, have falls concerns and are of high cost. Sit-stand workstations while researched more than other work positions still lack clarity in ratio for implementation and whether it is the alternation of the two positions or the effect of the actual transition which is beneficial.

Additional alternate work positions which appear to have merit to investigate further include under desk cycling, standing and standing-with-movement. Each has potential for implementation at relatively low cost, using an existing work area (no additional space) and without increased risk of falls.

2.6 Workstations considered further in this study

2.6.1 Under-desk cycling

Cycling while working can be undertaken using an upright cycle at a height adjustable desk, a recumbent cycle or under-desk cycle. When using an under-desk cycle the device is positioned underneath a desk, where a footrest would typically be located. The user sits on a standard office chair. Cycling can occur at the user's discretion. That is, the user has control over duration, frequency of use, and resistance applied. An under-desk cycle also has the added benefits of being portable and low cost compared to other options, such as walking workstations. Despite these potential benefits, under-desk cycling however has been less extensively researched compared to other work positons already mentioned (Torbeyns *et al.* 2017).

Cycling is an example of rhythmic movement. Muscle activation of rectus femoris and gastrocnemius has been measured as 7-8 times higher during moderate intensity ergometer cycling than during rest (Altenburg *et al.* 2013). Cycling also increases energy expenditure compared to just sitting. In a laboratory study by Straker *et al.* (2009), which compared upright cycling to just sitting, heart rate increased by 25% while cycling at a light intensity (30W). Elmer and Martin (2014), also in a laboratory study, found recumbent cycling (with self-selected resistance and pedalling rate, averaging 38W) resulted in metabolic cost elevated by ~2.5 times, compared to just-sitting. Oxygen consumption and heart rate were also substantially greater during cycling. Pedalling for 10 minutes each hour throughout an eight hour work day (80 minutes) was estimated to result in up to 1000 kcal per week of additional energy expenditure, compared to typing alone, thereby meeting the criteria for habitual moderate physical activity (Elmer and Martin 2014) based on United States criteria. A recent field study by Schellewald *et al.* (2018) of 30 office workers also found increased energy expenditure (1.3 -1.4 (± 0.5) metabolic equivalents) and heart rate (approximately 8%) with use of a workplace based cycle over a six week period. The participants had access to two different types of cycle devices which were both portable. Given the increased physical activity, cycling may have potential to positively impact cardiometabolic risks associated with sedentary behaviour (Dempsey *et al.* 2016).

2.6.1.1 Cycle workstation design

Studies of the various cycling options, upright, recumbent and under-desk, have had different ergonomic challenges which may result in feasibility issues. A laboratory study using a recumbent cycle had issues with knee clearance (Elmer and Martin 2014). The recumbent cycle also required an altered upper limb position and as a result the keyboard was higher than usual, potentially resulting in additional muscle activity necessary to elevate the arms and shoulders. A field study using a portable pedal device found participants' knees were hitting the underside of the desk (Carr *et al.* 2013). Upright cycles which typically do not have a backrest may lead to low back discomfort if used over an extended period (Davis and Kotowski 2015). In addition, a bicycle seat which has not been modified for office use could lead to buttock discomfort (Straker *et al.* 2009). With under-desk cycling workers can use their existing office chair thus avoiding seat and backrest issues found in other cycling studies. Previous issues of knee clearance would need to be addressed, through design, to allow optimal upper limb positioning. Further research is required to identify whether discomfort will be an issue if under-desk cycling is adopted for use in workplaces. For cognitive functions it is not yet clear whether the rhythmic movement when cycling will result in decrement or benefit for lower and higher order cognitive functions.

The remainder of Section 2.6.1 will review discomfort across body regions of low back, lower limb and upper limb when using a cycling work position. Mechanisms for discomfort will be explored for each region. Cognitive functions when performing under desk cycling is also discussed.

2.6.1.2 Low back discomfort with under-desk cycling and potential mechanisms

Implications for low back discomfort when using a cycling work position to perform office work are unknown. There is a lack of epidemiological or field studies which measure biomechanical changes in the low back when performing under-desk cycling in an occupational context. Laboratory studies of cycling (under-desk and recumbent) to date have used seating with limited or no adjustability in backrest angle or lumbar support which is not reflective of typical office chairs thus limiting ability to generalise results (Elmer and Martin 2014, Koren *et al.* 2016).

Low back angle

Sitting results in posterior pelvic rotation and reduction in lordosis which is postulated to increase the load on passive tissues (Harrison *et al.* 1999, De Carvalho *et al.* 2010). There is considerable debate in the literature about what the 'best' sitting posture is (O'Sullivan *et al.* 2012b). Increased lumbar flexion (slump) has previously been considered problematic due to increased intervertebral disc pressure and loading on posterior passive tissues while hyperlordotic postures may result in increased spinal loading through extensor muscle contraction (O'Sullivan *et al.* 2006, O'Sullivan *et al.* 2012b). As a result 'neutral' positioning has been advocated, however agreement of what constitutes neutral varies among practitioners (O'Sullivan *et al.* 2012b). It is not known if under-desk cycling would change sitting posture to more or less lordosis, or assist in maintaining sufficient lumbar lordosis to potentially positively impact stress distribution, loading and discomfort.

Low back movement

Postural movement has been postulated to assist in unloading passive tissues (Gallagher and Callaghan 2015) associated with prolonged sitting. While cycling creates obvious large movements in the legs, the dynamic seated posture of cycling is also expected to result in smaller spinal movements in the trunk (O'Sullivan *et al.* 2012a) along with low back and abdominal muscle activation to stabilise posture (Peterman *et al.* 2012). Whilst no studies have measured movement objectively when using an under-desk cycle, a number of authors have observed a tendency for the upper torso to sway when undertaking laboratory based cycling (Elmer and Martin 2014, Koren et al. 2016). Sway may positively impact discomfort through small trunk movements offsetting passive tissue loading, conversely however there may be points of friction with the seat back and both require further investigation.

Other studies where movement in sitting has been investigated include those on unstable surfaces. O'Sullivan *et al.* (2006) investigated sitting without a backrest on an unstable and stable surface to compare muscle activity and movement. Whilst the instability did not result in greater phasic motor activity in the trunk muscles measured (internal oblique, lumbar multifidus and erector spinae), it did result in greater excursions in movements of the lumbar spine. There was greater movement for unstable sitting than stable sitting in both the anterior-posterior plane and the medio-lateral plane. There were no differences between conditions in lumbar curvature or pelvic tilt, however, there was movement toward spinal flexion. In O'Sullivan et al's (2006) study there was also no difference in activity levels for the chosen muscles. Discomfort was not assessed during this study noting it was also only of short duration (five minutes). It is anticipated more trunk movement will occur during cycling than while just sitting. This movement may impact passive loading and thus positively influence discomfort for the low back during cycling.

Muscle fatigue

To ensure under-desk cycling is feasible for use in an office environment there is a need to balance muscle use and fatigue. No studies were located which have measured trunk or leg muscle fatigue (objectively) when using an under-desk cycle. It is postulated that rhythmic muscle contraction which allows periods of activity and rest may assist to manage fatigue (Callaghan and McGill 2001). A study which used an ergometer cycle and hourly bouts (eight minutes) of moderate intensity cycling found muscle activity (of leg muscles rectus femoris, vastus lateralis and gastrocnemius) was higher at rest. However it was not clarified whether participants considered this fatiguing (as this was not a variable reported) (Altenburg *et al.* 2013). Participants in a separate study generally did not experience 'muscle aches' on days they used the under-desk cycle (with average use 23 minutes per day), with a median score of 1.5 on a likert scale with 1=strongly disagree and 5=strongly agree (Carr et al. 2012).

Other studies of desk cycling have used perception of fatigue, rather than muscle fatigue, however it was not specified whether the intention was to measure physical or mental fatigue. Torbeyns *et al.* (2017) reported that there were no reports of participants feeling more fatigue when using the cycle compared to usual office work. With comments by participants such as '*I felt better, less fatigued'*, conclusions about the extent of muscle fatigue compared to generalised overall body or mental fatigue from this study are unclear. Preliminary evidence suggests muscle fatigue may not to be a problem when undertaking light cycling, however there is potential for fatigue if excessive duration, frequency or resistance are applied.

2.6.1.3 Lower limb discomfort with under-desk cycling and potential mechanisms

Depending on the type of cycle used, users may experience discomfort in the gluteal and hip region. This was evident in a cycling trial of only 6-10 minutes duration (Straker *et al.* 2009). In this prior study, it was noted that the upright cycle had not been adapted for office use and the small seat may have resulted in pressure causing discomfort. Another study, also of short duration (10 minutes), did not report buttock discomfort for participants using a recumbent cycle in a seated position more similar to an office chair, (Elmer and Martin 2014). Depending on the type of cycle, the sitting position and resulting pressure distribution are expected to change. For instance, an upright cycle may result in greater likelihood to lean forward (weight will be in front of ischial tuberosities) or sitting more directly upright (weight will be directly above tuberosities). In contrast, if seated in a more reclined position as may be more likely with a recumbent cycle, weight will be more posterior and possibly behind the tuberosities (Pope *et al.* 2002). It is not known how under-desk cycling will impact pelvic tilt and thus pressure on tuberosities over time. This may also be impacted by the posture assumed by the individual.

Prolonged sitting has been linked to lower limb swelling (Winkel and Jorgensen 1986b, Seo *et al.* 1996). Increased leg muscle use, as occurs during cycling, is anticipated to result in increased muscle pump action and assist with venous return (Lin *et al.* 2012b). Ergometer cycling has previously been shown to reduce leg swelling compared to sitting, by 1.6% at 50W and 1.9% at 100W (Stick *et al.* 1989). The impact of leg movement on swelling was also studied by Sherman and Hedge (2003) who gave seated participants access to a dynamic (motorised) footrest, which passively moved the participants' feet in an oscillating motion (4 movements per minute per foot), and compared this to a static footrest. Participants were found to move more (voluntarily) when using the static footrest however skin surface temperature was higher with the dynamic footrest than the static. Results from this study suggest higher blood flow during the dynamic condition although there was no effect on measured calf circumference by either condition. Thus, it could be argued that there was insufficient active movement to assist venous return through the muscle pump action. At a physiological level, the calf muscle pump is hypothesised to counteract the intravascular pressure during contractions and increase lymphatic flow thus reducing the fluid in the interstitial space (Stick *et al.* 1989).

2.6.1.4 Upper limb discomfort with under-desk cycling and potential mechanisms

Upper limb positioning and the subsequent ability to perform office tasks while cycling can be impacted by cycle workstation design. Upper limb position will be determined by the desk height, which is in-turn dependent on ensuring adequate knee clearance. In the study by Elmer and Martin (2014), knee clearance requirements resulted in the upper limb being supported by the tray table with greater shoulder flexion and less elbow flexion than a standard seated position. Other studies have not required office based tasks to be completed while using the under-desk cycle and thus impact on tasks such as computer use was not measured (Carr *et al.* 2012). Studies which used an upright cycle have not described participant positioning, including the impact of the cycle on desk height, whether forearms rested on the desk surface or were able to float, and whether there was any upper limb discomfort (Straker *et al.* 2009, Torbeyns *et al.* 2016a, Torbeyns *et al.* 2017). Despite the lack of evidence, positioning of the upper limb is anticipated to have an effect on muscle fatigue and discomfort.

Postural sway, which has been noted to occur during cycling (Elmer and Martin 2014, Koren *et al.* 2016), has potential to influence fine motor performance. Koren *et al.* (2016) found typing a given passage of text took significantly longer when using an under-desk cycle. When cycling at a lower intensity (40W) the same passage of text was typed 7.3% slower than no cycling and 8.9% slower when cycling at higher intensity (80W) compared to no cycling. In contrast, typing errors did not differ between these two conditions when compared to not cycling. Mouse use was not assessed as part of the study. Straker *et al.* (2009) also found a small effect on typing speed (3% slower) for upright cycling at low intensity (5W considered 'free wheeling') but no effect at higher intensity cycling (30W) on typing speed. Participants indicated having to maintain a predetermined cycling speed was distracting and this may have impacted results. Mouse pointing was reduced for both cycling conditions with faster cycling slightly less affected. In contrast, Commissaris *et al.* (2014) found typing speed was unaffected, but did find mouse dexterity reduced, when using an upright cycle. The results of these studies may have been influenced by the type of cycle used. An upright cycle has a narrower seat and lack of back rest impacting postural support and potentially resulting in greater torso sway than a recumbent cycle.

2.6.1.5 Cognitive functions when under-desk cycling

A number of laboratory studies have examined cognitive functions and cycling (Commissaris *et al.* 2014, Torbeyns *et al.* 2016b, Mullane *et al.* 2017). Some authors have explored lower order cognitive functions (e.g. reaction time) while others have investigated higher order executive functions (e.g. reasoning). There is speculation that individual cognitive functions may be affected differently by varying levels of activity and arousal (Chang *et al.* 2012).

For lower order cognitive functions, results have shown no detriment from cycling. Torbeyns et al. (2016b) found 30 minutes upright cycling had a positive effect on response speed using tests of selective attention, with accuracy being maintained. Other laboratory studies of short duration have found there was no effect of cycling (Commissaris et al. 2014, Koren et al. 2016). Koren *et al.* (2016) used a general cognitive ability test (n=13) with math vocabulary and reasoning components and compared sitting to cycling at 40W and 80W for 30 minutes per condition. Only cognitive test time and score were provided. Pairwise comparisons found there were no significant differences in test time between conditions.

For higher order executive functions, studies have shown mixed results for the impact of cycling intensity on cognitive functions. Working memory accuracy was negatively impacted by higher intensity (40% or heart rate reserve) cycling but not affected on lower intensity cycling in a laboratory study over approximately 30 minutes per condition (Commissaris et al. 2014). In another study, intermittent bouts of cycling over a six hour period at 20W with a cadence of 25-30 rpm resulted in significantly improved memory and executive functions (Mullane et al. 2017). Torbeyns *et al.* (2016b) found short term memory did not deteriorate while cycling over 30 minutes at 30% of participant maximum power. Based on these results there may be an optimal intensity for cycling to avoid a negative impact on higher order cognitive functions, a theory which aligns with Brisswalter et al's (2002) hypothesis outlined in Section 2.4.1.3.

A study which examined electroencephalogram data found there was a 20% increase in alpha-2 brainwave activity after 20 minutes of cycling compared to baseline suggestive of cortical relaxation (Wollseiffen *et al.* 2016). It had been postulated by that study's authors that increased motor cortex brain activity would result in reduction in frontotemporal brain activity, indicative of cortical relaxation, resulting in overall improved cognitive performance. However, cognitive function testing showed there was only an improvement in decision making but not in memory. Despite the neurophysiological changes demonstrating an increase in brain activity, there was limited translation to objective results in cognitive performance.

2.6.1.6 Mental state with under-desk cycling

Mental state also has potential to be impacted by cycling. A field study over 5 months where participants' cycled for 98 mins (average) per week found there was a positive impact on mental state for some participants (Torbeyns *et al.* 2017). Approximately one third of participants experienced a positive effect on attention while 53% reported no effect on attention and 16% reported a negative impact. Motivation was reported to be positively influenced in 68% of participants. About half (56%) felt more energetic and none reported feeling more fatigued during cycling than during a usual work week without any desk cycling. A limitation of the results was the lack of objective baseline data and repeat measures throughout the study rather than one questionnaire at conclusion to reduce recall bias. Greater understanding of the potential for cycling to influence mental state such as perceived attention, mental fatigue and concentration would be valuable as this is likely to influence initial and long-term usage.

Gap: Use of under-desk cycling and the acute influence on discomfort for the low back, lower limb and upper limb requires further examination to understand when discomfort may be an issue and what mechanisms may be responsible. In addition, the impact of using an under-desk cycle over prolonged periods on cognitive functions important to office workers is not well understood.

2.6.2 Standing

With current concerns of excessive sitting in office workplaces, a common alternate work position option is to replace sitting with standing (Callaghan *et al.* 2015). In many instances this is through a stand permissive desk which allows users to alternate between sitting and standing as outlined in Section 2.5.3.3. Understanding the risks associated with a standing only work positions is the focus of this Section.

Laboratory studies have shown that standing typically results in sporadic movements consisting of fidgets, drifts and larger weight transfers (Gallagher and Callaghan 2015). Due to the use of postural (stability) muscles and increased heart rate, standing has been suggested to have a modestly higher energy expenditure than sitting (Barone Gibbs *et al.* 2016) although not all evidence supports standing increasing energy expenditure (Burns *et al.* 2017). Energy expenditure has previously been found to be 6% greater while standing with feet constrained, compared to just-sitting (Beers *et al.* 2008). A factor which would appear to influence energy expenditure is the amount of extraneous movement undertaken by the individual via weight shift and fidgeting (Beers *et al.* 2008) which is expected to vary. A more recent study which instructed participants to stand naturally and thus included fidgets found an increase in energy expenditure of 12% for standing, compared to sitting (Betts *et al.* 2018).

Time spent standing has been found to be beneficially associated with all-cause mortality in epidemiological studies, independent of reported sitting and moderate-to-vigorous physical activity levels (van der Ploeg *et al.* 2014). It has also been suggested that standing may be a healthier alternative to prolonged sitting (Katzmarzyk 2014). However, epidemiological studies of occupational prolonged standing (e.g. workers in retail and industrial settings) suggest there may be negative health issues associated. The risks include perinatal risks (Mozurkewich *et al.* 2000, Magann *et al.* 2005), atherosclerotic progression (Krause *et al.* 2000), chronic venous insufficiency and varicose veins (Beebe-Dimmer *et al.* 2005, Tuchsen *et al.* 2005), and symptoms in the back (Coenen *et al.* 2016) and lower limbs (Leroux *et al.* 2005). Therefore, while standing may be thought to be a solution to some of the negative health consequences of prolonged sitting for office workers, there are health risks associated with too much standing.

Currently, the evidence base related to prolonged standing for office workers has gaps (Callaghan *et al.* 2015, MacEwen *et al.* 2015) which are a concern to industry if increasing standing at work is to occur to offset excessive sitting. The acute effects of prolonged standing particularly low back and lower limb discomfort, and potential influence on cognitive functions which may impact work performance needs to be determined and interventions developed to address any problems.

The remainder of Section 2.6.2 will focus on discomfort for the low back, lower limb and upper limb when standing and associated mechanisms. The impact of standing on cognitive functions will also be discussed.

2.6.2.1 Low back discomfort with standing and potential mechanisms

A systematic review by Coenen *et al.* (2016) found an association between low back symptoms and occupational standing of at least two or four hours per work day. The meta-analysis of 39 articles which had investigated low back symptoms and occupational standing included 82,229 participants. In contrast, a previous systematic review (studies between 1966 to 2007) concluded there was moderate to strong evidence *against* occupational standing being independently causative of low back pain (Roffey *et al.* 2010b). A total of 18 studies were included in Roffey et al's (2010b) review. It was acknowledged that observational studies and laboratory studies had found an association, but the authors argued that this was not sufficient to prove causality. A noted limitation of the studies was the inability to determine the time spent standing (as compared to walking), and the conditions in which standing was undertaken. For instance, some studies included occupations such as nurses however the amount of *static* standing was not measured and neither were the loads of other tasks performed throughout a work day, such as manual handling. An epidemiological study by Tissot *et al.* (2009) (n=4493 standing workers and n=3237 sitting workers) found standing to be associated with low back pain. Further, the prevalence of low back pain was significantly higher among those who undertook constrained (being unable to freely alternate position) standing.

A recent systematic review of laboratory studies of prolonged standing found there was an association with low back symptoms across all 17 included studies (Coenen *et al.* 2017b). Laboratory studies with uninterrupted standing of greater than 20 minutes were reviewed to allow investigation of a dose-response association. It was noted that not all people developed low back symptoms and two subgroups 'pain developers' and 'non-pain developers' were evident. Pain developers were considered to be those who rated an increase in discomfort with a bout of standing while non-pain developers remained free of reported symptoms. The authors concluded that when the data was pooled (all participants) a clinically relevant symptoms intensity would occur after 71 minutes of prolonged standing. However when a stratified analysis was undertaken using the studies which had identified pain developers, a clinically relevant symptom intensity would be present after 42 minutes.

Laboratory studies which have found discomfort with prolonged standing for some participants and not others (Gregory and Callaghan 2008, Gallagher *et al.* 2011, Antle and Côté 2013, Antle *et al.* 2013, Gallagher *et al.* 2014, Gallagher and Callaghan 2015, Sorensen *et al.* 2015, Gallagher and Callaghan 2016, Karakolis *et al.* 2016) have also investigated possible mechanisms. These mechanisms have included low back posture, amount of movement and muscle fatigue. Another mechanism which has been suggested is spinal shrinkage as a result of loading (Le and Marras 2016). Of concern is that those people who develop discomfort during prolonged standing may be predisposed to developing clinical low back pain in the future (Nelson-Wong and Callaghan 2014). Whilst there seems to be a clear association between prolonged standing and discomfort for some individuals, the mechanisms leading to the discomfort are not yet clear. Thus a greater understanding of the predominant factors which influence discomfort, and using this knowledge inform potential ways to prevent or manage discomfort is important.

Low back angle

In attempting to understand mechanisms for low back discomfort during prolonged standing, one of the factors which has been investigated via laboratory studies is the low back angle. Gregory and Callaghan (2008) found prolonged standing resulted in increasing lumbar flexion (slumping) and low back discomfort over the two hour study duration. It was suggested that the increased flexion may have impacted the facet joint separation and ligament lengths. The intervertebral joint passive structures are considered sensitive to such changes and the altered loading may have played a role in discomfort development (Gregory and Callaghan 2008). In contrast, a laboratory study by Sorensen *et al.* (2015) found greater lumbar lordosis was related to low back pain during prolonged standing. Sorensen *et al.* (2015) compared lumbar lordosis in pain developers and non-pain developers and found there was a relationship with larger lumbar lordosis in pain developers compared to non-pain developers. Those who stood with more lordosis had higher intensity of low back pain. The difference in loading on posterior vertebrae facet joints, stimulation of nociceptors in facet joint capsule, and/or outer layers of the annulus of the intervertebral disc compared to standing with less lordosis were considered as potential contributors to symptoms (Sorensen *et al.* 2015). A shortcoming of this study was the lordosis measurement was only taken at baseline. It is not clear if participants who went on to develop pain (versus those who did not) had differences in lordosis over time or whether usual lordosis (as measured at baseline in this study) is a reliable indicator of likelihood of pain development.

Low back movement

Another factor which has been examined in attempting to understand the mechanisms for low back discomfort, is the amount of movement undertaken. Typically, this is measured by displacement of centre of gravity (with the pelvis as the point of reference) or whole body weight shift. Previously it has been suggested that during prolonged standing asymmetrical positions will tend to be adopted with unequal weight on the legs (Whistance *et al.* 1995). Further, weight transfers become more frequent over time (Gallagher *et al.* 2011, Callaghan *et al.* 2015). Higher number of weight shifts have also been associated with higher ratings of discomfort (Gregory and Callaghan 2008).

Differences in the pattern of movement have also been suggested. Pain developers were found in one study to have greater mediolateral fidgets versus non-pain developers (Gallagher *et al.* 2011). In a laboratory study over two hours (n=32), non-pain developers had earlier and more lumbar spine flexion/extension fidgets and large body weight transfers (Gallagher and Callaghan 2015). The aforementioned fidgets were suggested as a strategy to prevent static loading. If the impact of sporadic movement, like fidgets, on discomfort when standing was better understood it may help to provide guidance on equipment (such as footwear and/or floor surface) and overall workstation design which encourages small movement.

Muscle Fatigue

Low back discomfort arising from prolonged standing has been linked to fatigue of the muscles required to maintain an upright posture (Le and Marras 2016) although evidence to support this is mixed. Typically during standing there are low levels of muscle exertion via isometric contractions (Balasubramanian *et al.* 2009, Garcia *et al.* 2016) and some co-activation of trunk muscles (Callaghan *et al.* 2015).

Hansen *et al.* (1998) investigated postural fatigue of the paraspinal muscles during standing work (with a task of letter sorting) over two hours and found mean power frequency decreased significantly for left side paraspinals suggesting fatigue. Although paraspinal muscle activity was only at low levels (4-6% of maximum voluntary contraction), perceived muscle fatigue increased considerably over the two hours. In a more recent study, there was no evidence of a trunk muscle fatigue associated with standing however the study was of relatively short duration at 32 mins (Antle *et al.* 2013). It has been argued that movement to break up static positions may positively impact muscle fatigue (Garcia *et al.* 2016). Balasubramanian *et al.* (2009) undertook a study (n=9 males) with standing and walking conditions (1 hour per condition). There was a significant difference in the fatigue rate of erector spinae (right side, which may have been related to the task being performed) with fatigue in lower back muscles more predominant in standing than walking. During the study, participants walked from one work table to another work table approximately 1-2 metres distance away, then continued working. The results of that study suggest that even limited amounts of movement can be beneficial to avoid low back discomfort development due to prolonged standing. Intermittent muscle co-activation, such as occurs with movement, allows a contract-relax pattern (Le and Marras 2016) in comparison to being constantly activated with low postural load, which may assist in reducing fatigue onset.

2.6.2.2 Lower limb discomfort with standing and potential mechanisms

Epidemiological evidence of occupational standing has found inconclusive evidence of an association between substantial amounts of standing and lower limb symptoms (Coenen *et al.* 2016). The meta-analysis conducted included a large sample (n=31,924), however was not limited to office workers and thus workers may have had other physical demands as part of their work tasks which influenced results. A further limitation was that most studies used self-report for quantifying occupational standing and therefore objective measurement of how much movement occurred versus more static standing was not available.

One of the studies included in the aforementioned systematic review was an epidemiological study by Messing *et al.* (2008) that used data from the 1998 Quebec Health and Social Survey (n=7,757). Participants were asked to provide information on their work positions during a normal work day. If they usually stood, they were asked how much movement they undertook (relatively fixed, possibility of making one to two steps, moving more than this or whether they had opportunity to sit at will). For workers who usually stood, the prevalence of lower limb pain was highest in the knees followed by ankle/feet. Female workers reported a higher prevalence of lower limb pain than males despite females overall working less hours. The evidence also suggested there may be differences in reported pain as a result of the type of movement undertaken whilst standing.

Venous issues

Studies have found an increased risk of varicose veins with higher standing exposure at work (Tuchsen *et al.* 2000, Tuchsen *et al.* 2005, Tabatabaeifar *et al.* 2015). A study by Bahk *et al.* (2012) of 2,165 workers across a range of industries with varying standing exposures (chronic duration and volume per day), also found a higher varicose veins prevalence for females. There was a sex difference in the amount (chronic duration) of occupational standing work, with females having stood for shorter periods of time (1-4 years 39%, 5-9 years 29% and greater than 10 years 20%) than males (1-4 years 24%, 5-9 years 16% and greater than 10 years 50%). When viewed from a volume per day perspective, a greater percentage of women stood consecutively for more than 8 hours (66%, men 56%) and more than 4 hours (women 59%, men 36%). Therefore, while the study found women had less chronic exposure to prolonged standing than males, the volume during that exposure was higher which may explain the higher varicose vein findings for women.

The association of lower limb discomfort with prolonged standing has been supported by a considerable number of laboratory studies (Coenen *et al.* 2017b). Mechanisms suggested for the discomfort in the lower limb when undertaking prolonged standing have included circulatory changes impacting venous return in addition to muscle fatigue and effects on passive tissues (Messing *et al.* 2008). Vascular changes have been found to occur as early as eight minutes after commencing standing (Antle et al. 2013). Standing, and the inherent effect of gravity, requires additional venous pressure to pump blood from the lower limb and avoid pooling (McCulloch 2002). Typically, one-way venous valves together with the muscle pump action return the deoxygenated blood back to the heart (McCulloch 2002, Beebe-Dimmer *et al.* 2005). However, in standing with limited movement, and thus minimal contraction and relaxation of the leg muscles, it has been suggested the muscle pump action may be insufficient to assist venous return (Coenen *et al.* 2017b). It is acknowledged though that the muscle pump will only reduce venous stasis if the venous valves are intact (Tuchsen et al. 2000).Where venous valves become incompetent, this can result in the superficial veins becoming lengthened and dilated, which is referred to as varicose veins (Raffetto and Khalil 2008). Therefore, standing may constitute a risk of varicose veins for at least some people however causation is hypothesised to be multifactorial (Raffetto and Khalil 2008). Structural differences such as the walls of veins becoming leaky and/or having structural abnormalities may explain inter-individual effects (Raffetto and Khalil 2008). For those who have varicose veins, prolonged standing may be a precipitant for symptoms including swelling and heaviness (Tuchsen *et al.* 2000) resulting in overall discomfort.

Muscle fatigue

Another mechanism which may play a role in discomfort of the lower limb during prolonged standing is muscle fatigue (Balasubramanian *et al.* 2009). Some evidence suggests thigh (quadriceps and hamstring) muscle activity in standing is approximately 2.5 times higher than during sitting (Tikkanen *et al.* 2013). Garcia *et al.* (2015) studied lower limb muscle fatigue in participants who stood for five hours in a laboratory. Participants had five minute rest breaks each hour along with a 30 min break (lunch). Muscle fatigue was not evident after two hours, however, after five hours there was a reduction in muscle twitch force for gastrocnemius and tibialus anterior muscles. In a separate study of standing for five hours with three seated rest breaks, fatigue effects were not evident after two hours, however, there was a decrease in muscle twitch force amplitude after five hours (Garcia *et al.* 2016).

Feet issues

The feet have also been an area of discomfort during prolonged standing (McCulloch 2002, Antle et al. 2015). Messing and Kilbom (2001) compared foot discomfort in standing retail workers and seated office workers. The standing workers had an increased sensitivity of their feet measured via a lower pressure-pain threshold. Those who reported pain in their feet were more frequently observed to be 'leaning' than those who did not report pain. Unfortunately, the observation of 'leaning' was not distinguished as either an asymmetric body position (such as lateral weight shift) or leaning on a counter/support surface. The study authors suggested leaning was used to counteract pain. In another study, pressure-pain threshold, assessed at seven points over the sole of the foot, decreased over time for those who usually stood and was influenced by the type of shoes being worn and amount of walking (Laperriere et al. 2006). The mechanisms which have been suggested for foot discomfort include connective tissue creep, with prolonged loading stretching the ligaments which support the longitudinal and transverse arches (Messing and Kilbom 2001), circulation changes, and prolonged static loading on muscles (Laperriere et al. 2006).

2.6.2.3 Upper limb discomfort with standing and potential mechanisms

In a systematic epidemiological review Coenen *et al.* (2016) concluded there may not be an association between occupational standing and upper limb symptoms. It is worth noting that the studies included in the review were not solely office workers and also included occupations such as nurses, teachers, dentists and rag-pickers. The upper limb physical demands of these manual occupations would be considerably different to office based workers. There is however a limited number of studies of office workers which have focussed on the upper limb and the effect of occupational standing. As outlined in Section 2.3.7, referring to upper limb discomfort when sitting, the task undertaken when standing may have greater influence on development of upper limb discomfort than the work position of standing. A factor which may differ between positions is the movement available in standing and the implications on reach (more movement of whole body rather than extended reach which is postulated to be more likely when on an office chair) (Roelofs and Straker 2002).

An example of this is a field study of bank tellers which found standing for a whole day at work had less upper limb discomfort compared to sitting for a whole day (Roelofs and Straker 2002). The authors postulated that standing was less constrained and allowed greater ease of reach (Roelofs and Straker 2002). Another field study, by Coenen *et al.* (2018), investigated upper limb symptoms in 216 office workers who stood, sat and stepped (walked). The amount of time spent standing did not show any statistically significant association with prevalence of upper limb musculoskeletal symptoms. However, over 80% of the participants reported upper limb symptoms being present in the three months prior to the study. This high prevalence is postulated to be partially a result of those workers who are unable to perform more manual work transitioning to office based work. It is also possible that the office based work may be a factor. Other research on sedentary occupations has included dentists. A study by Barghout *et al.* (2011), of dentists (n=200), found 39% reported shoulder pain and 26% reported hand/wrist pain (Barghout *et al.* 2011). Interestingly, hand and wrist pain was most prevalent in those who worked in standing and least prevalent in those who alternated between sitting and standing. Perhaps more so than other body regions, discomfort in the upper limb is influenced by workplace design, individual work habits and work structure (duties, work flow). As a result, factors with potential to influence upper limb symptoms during prolonged standing appear to be multifactorial.

Workstation design has been an issue in some studies of the upper limb when using alternate work positions. In a field study by Alkhajah *et al.* (2012) which compared use of a sit-stand device to only sitting, the type of equipment used for the sit-stand condition does not appear to have been optimal. An apparatus (Ergotron) was mounted to the desk surface to elevate the screen, keyboard and the mouse. Participants reported insufficient support for their hands and wrists when typing. Discomfort was not measured in that study to establish if the discomfort was evident only when standing and using the apparatus.

A systematic review of laboratory studies of the association between prolonged standing and upper limb musculoskeletal symptoms, found there was limited and inconsistent study findings (Coenen *et al.* 2017b). Some of the laboratory studies in this review were not office based tasks and did not focus on or report in detail upper limb findings (Antle and Côté 2013, Antle *et al.* 2015). Kar and Hedge (2016) found upper body discomfort was lower in standing compared to sitting when undertaking a typing task. The authors of that study did not provide any suggestions as to why standing had less discomfort compared to sitting. It is noted that the standing work position was a fixed height (and unadjusted for individual's height), while during sitting a height adjustable chair was available. The standing work position is likely to have resulted in varying suitability, and therefore discomfort, for participants depending on their height, however it is not clear if this impacted results as the authors did not examine this. Further, each condition was of only 15 minutes duration (repeated twice) and thus discomfort outcomes do not provide information about prolonged positioning.

2.6.2.4 Fine motor dexterity with standing

For office workers, functional use of the upper limb when standing typically requires ability to type and use the mouse efficiently. Evidence suggests standing can negatively impact fine motor dexterity, particularly for high precision tasks, through additional small upper body movements when compared to sitting (Straker *et al.* 2009, Commissaris *et al.* 2014). There may be however, less impact on fine motor tasks from just standing compared to rhythmic movement alternatives such as walking or cycling (Straker *et al.* 2009, Commissaris *et al.* 2014, Tudor-Locke *et al.* 2014). This is postulated to be due to a more stable upper body when standing compared to the rhythmic movement alternatives. Each of the cited studies were undertaken in laboratory settings over acute periods typically up to two hours thus the ability for participants to become conditioned to work in standing was limited.

2.6.2.5 Cognitive functions when standing

With standing there is an expected slight increase in energy expenditure (Barone Gibbs *et al.* 2016). It has been postulated that cognitive functions may be positively affected with moderately increased activity level (Chang *et al.* 2012), however standing may not increase activity level sufficiently to reach this threshold. No epidemiological or field studies were identified which assessed cognitive functions while using a standing only work position. A number of laboratory studies have assessed cognitive functions during standing although duration tended to be considerably less than a full work day (eight hours) and in some cases standing was not prolonged (less than one hour) (Schraefel *et al.* 2012, Commissaris *et al.* 2014, Bantoft *et al.* 2016). Available comparisons of cognitive functions when undertaking standing and sitting have shown mixed results (Russell *et al.* 2016). Bantoft *et al.* (2016) found no significant differences in short term memory and attention between standing, sitting or walking at low intensity over one hour. Russell *et al.* (2016) also found no difference between sitting and standing in selective attention, working memory and work performance. In a study of meetings held in standing and sitting positions, the standing meetings were shorter by 34% and decisions taken during the meetings were assessed to be not any worse than while sitting (Bluedorn *et al.* 1999).

In studies which have found cognitive function differences between standing and sitting there is concern that confounders may have influenced the results. Mullane *et al.* (2017) had participants undertake intermittent standing for varying bouts of between 10 to 30 minutes over a six hour period (compared to only sitting). Cognitive functions testing occurred while participants were sitting, and was scheduled directly after the participants had completed a standing bout, twice per day. Memory, attention and executive functions were higher than the just sitting condition. In this study, the transition to standing, and additional metabolic cost of transitioning compared to simply prolonged standing in the other studies may have had an influence on results. A study by Schraefel *et al.* (2012) which investigated sitting versus standing found there was a negative impact of just-standing on executive functions in the area of complex attention, described as the ability to maintain focus and attention amidst distraction. The work position used during standing had increased neck flexion due to a relatively low position of the laptop (comparative to the participant's eye). The authors did not investigate this and thus it is not known if this had an impact on results.

Studies of cognitive functions when using alternate work positions have also been criticised for having poor design (lack of control group, lack of counterbalancing, failure to account for novelty effects), interpretation of means without reference to significance or effect sizes, and a reliance on self-reported data (Russell *et al.* 2016). The impact of prolonged standing on cognitive functions, both lower and higher order, is not known. Further research which is well designed to reduce likelihood of confounders such as poor positioning is required to determine whether an impact on work performance is expected and under what conditions.

2.6.2.6 Mental state with standing

Standing may have an acute impact on mental state through increased arousal levels (Bantoft *et al.* 2016) secondary to increased cardiovascular system activity (Wollseiffen *et al.* 2016). It is not clear however if standing provides sufficient increase in metabolism to result in the positive effect reported via exercise (Chang *et al.* 2012). Alternatively, rather than improving arousal, standing may provide a restorative effect for those who are already fatigued (Russell *et al.* 2016). There is limited research able to be located for mental state during standing only work. The majority of the research has included sit-stand work stations with autonomy for participants to alternate between conditions as desired. Therefore it is not clear how use of a standing work position over prolonged periods may impact mental state.

Gap: Prolonged standing is known to result in low back and lower limb discomfort. Identification of when standing should be interrupted is required to inform industry. Further examination of variables including low back angle, movement, muscle fatigue and swelling may help to explain mechanisms of discomfort development. The research of prolonged standing and effect on cognitive functions is limited. Understanding the impact of standing on specific cognitive functions important to office workers may influence adoption by industry.

2.6.3 Standing-with-movement

Given the increase of standing work positions for office based workers in industry, research on options which may address the musculoskeletal issues outlined in Section 2.6.2 above is relevant. In the early 1990's Bridger *et al.* (1992) suggested further investigation of use of a footrest to address low back symptoms arising when standing. More recent research which has focussed on prolonged standing has suggested use of a footrest may be a way to facilitate movement on a frequent basis (Gallagher and Callaghan 2015). Should this provide a solution for addressing issues when undertaking prolonged standing, implementation would be feasible as a footrest is readily available and low cost. There are a number of other ways movement could be introduced when standing (see Section 2.5.1) including unstable surfaces (eg mats), shoes (eg non-flat sole) or other equipment (eg rope or bar under a desk).

The remainder of this thesis will consider standing-with-movement to be use of a footrest to raise a foot while standing. The use of a footrest when standing allows postural variety through intentional movement to shift body weight. This alternate raising of feet provides opportunity for changing the loading on weight bearing joints and low back posture. It is not known how standing-with-movement impacts energy expenditure. It was been suggested standing-with-movement may be slightly higher than just standing given the larger movements when using the footrest, compared to shuffling of the feet or unconscious drifts during only standing (Beers *et al.* 2008, Tudor-Locke *et al.* 2014). The amount of movement which occurs when using a footrest in standing and whether this is sufficient to address musculoskeletal issues is not known. It is also not clear how standing-with-movement may impact blood flow, muscle use and metabolism compared to just-standing.

There are no epidemiological or field studies of standing-with-movement specific to use of a footrest. Studies of using a footrest while standing have however been undertaken in laboratories. The few which have assessed use of a footrest or foot-rail while undertaking prolonged standing, have had either fixed use protocols and allowed unconstrained use (Bridger and Orkin 1992, Satzler *et al.* 1993, Rys and Konz 1994, Whistance *et al.* 1995, Son *et al.* 2018).

2.6.3.1 Footrest design

The first known study which trialled use of a footrest, used a footrest at a height of 25cm that was angled approximately 15 degrees toward the participant (Bridger and Orkin 1992). Unfortunately, discomfort was not included as a dependent variable with the study's primary aim being investigating low back posture. A further study by Satzler *et al.* (1993) trialled a flat footrest (8cm high), a footrest with 15 degree angle (with front 8cm high) and a foot-rail (8cm high). Some participants advised that the height of the footrest was too high, others found the inclined surface too steep and some felt unstable with the foot-rail. The authors concluded the two footrests were rated more favourably by participants than the foot-rail, and being without a standing aid was least preferred. A further laboratory study by Whistance *et al.* (1995) trialled use of a foot-rail with participants in bare feet. There was no discussion of the equipment used and how it may have affected results, however, it is anticipated that if used over a prolonged period foot discomfort may have be an issue given the lack of footwear. Based on these studies the impact of equipment design would seem to have important implications in determining both feasibility and benefit.

A more recent study by Son *et al.* (2018) compared footrest height as a percentage of the participants height (5%, 10% and 15% of body height) with no footrest. Thirteen males who had a history of non-specific back pain undertook standing for two hours for each condition. The footrest at 10% of body height was found to result in the lowest muscle fatigue and discomfort. It was not investigated how participants with a history of low back pain, although asymptomatic at time of study, may vary from those healthy individuals and how this may have impacted results.

The remainder of Section 2.6.3 will address discomfort in the body regions of low back, lower limb and upper limb when undertaking standing-with-movement. Possible mechanisms for discomfort will also be discussed. Finally, cognitive functions and implications of using a standing-with-movement work position on cognitive functions will also be discussed.

2.6.3.2 Low back discomfort with standing-with-movement and potential mechanisms

Low back angle

The use of a footrest has previously been recommended to assist with low back pain. Increased posterior pelvic tilt, as occurs acutely when using a footrest, has been found to reduce lumbar lordosis (Bridger and Orkin 1992, Levine and Whittle 1996). In a laboratory study with 30 participants, Bridger and Orkin (1992) found an inclined footrest (15 degrees), which raised the arch of the foot 25cm, resulted in four degrees of increased posterior pelvic tilt. Bridger *et al.* (1992) suggested that as a result of the pelvic tilt change the low back angle would also have altered to have less lordosis, based on previous research by other authors (low back angle was not measured in the study). This change in low back angle is hypothesised to prevent movement toward excessive lumbar lordosis and subsequent additional loading on zygapophyseal joints. The unloading of passive tissues including zygapophyseal joints, joint capsule and intervertebral discs may assist in managing discomfort (Gallagher *et al.* 2014). Changes in low back angle, moving between more and less lumbar lordosis, along with changes in pelvis tilt, has been postulated to attenuate development of discomfort (Gallagher *et al.* 2013). The use of a footrest which facilitates this movement may therefore have merit in reducing low back discomfort during standing.

Whistance *et al.* (1995) also found use of a footrest resulted in more posterior tilt of the pelvis compared to standing without a footrest. In that study, participants undertook the position for 10 minutes while completing a puzzle. The height of the footrest was not detailed, however based on the photographs it appears to have been at mid-calf level. Participants did not perceive footrest use to have considerably less discomfort than other standing positions trialled, however there was an increase in trunk flexion in order to complete the task which may have impacted results. If a more upright position had been trialled, such as would be expected of office workers when using a computer and a raised screen, low back discomfort results may have been different.

The recent study by Son *et al.* (2018) assessed lumbar flexion-extension posture when using footrest of varying heights (level, 5%, 10% and 15% of body height). Kinematic data were collected at baseline for one minute, after one hour, and then finally at study cessation of two hours. Lumbar flexion-extension posture was found to vary between the conditions. Lumbar posture deviation from baseline was lower for the 10% height footrest than the other conditions. The authors suggested that maintaining a spinal posture which did not have excessive lordosis or kyphosis, as was found in the 10% condition, may have been a factor in the reduced discomfort reported by participants. Son et al's (2018) study also found that a difference in footrest height resulted in significant differences in lumbar angle. For pelvic angle, the 10 and 15% of body height footrests did not differ to each other, however all other pairwise comparisons had a significant difference to standing on level ground. These findings confirm suggestions from earlier research (Bridger and Orkin 1992, Levine and Whittle 1996) that lumbar and pelvic angle changes would occur when using of a footrest.

Low back movement

As outlined in Section 2.6.2, for prolonged standing, the movement which occurs can be categorised into three types of movement. Firstly, fast and large movement which returns to the same location (fidget), secondly fast movement from one location to another (shift) and finally slow continuous movement (drift) (Duarte and Zatsiorsky 1999). The intentional movement to raise a foot on the footrest would be expected to result in a shift of body weight.

This shift may be from a starting position of symmetrical standing with both feet on the ground to raising one foot, or an asymmetrical starting position where one foot is already raised and switched with the other foot. Previous research has found non-pain developers tend to use more large body weight transfers than pain developers during prolonged standing (Gallagher and Callaghan 2015). Therefore, a protocol which encourages this type movement, such as alternating use of footrest, may assist in preventing or managing low back discomfort.

Standing with a foot raised on a footrest may be slightly less stable compared to standing with two feet on the ground, and thus may promote smaller or micro-movement in the low back or trunk. A laboratory study by Ganesan *et al.* (2015) investigated postural stability using a footrest (15cm high) via measurement of centre of pressure displacements over two trials of 30 seconds. Movement increased when using a footrest, in both anterior-posterior and medio-lateral directions. Given the short duration (30 seconds per trial) it is not known how this may have changed if undertaken over a prolonged period of time. The continuation of smaller movements when a foot is raised on a footrest, as occurred in Ganesan et al's (2015) study, may also assist in preventing or managing discomfort over longer durations. Gallagher and Callaghan (2015) found non-pain developers used more fidget movements during the first 15 minutes of prolonged standing compared to pain developers. It was postulated that increased movement reduces static loading on lumbar spine passive tissues assisting with discomfort levels. Therefore, controlled instability which has the potential to provide inherent smaller micro-movement as well as larger weight shifts may aid discomfort.

Only three studies were able to be located which measured the frequency of foot alternation (alternately placing a foot on a footrest) in accessing the footrest. In the first, undertaken by Satzler et al. (1993), there was unconstrained use of the standing aids. The aids were a footrest, angled footrest and a foot-rail. Participants were found to move on or off the footrest/foot-rail on average every 90 seconds (Satzler et al. 1993). The foot-rail was used 59% of the time versus 75% for the angled footrest and 83% for the flat footrest. Discomfort did not differ across conditions. There was no analysis of pain developers or non-pain developers and frequency of foot alternation. The second study by Rys and Konz (1989) (cited in Rys and Konz (1994)) had a protocol which required participants to place a foot on a footrest for one minute out of every seven minutes, over a total of 240 minutes of standing. From the available study details there was less discomfort in nine out of 12 body parts when using the footrest compared to standing on level ground discomfort, with significant differences for the heel and neck. The final study used a protocol of 15 minutes for alternation of feet with varying height footrests based on participant height as outlined above (Son *et al.* 2018). The participants all had a history of non-specific low back pain. Use of a footrest was found to result in lower discomfort than not using a footrest. It is possible the chosen sample (previous back pain) may have affected results. Generalisability to the non-low back pain population should be undertaken with caution. Shorter duration of alternation may be preferred by healthy individuals given the considerably higher frequency of movement indicated in the Satzler *et al.* (1993) study. Other studies such as Whistance *et al.* (1995) did not measure frequency of foot alternation however identified this was important for future research.

When given the opportunity for unconstrained movement individuals utilise different movement strategies. The research to date has had considerably different protocols for use of the footrest and studies to date have not examined how pain developers or those with pre-existing conditions may differ to the healthy population. Currently, the evidence does not provide sufficient guidance on the amount of movement which is required to manage discomfort during prolonged standing.

Muscle fatigue

Only one study was able to be located which measured trunk muscle activity while using a footrest. Son *et al.* (2018) measured lumbar erector spinae activity over two hours while standing across four conditions (standing on level ground then three varying height footrests). Trunk muscles EMG was not measured during office type tasks but rather was measured for one minute at baseline and then at 120 minutes while holding an external load (weighing 10% of body weight). Median frequency was lower (considered to be representative of muscle fatigue) after 120 minutes when standing on level ground compared to use of a footrest which was either 10% or 15% of body height. Erector spinae median frequency, when using the 5% body height footrest, however, was not significantly different to when standing on level ground. The results of this study suggest that use a footrest which is at least 10% of body height may have ability to impact lumbar erector spinae muscle fatigue.

Given the limited research able to be located, it is not yet known how use of a footrest while standing may impact trunk muscle fatigue. Other studies have found a sloped surface, which increased posterior pelvic tilt and flattened the lumbar lordosis, resulted in increased erector spinae muscle activity (Gallagher *et al.* 2013). While Dolan *et al.* (1988) found that asymmetrical standing resulted in increased erector spinae activity on the side of the weight bearing leg. Using a footrest requires a large weight shift movement when alternating the raised leg. During the movement a change in the trunk muscles activity, contraction and relaxation, is anticipated. As indicated by Dolan *et al.* (1988), once one foot is raised, trunk muscle activity may increase unilaterally. It is unclear to what extent fidget type movements while one foot is raised may impact static muscle contraction and potential fatigue.

Other studies of muscle fatigue which may aid understanding have compared static standing and more dynamic standing (although without any footrest). Balasubramanian *et al.* (2009) found stationary standing resulted in increased fatigue of erector spinae and trapezius compared to dynamic postures (such as walking). It is acknowledged that the weight shift in using a footrest is not equivalent to the rhythmic contractions as would occur during walking. During walking muscles have a work/rest cycle which will also be impacted by speed of walking and arm swing (Callaghan *et al.* 1999). Slower walking will result in less movement and more static loading (Callaghan *et al.* 1999). When comparing walking to the movement required to alternate a foot on and off a footrest, it is expected that the muscle contraction will be less with accessing a footrest. As such, how this may impact fatigue requires further investigation.

2.6.3.3 Lower limb discomfort with standing-with-movement and potential mechanisms

The impact on of using a footrest when standing on lower limb discomfort varied in previous studies. In the study by Whistance *et al.* (1995), discomfort increased for the supporting leg. The study does not describe whether participants alternated the raised foot within the 10 minutes of the condition. If participants did not alternate, and noting discomfort in the supporting leg, then 10 minutes appears to have been too long. Rys and Konz (1989) (cited in (Rys and Konz 1994)) reported the heel had significantly less discomfort when using a footrest compared to just standing. While nine out of the 12 body parts assessed had lower discomfort when using a footrest, the other body parts do not appear to have been significantly different based on the reporting provided. In Satzler *et al.* (1993) neither condition, standing with or without a footrest, had an effect on discomfort in any of the measured body regions. It is therefore not clear how the footrest impacted discomfort for the entire lower limb, and how discomfort varied between the supporting versus raised leg (Satzler *et al.* 1993, Rys and Konz 1994).

Static loading

Factors which are postulated to contribute to discomfort in the lower limb during standing-with-movement include static loading of passive tissues and swelling. The loading and unloading of lower limb when alternating feet to use the footrest is expected to provide benefit to passive tissues and allow muscle relaxation of the unloaded limb (Gallagher and Callaghan 2015). However, as noted above there is additional loading on the supporting leg. Understanding the effect of timing for alternating foot placement seems to be important to prevent increased discomfort in the supporting leg.

Venous issues

The second factor which is anticipated to contribute to lower limb discomfort during prolonged standing-with-movement is swelling. As outlined earlier in Section 2.6.2.2. Prolonged standing has been found to result in venous pooling. It was outlined in Section 2.6.2.2 that during standing, if minimal movement is occurring, there is likely to be reduced muscle pump action which negatively impacts lower limb swelling (Beebe-Dimmer *et al.* 2005). In standing-with-movement however, larger weight shift movements are expected compared to just standing which may increase the muscle pump action and aid venous return. No studies which examined lower limb swelling during standing and using a footrest have been located. Antle *et al.* (2015) however, compared use of an angled footrest while participants used a high angled seat stool to 'prop' (placing partial body weight through buttocks) on. The study found there was benefit to vascular outcomes compared to just-standing and it was suggested the stool allowed opportunity for postural shifting which may have assisted with venous return. Whilst not directly comparable to use of a footrest while standing, it is noted that there was potential benefit from movement and the inherent muscle pump action assisting with venous return. Further any fidgets found when using a footrest (Ganesan *et al.* 2015) may also assist with the venous return via muscle pump action.

While the evidence base is currently limited in understanding how standing-with-movement using a footrest may impact lower limb discomfort, there appears to be some promise of benefit. One of the aspects which is anticipated to influence outcomes is the time spent on the supporting leg. Further factors are the extent movement through weight shift influences muscle activity levels and muscle pump action to attenuate swelling.

2.6.3.4 Upper limb discomfort with standing-with-movement and potential mechanisms

Studies which have trialled use of a footrest have provided limited details for the upper limb and the impact on upper limb discomfort. Satzler et al's (1993) laboratory study of three standing aids compared to standing without an aid, found no differences for the upper body areas measured (shoulder and neck). The duration was 30 minutes and participants stood in front of a music stand on which reading material was placed. As a result, the upper limb is expected to have been unsupported for the majority of the time. This is not comparable to computer based work where the upper limb is typically supported while using the keyboard or mouse. Rys and Konz (1994) cite their earlier study in 1989 which collected discomfort data for 12 body parts. In the available article, the body parts were not identified. It is noted though that in the results the body areas with highest levels of discomfort are listed. No upper limb body areas are identified as having the highest levels of discomfort. It was also not described what upper limb activity participants undertook during the study and how this may have impacted the results.

One of the concerns in using a footrest for a work position is how this may impact fine motor dexterity, which is particularly relevant for office workers. As outlined above standing-with-movement will result in an asymmetrical posture (Dolan *et al.* 1988). When alternating the raised foot, torso movement is expected with body weight shift. Other smaller fidget micro-movements may also occur. Alternative work positions with rhythmic movement such as cycling and walking have been found to negatively impact fine motor activities (Straker *et al.* 2009, Commissaris *et al.* 2014, Koren *et al.* 2016). As alternating feet on a footrest is an intentional movement and not continuous, it may not impact fine motor dexterity to the extent previously shown for rhythmic work positions.

2.6.3.5 Cognitive functions when standing-with-movement

No epidemiological, field or laboratory studies were able to be located which evaluated cognitive functions while standing using a footrest. It is therefore not known how standing-with-movement may influence cognitive functions. The mechanisms which may result in differences for cognitive functions for standing-with-movement, compared to only sitting and only standing, are potentially small differences in energy expenditure and greater interruption to postural monotony. As outlined above, there may be an increase in postural muscle contraction required during standing-with-movement, which may slightly increase energy expenditure compared to just standing and just sitting (Barone Gibbs *et al.* 2016). Increased intentional movement in standing-with-movement has potential to interrupt postural monotony. This interruption may have a different impact to just standing with no intentional movement requirements and the constant rhythmic movement of under-desk cycling. Previous authors have highlighted that the work positions can impact cognitive functions differently (Labonté-LeMoyne *et al.* 2015) and thus further research is required to clarify how standing-with-movement differs to the other positions.

When using a footstool in standing there is a potential additional dual task demand. Standing in an asymmetrical posture and the increased need for balance control may detract from work task performance (Schwartz *et al.* 2018). Previous research suggests the interaction between position and cognition is a general effect on cognitive processing capacity, rather than just spatial processing when additional demands related to balance are present (Yardley *et al.* 2001, Siu *et al.* 2009). Capacity sharing theory would suggest that increasing postural demand may impact cognitive performance (Pashler 1994). Thus, it is unknown what the cognitive effect of standing-with-movement may be.

In a laboratory study by Barra *et al.* (2015), participants (n=42) stood in an asymmetrical unstable posture (with feet in a line) and completed a cognitive function test of attention which was then compared to sitting. The study found the level of instability when standing with feet in a line did not result in a reduction of cognitive function compared to sitting. It is noted that this study placed participants in a more challenging position from a stability perspective than standing-with-movement is expected to and thus standing-with-movement may have a different effect on cognitive performance. Walking is another work position which results in balance processing requirements. As outlined in Section (2.5.3.2) previous studies have found no detriment in cognitive functions tasks during walking (Alderman *et al.* 2013, Larson *et al.* 2015, Bantoft *et al.* 2016).

It is also not known how standing-with-movement may impact mental state as no studies were able to be located which investigated this. The transitions to raise a foot on a footrest, when standing, may impact postural monotony however research to test this hypothesis is required.

Gap: Standing-with-movement is a novel work position with limited evidence about discomfort for all body parts. Consideration of the mechanisms for discomfort is also limited (low back) or unreported (other body regions). It is not known if standing-with-movement will provide sufficient movement to reduce musculoskeletal symptoms nor what movement pattern (timing of foot raising) is desirable. Further, no research is reported on cognitive functions and standing-with-movement, and thus it is unknown what effect standing-with-movement may have on specific cognitive functions.

2.7 Literature review conclusion

Current literature has identified negative health and cognitive functions concerns related to sedentary behaviour (Katzmarzyk *et al.* 2009, Dunstan *et al.* 2012, Chau *et al.* 2013). For office based workers, their occupation makes a substantial contribution to their overall sitting exposure (Parry and Straker 2013). While efforts are being made to reduce prolonged sitting at work through a range of strategies, industry requires further guidance to aid implementation and prevent or minimise new risks to workers.

One of the strategies to reduce occupational sitting is the use of work position alternatives to sitting, however, more research is required to understand the issues associated with the alternate positions and thus help inform policymakers on optimal strategies to reduce risks and promote productivity (Tudor-Locke *et al.* 2014, Callaghan *et al.* 2015, Huysmans *et al.* 2015).

An important issue for alternative work positions is musculoskeletal discomfort (Neuhaus *et al.* 2014a, Straker *et al.* 2016). Alternative work positions can result in increasing discomfort for specific and different body areas such as gluteal discomfort during cycling and the lower limb during standing. Industry would also benefit from information on the optimal timing for workers to interrupt prolonged sitting or standing to manage discomfort.

Another important issue for industry is any potential work performance impact using an alternative work position. Research on work performance when using alternate work positions has to date primarily included fine motor performance (such as typing and keyboard use) (John *et al.* 2009, Straker *et al.* 2009, Kar and Hedge 2016), industry specific measures (Chau *et al.* 2015b) or self-reported productivity (Alkhajah *et al.* 2012, Pronk *et al.* 2012). Assessment of cognitive functions during use of work positions for a prolonged period has been limited with a number of studies having assessed conditions after only one hour, and in many instances considerably less than one hour (Schraefel *et al.* 2012, Commissaris *et al.* 2014, Oppezzo and Schwartz 2014, Bantoft *et al.* 2016, Koren *et al.* 2016, Torbeyns *et al.* 2016b). Uptake by office-based industry is expected to be assisted by a better understanding of the impact of alternative work positions on cognitive functions underpinning work productivity.

There are potential risks to workers in using alternative work positions without due consideration to implications for musculoskeletal discomfort. Research needs to address when interruption to a prolonged position should occur and identify how this varies for specific alternative work positions. Further, by clarifying which body areas are at risk in each work position and possible mechanisms research may aid in developing recommendations to avoid or manage discomfort. From a cognitive perspective, research should consider specific functions which are important to office workers. This is expected to include ability to maintain attention over longer periods and higher order cognitive function such as complex problem solving. Research addressing the above issues will help inform industry and prevent additional risks while promoting maximum work productivity, both short and longer term. Thus, this research is of benefit to both organisations and their workers.

The following 4 chapters describe two laboratory studies (Study 1 and Study 2) which examined prolonged sitting and three alternative work positions: under-desk cycling, just-standing and standing-with-movement. Discomfort and cognitive functions are assessed in each work position while additional consideration is given to low back angle, movement, muscle fatigue and mental state. Swelling and feasibility were also investigated for just-standing and standing-with-movement.

Chapter 3 Just-sitting

This chapter reports on the discomfort and cognitive function outcomes for just-sitting undertaken in Study 1 and is a verbatim copy of the paper now published in International Journal of Environmental Research and Public Health:

Baker, R., Coenen, P., Howie, E., Williamson, A., & Straker, L. (2018). The short term musculoskeletal and cognitive effects of prolonged sitting during office computer work. International Journal of Environmental Research and Public Health, 15(8), 1678.

Discomfort and cognitive function were assessed regularly while participants maintained sitting for a two hour duration. Discomfort intensity was assessed by body location and cognitive function was assessed using tests of sustained attention and creative problem solving. Mechanisms which may have been responsible for the increases in discomfort were explored including low back angle, movement and muscle fatigue. Mental state was also considered for impact over time. The paper also considered potential correlations between discomfort and cognitive function.

The short term musculoskeletal and cognitive effects of prolonged sitting during office computer work

3.1 Introduction

A rapidly increasing body of evidence supports an association between sedentary behaviour and the risk of adverse health outcomes (Straker *et al.* 2016). These include negative cardiometabolic outcomes such as type two diabetes (Dunstan *et al.* 2012), and some cancers (Schmid and Leitzmann 2014). In addition there is epidemiological evidence of increased risk of premature mortality (Katzmarzyk *et al.* 2009, van der Ploeg *et al.* 2015) and obesity (van Uffelen *et al.* 2010) however this is inconclusive. As sedentary (e.g. office) jobs become more prevalent (van der Ploeg *et al.* 2015) the health risks for office workers are an increasing concern for society and industry. However the impacts of prolonged sitting on musculoskeletal discomfort across the body and on cognitive function are not yet clear.

Prolonged sitting is a potential hazard for workers' musculoskeletal health (Pope *et al.* 2002, Marshall and Gyi 2010). For the low back there is mixed evidence regarding the association between sitting at work and low back pain (Hartvigsen *et al.* 2000, Van Nieuwenhuyse *et al.* 2004). Laboratory studies have found increased discomfort (if not pain) in the low back with prolonged sitting (Sondergaard *et al.* 2010, Karakolis *et al.* 2016). In understanding why discomfort may arise, one hypothesis suggests sustained low level activation and loading of passive tissues (Morl and Bradl 2013) to be responsible. Other hypotheses include postural changes such as flattening of the lumbar lordotic curve with increased sitting time (Le and Marras 2016) and chronic muscle deconditioning due to habitually lower levels of activation (Morl and Bradl 2013) leading to muscle fatigue with prolonged low loading in static postures. In order to understand why discomfort occurs, further research on muscle fatigue and postural factors possibly contributing to the development of discomfort is required.

Whilst a causal relationship between prolonged sitting and work-related musculoskeletal disorders of the lower limbs is not clear (da Costa and Vieira 2010), a number of individual studies have found associations. Studies suggest there may be an association between sitting and buttock pressure and discomfort (de Looze *et al.* 2003, Reid *et al.* 2010). Laboratory studies of prolonged sitting have also reported lower limb discomfort (Sondergaard *et al.* 2010) and suggested a link with lower limb swelling (Winkel and Jorgensen 1986a, Chester *et al.* 2002). During prolonged sitting there is typically minimal leg muscle activity, compared to during more active work positions such as walking or cycling, which may impact vascular return (Reid *et al.* 2010) causing leg swelling. Further, there is a passive load on tissues particularly at the buttock but also the thigh (Makhsous *et al.* 2009). A better understanding of these multifaceted mechanisms including muscle activity and leg swelling which could contribute to discomfort may assist with developing clear protocols to prevent or minimise lower limb discomfort where prolonged sitting is required.

Neck and upper limb symptoms among office workers have been studied more widely, however evidence of an association is mixed. Wærsted *et al.* (2010) concluded from a systematic review that there was limited epidemiological evidence for an association between computer work and neck disorders. For example, Gerr *et al.* (2002) tracked 632 new computer users and found over 50% reported neck and upper limb musculoskeletal issues within 12 months. In considering just the upper limb, da Costa and Vieira (2010) found reasonable evidence supporting computer work to be a risk for wrist/hand discomfort in a systematic review, however they reported a lack of conclusive evidence for shoulder and elbow discomfort. In a field study by Roelofs and Straker (2002) bank tellers had increased discomfort in the upper limb with just-sitting for one day compared to other work positions while a two week study by Davis and Kotowski (2014) found greater discomfort in the upper limb for call centre workers in sitting postures compared to sit-stand work postures. Laboratory studies have also found an increase in neck and shoulder discomfort associated with prolonged sitting (de Looze *et al.* 2003, Sondergaard *et al.* 2010). Despite the lack of consensus of the risk office work presents for the upper limb, it is clear discomfort is evident for some office workers. This has been postulated to be due to increased demands on postural musculature due to the arm being unsupported over prolonged periods (Roelofs and Straker 2002), as well as repetitive movement and increased muscle activity associated with computer work (Wærsted *et al.* 2010). Further clarity of how factors influence upper limb discomfort during sitting will support guidance to industry.

In addition to musculoskeletal risks, concern has also been raised about the impact of sedentary behaviour on cognition, which has potential to affect office workers' performance. Emerging evidence suggests there may be a negative association (Voss *et al.* 2014, Falck *et al.* 2017) between habitual sedentary behaviour and cognition. Considering acute effects, Hasegawa *et al.* (2001) found longer task time during prolonged sitting (90 minutes) resulted in lower work performance. Mental state has also been considered in laboratory studies with self-reported fatigue levels being higher during prolonged sitting compared to other work positions (Thorp *et al.* 2014, Wennberg *et al.* 2016). Field studies which considered sitting compared to a sit-stand work position found sitting resulted in more fatigue and self-rated lower energy level (Dutta *et al.* 2014) as well as reduced focus and productivity (Pronk et al.

2012). Evidence suggests that higher levels of physical activity, such as during exercise, can influence brain function in the short term through acute physiological response including increases in heart rate, oxygen uptake, respiration and blood flow including cerebral blood flow (Perrey 2013). From a longer term perspective higher levels of habitual physical activity have been associated with better levels of cognitive function (Falck et al. 2017). Thus, sitting (with a relatively low energy expenditure (Barone Gibbs et al. 2016)) has potential to result in a decline of cognitive function over time. For knowledge based occupations (such as office workers) where prolonged sitting is required, an understanding of how cognitive function may change over time would assist in guiding recommendations to optimise work performance.

An increasing evidence base suggests there may be health risks from prolonged sitting. Further there may be an increased risk of musculoskeletal discomfort and cognitive decrement. The current study aimed to examine discomfort and two areas of cognitive function over two hours of prolonged sitting. It was anticipated that discomfort would increase and cognitive function would decrease during this period. Sustained attention and more the complex cognitive function of problem solving were selected as cognitive functions likely to be important for knowledge based office work and there may have been differential effects on lower versus higher order cognitive function. A dditional factors of muscle fatigue, low back angle, pelvis movement and mental state were also measured to explore potential mechanisms underlying these anticipated changes. As it was expected that discomfort may affect cognitive function the correlation between these variables was also explored.

3.2 Method

A convenience sample of twenty adults was recruited via personal and professional networks including through a university physiotherapy department. Male participants (n=7) were aged 32 (SD 9.3, range: 20 -45 years) years, with weight 79.6 (4.4) kg and height 180.6 (6.2) cm while female participants (n=13, noting one participant chose not to provide age/weight/height data) were aged 36.2 (7.6, 20 - 45 years) years, with weight 64.2 (15.4) kg and height 166.5 (7.3) cm. All male participants self-identified as undertaking a sedentary occupation while for females 10 identified as sedentary, one as standing and one as undertaking physical work. The inclusion criteria were between 18 – 65 years of age, English and computer literacy and physical ability to undertake sitting for two hours. Exclusion criteria were those for whom workstation set-up was anthropometrically unsuited due to height or girth and those who had known pre-existing pain. One potential participant was excluded.

3.2.1 Design and procedure

This laboratory-based study had a repeated measures design. Participants sat for two hours and were encouraged to remain sitting but were able to fidget or stand briefly if they needed to due to discomfort. Measurements were taken during participant's usual sitting posture (without postural prompting).The independent variable was time sitting and dependent variables were discomfort, cognitive function (creative problem solving and sustained attention), muscle fatigue, low back angle, pelvis movement and mental state. Measures of all dependent variables were taken at commencement and repeated at 30 minute intervals (five measures in total). Participants visited the laboratory prior to study commencement to be familiarised with the procedure and tests.

Participants undertook self-directed computer or paper based activity each two hour period. A desk (A7TR78928H, Steelcase, Sydney, Australia) was adjusted to allow 90 degrees elbow flexion with fingers resting on the home row of the keyboard. The forearms were able to rest on the desk surface with a close to neutral wrist position. A standard adjustable office chair with backrest was used. The top of the computer screen (15 inch, Acer, Taiwan) was altered to participant eye level and a height adjustable footrest (Z rest, Ergolink, Perth, Australia) was used by all participants to allow 90 degrees knee flexion (see Figure 3.1).

Figure 3.1 Participant work position during just-sitting

3.2.2 Dependent variables

3.2.2.1 Discomfort

Participants rated intensity of musculoskeletal discomfort using an electronic (modified) version of the Nordic Musculoskeletal Questionnaire (NMQ). Nine body areas were rated against anchors 0 =*'no discomfort'* and 100 =*'discomfort as bad as it can be'*. The NMQ has been used extensively to identify location and intensity of musculoskeletal discomfort with acceptable reliability (Kuorinka *et al.* 1987). Combined scores were calculated (averaging body areas) for upper limb (shoulder, elbow, wrist/hand), lower limb (hip/thigh/buttock, knee, ankle/feet) and total body (all scores).

3.2.2.2 Cognitive function

The Ruff Figural Fluency Test (RFFT) was used to examine problem solving (Ross *et al.* 2003). The RFFT was chosen as a test which was not overtly novel, thereby avoiding unduly altering attentional level as a result of the testing process (Oken *et al.* 2006). Participants were required to join five dots, within a defined box, to create as many unique designs as possible for one minute per part. Each part had a maximum of 35 possible designs. Two consecutive parts of the five part RFFT were completed each testing session. Participants used their computer mouse to draw the designs, with total number of designs and errors (repeat of design or not within the rules) manually tallied by the researcher. The rules required a design to be contained to that box and not enter a neighbouring box or interlink with a neighbouring figure. Designs with alternate orientation (rotation) were considered unique. The RFFT has shown inter-rater reliability of scoring for unique designs of 0.98 (intra-class correlation coefficients) and for perseveration errors of 0.94 and has evidence of convergent validity with other executive function tests (Ross *et al.* 2003).

Sustained attention was measured using a Go/No-go test, the Sustained Attention to Response Test (SART) (*http://www.millisecond.com/download/library/SART/*). The SART has been widely used (Head and Helton 2014) and requires participants to press the spacebar for all the digits which flash briefly (250ms) on the screen (Go response), except the number three (No-go response), over a period of four minutes 20 seconds. Participants were instructed to respond as quickly as possible whilst concurrently aiming to minimise errors. No-go success (%) and response time (millisecond) were used for analysis.

3.2.2.3 Mental state

A scale based on the Visual Analogue Scale for Fatigue, which has evidence for reliability and validity (Lee *et al.* 1991), was used. The scale consisted of five visual analogue items with anchors of: *'not at all alert/tired/drowsy/fatigued'* to *'extremely alert/tired/drowsy/fatigued'* and *'concentrating was no effort at all'* to '*concentrating was a tremendous chore*'. The scales were computer administered with participants using a mouse to mark their perception. Scores from all items were averaged and normalised to a 0-100 scale for further analysis as a measure of mental state.

3.2.2.4 Muscle fatigue

Muscle activity data was collected for 10 seconds using surface electromyography (EMG), via Octopus AMT-8 EMG Cable Telemetry System (Bortec Electronics Inc., Calgary, Canada), with a sample rate of 2000Hz. Skin preparation was undertaken (area shaved, cleaned with ethyl alcohol and lightly abraded with fine sand paper) before self-adhesive disposable Ag/AgCl (6mm gel diameter) electrodes (Neuroplus, Vermed, New York, USA) were secured with tape over the following muscles: right side upper trapezius (with 20mm centre to centre distance 20mm lateral to the midpoint between the acromion process and C7 spinous process (Veiersted *et al.* 2013)), external oblique (just below the rib cage and along a line connecting the most inferior point of the costal margin and the contralateral pubic tubercle (Dankaerts *et al.* 2004)), lumbar erector spinae (iliocostalis lumborum pars thoracis at L1 spinous process level midway between the midline and the lateral aspect (O'Sullivan *et al.* 2006)), rectus femoris (midway along a line between the anterior superior iliac spine and superior border of the patella (Rouffet and Hautier 2008)) and biceps femoris (midway laterally on the posterior part of the thigh (Rouffet and Hautier 2008)). The common earth electrode was placed on the acromium.

Muscle activity was normalised against submaximal reference voluntary contractions (held for three seconds, repeated three times for each muscle) as follows: upper trapezius (elevating the upper arm in 90 degrees abduction in the scapular plane while seated (Veiersted *et al.* 2013)), external oblique (in supine with hips flexed to 45 degrees and knees flexed to 90 degrees performing a double leg raise 1cm off the supporting surface (Dankaerts *et al.* 2004)), erector spinae and biceps femoris (lying prone position with knees bent to 90° and both knees lifted 5cm off the supporting surface (Dankaerts *et al.* 2004)), rectus femoris (sitting with hips flexed to 90° and the tested knee extended to 45° (Kollmitzer *et al.* 1999) with 2kg weight secured at ankle).

EMG data was band pass filtered (high 10Hz and low 1000Hz) by the amplifier. A customised program (LabView, National Instruments Inc., Texas, USA) was then used to process the EMG data including demeaning, rectifying and finally visual inspection. Muscle fatigue was operationalised using median frequency and normalised amplitude. Amplitude and/or frequency measures have been widely used to indicate muscle fatigue while undertaking prolonged postures (Halim *et al.* 2012, Antle and Côté 2013). Mean median frequency and normalised mean amplitude (as a percentage of middle submaximum voluntary reference contraction) were calculated for each sample and used for further statistical analysis. Reliability and validity of these measures has previously been demonstrated in our laboratory (Dankaerts et al. 2004). Outliers (> 1.5 times the interquartile range) were removed.

3.2.2.5 Low back angle and pelvis movement

Low back angle and pelvis movement were measured using 3 Space Fastrak (Polhemus Navigation Sciences Division, Vermont, USA) with 10 second samples (at 25Hz) (in line with Gallagher and Callaghan (2015). Fastrak is an electromagnetic device which generates a low frequency magnetic field and determines the position and orientation of sensors relative to the field source (Pearcy and Hindle 1989). Sensors at T12, L1 and S2 (based on the protocol by Levine and Whittle (1996)) were secured over spinous processes. The earlier mentioned Labview program calculated a total low back angle (as the angle between T12 and S2 in the sagittal plane) and pelvis movement (as the distance, in centimetres, of transverse plane displacement of the S2 sensor (O'Sullivan *et al.* 2006)) for analysis.

3.2.3 Statistical Analysis

Mixed-models with random intercepts for participants were used to assess changes over time (with five repeated measures over two hours as independent variable) for each of the dependent variables. Data were examined for normality via histogram, and kurtosis and skew statistics. For normally distributed data (cognitive function including problem solving and sustained attention, low back angle and perceived mental state) linear models were used. Skewed data (muscle fatigue, pelvis movement) were logarithmically transformed and then used in linear models (tables present back transformed data). Negative binomial models were used for data with a count distribution (discomfort). Betas (for linear models) and incident rate ratios (IRR, for negative binomial models) together with 95th percent confidence intervals and p-values are reported depicting the change in the respective dependent variables over time. Changes in discomfort greater than 10/100 were considered clinically meaningful based on Hägg et al. (2003) and tested with pairwise comparisons to baseline discomfort using negative binomial models.

To explore potential mechanisms, correlations were examined between changes (measures at baseline compared to 120 minutes) over the two hour period for low back discomfort (with erector spinae and external oblique amplitude and median frequency, low back angle in sagittal plane and pelvis movement in transverse plane), lower limb discomfort (with biceps femoris and rectus femoris amplitude and median frequency and pelvis movement) and upper limb discomfort (with trapezius amplitude and median frequency and pelvis movement). In addition, correlation of total body discomfort with the two areas of cognitive function and mental state were examined. Pearson (normally distributed data) and Spearman (non-normal data) tests were used to assess correlations.

In all analyses, statistical significance was accepted at alpha probability of $p<0.05$. The software used for analysis was STATA (StataCorp 2015, Stata Statistical Software: Release 14. College Station TX: StataCorp LP). Correlations were categorised according to weak $r<0.29$, moderate $r=0.30 – 0.49$, and substantial $r> 0.5$ (Plichta and Kelvin 2013).

3.3 Results

One participant elected to stand briefly once (after completing discomfort rating at the 60 minute time point). At no time during the two hours did the discomfort ratings of this participant reach clinically meaningful levels in any body region (highest rating was 4/100).

Discomfort increased significantly over time across all body areas (see Table 3.1 and Figure 3.2). Pairwise comparisons showed the clinically meaningful discomfort increases from baseline that were apparent by 90 or 120 minutes were also statistically significant for the low back (120 mins IRR=4.20, p=<0.001) and hip/thigh/buttock (90 mins: IRR=14.67; 120 mins IRR=19.75, p=<0.001).

Table 3.1 Discomfort [mean (standard deviation)] over 2 hours of prolonged sitting with incident rate ratio (IRR) for effect of time

Variable	Minutes - group means (sd)					Time effect		
	0	30	60	90	120	IRR	Conf Interval	p value
Discomfort (/100)								
Neck	3.1 (4.2)	3.6 (3.6)	8.7 (10.1)	11.8 (14.9)	11.6 (17.3)	1.38	1.19-1.61	<0.001
Shoulder	2.2 (4.4)	3.1 (3.4)	7.9 (10.9)	10.0 (15.5)	11.1 (17.6)	1.47	1.29-1.67	<0.001
Elbow	0.9 (2.4)	1.9 (2.8)	2.4 (3.9)	3.3 (5.0)	2.4 (3.1)	1.28	1.11-1.47	0.001
Wrist/hand	0.7 (1.6)	1.4 (2.4)	2.4 (4.8)	2.3 (4.3)	2.6 (5.1)	1.30	1.12-1.52	0.001
Upper back	3.5 (7.8)	4.5 (7.6)	8.0 (10.1)	10.8 (15.6)	11.7 (15.4)	1.44	1.25-1.67	<0.001
Low back	4.8 (7.2)	5.5 (6.8)	7.9 (8.4)	12.2 (12.8)	16.3 (14.3)*	1.47	1.32-1.65	<0.001
Hip/thigh/ buttock	1.1 (2.7)	2.2 (4.8)	5.8 (8.8)	11.5 (13.8)*	14.8 (17.5)*	2.19	1.81-2.65	<0.001
Knee	1.5 (3.1)	1.7 (3.2)	3.7 (5.9)	4.7 (8.5)	3.8 (6.8)	1.33	1.16-1.53	<0.001
Ankle/foot	1.0 (2.9)	1.5 (2.1)	2.6 (4.4)	2.9 (3.9)	3.7 (5.5)	1.42	1.20-1.70	<0.001
Upper limb	1.3 (2.0)	2.1 (2.0)	4.2 (5.1)	5.2 (7.1)	5.4 (7.0)	1.38	1.27-1.50	<0.001
Lower Limb	1.2 (2.7)	1.8 (2.6)	4.1 (5.2)	6.3 (7.5)	7.4 (7.5)	1.66	1.48-1.86	<0.001
Total body	2.1 (2.8)	2.8 (2.5)	5.5 (5.0)	7.7 (7.0)	8.6 (7.7)	1.43	1.33-1.53	<0.001

Confidence Interval is 95th

*statistically significant pairwise comparisons of clinically meaningful increases from baseline

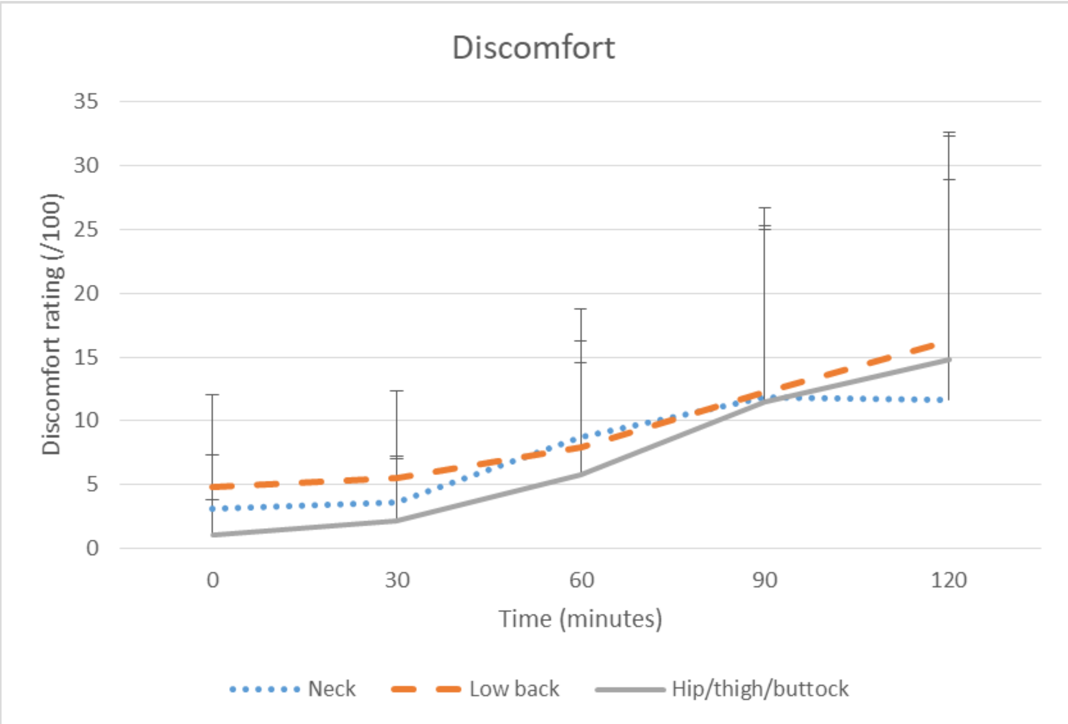

Figure 3.2 Discomfort (mean + standard deviation) for neck, low back and hip/thigh/buttock over two hours prolonged sitting (non transformed data)

There was no significant change over time in sustained attention (No-go success or reaction time). While the mean number of creative problem solving unique designs did not change significantly over time, errors increased significantly over time (group mean at baseline 1.8 [SD 3.2] to 2.8 [3.1] at 120 minutes) with pairwise testing (compared to baseline) also statistically significant at 120 minutes (IRR 1.05, p=0.036) (Table 3.2 and Figure 3.3). Perceived mental state deteriorated over time. Pairwise testing (compared to baseline) showed statistically significant differences at 90mins (β=7.47, p<0.001) and 120mins (β=9.28, p<0.001).

Table 3.2 Cognitive function [mean (standard deviation)] over 2 hours of prolonged sitting with coefficient (Beta) for effect of time

Variable	Minutes - group means (sd)					Time effect		
	0	30	60	90	120	Beta	Conf Interval	p value
Sustained attention								
no-go success (%)	59.4 (29.7)	57.6 (30.1)	54.8 (30.1)	56.2 (27.5)	54.4 (30.7)	-1.14	-2.68-0.40	0.148
reaction time (msec)	375.9 (73.3)	365.4 (68.1)	361.2 (74.1)	373.1 (66.8)	365.5 (62.6)	-1.30	-5.2-2.81	0.534
Problem Solving								
unique designs (n)	42.1 (9.1)	40.2 (8.8)	41.3 (8.5)	43.2 (8.7)	39.6 (8.7)	-0.22	-0.69-0.26	0.372
errors (n)	1.8 (3.2)	1.8 (2.8)	2.3 (3.6)	2.2 (2.3)	2.8* (3.1)	0.25	0.03-0.47	0.026

Confidence Interval is 95^{th}

*statistically significant pairwise comparisons from baseline

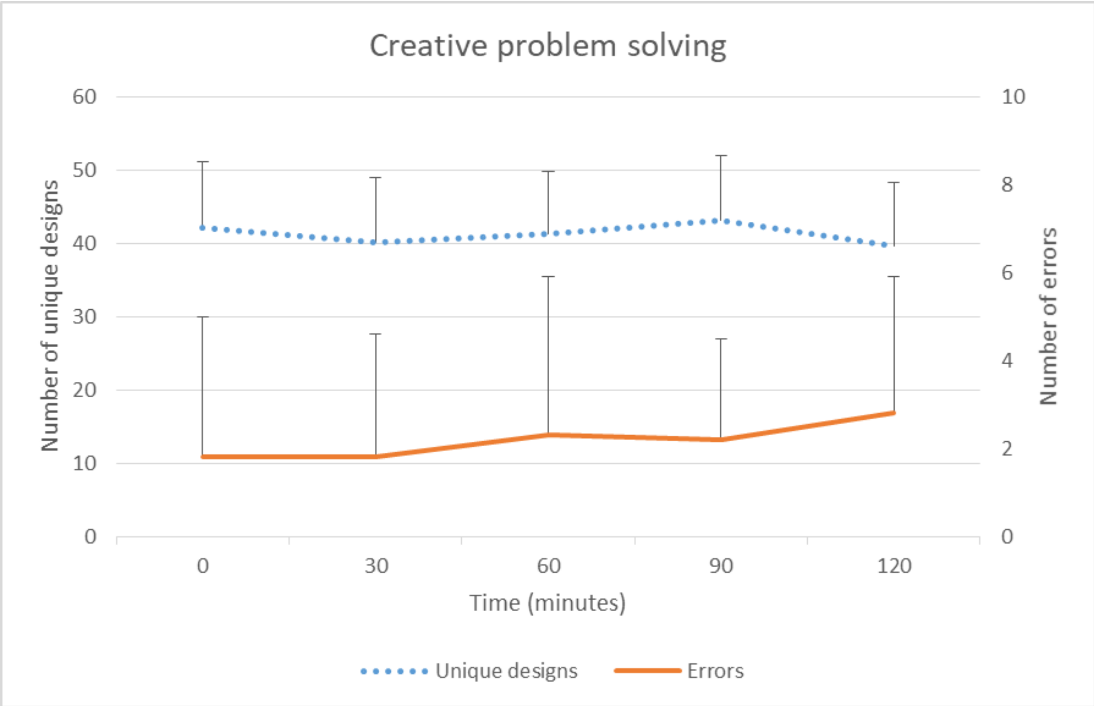

Figure 3.3 Mean (+ standard deviation) creative problem solving (unique designs and errors) over two hours of prolonged sitting (non transformed data)

Samples were taken approximately every three minutes to ensure consistency of the data. Samples either side of those chosen were visually similar. Based on visual inspection for artefacts and checking outliers, EMG data were excluded for specific time points of one participant's erector spinae, five participants' biceps femoris and two participants' external oblique. Amplitude and median frequency of erector spinae, trapezius, rectus femoris, biceps femoris and external oblique muscles did not change significantly over the two hours (Table 3.3). Low back angle (sagittal mean) appeared to change from -5.9 degrees (group mean at baseline) [SD 15.6] to -0.5 degrees [13.4] at 120 mins into less lordosis and closer to usual sitting posture (group mean sitting posture -5.1 degrees). Pelvis movement appeared to increase from 1.6cm/sec [1.0] at baseline to 2.2cm/sec [1.4] at 120 mins over the two hours. However there was no significant time effect for low back angle or pelvis movement.

Table 3.3 Muscle fatigue, low back angle and movement, calf swelling and mental state [mean (standard deviation)] over 2 hours of prolonged standing with coefficient (Beta) for effect of time

Variable	Minutes - group means (sd)					Beta	Confidence Interval	p value
	0	30	60	90	120			
Muscle fatigue (A – Amplitude (% reference contraction), MF- Median Frequency [hertz])								
erector spinae - A	25.6 (48.3)	24.3 (30.3)	20.8 (19.0)	18.2 (16.0)	18.1 (18.3)	1.05^	0.81 – 1.10^	0.532
erector spinae - MF	84.4 (40.1)	82.7 (38.0)	87.7 (44.4)	100.0 (49.0)	99.3 (55.2)	1.10^	1.00 – 1.17^	0.065
trapezius - A	47.6 (124.6)	36.1 (86.7)	46.8 (113.1)	41.2 (112.6)	31.1 (49.8)	0.98^	0.81 – 1.15^	0.710
trapezius - MF	73.3 (16.2)	71.3 (15.5)	70.2 (14.1)	68.4 (13.2)	72.0 (15.5)	1.00^	0.95 – 1.02^	0.459
rectus femoris - A	20.2 (36.7)	19.2 (36.8)	23.2 (38.2)	21.2 (52.2)	25.3 (48.0)	0.98^	0.89 – 1.10^	0.620
rectus femoris - MF	107.4 (68.7)	105.6 (72.5)	99.4 (67.9)	120.3 (81.0)	92.6 (51.6)	0.98^	0.85 – 1.12^	0.786
biceps femoris - A	10.1 (8.2)	11.3 (8.1)	12.7 (14.3)	9.9 (7.7)	12.5 (16.4)	0.93^	0.95 – 1.29^	0.206
biceps femoris - MF	164.7 (63.1)	158.9 (68.0)	151.1 (82.0)	186.7 (63.4)	152.0 (64.1)	1.00^	0.89 – 1.15^	0.884
external oblique - A	17.2 (15.7)	24.9 (28.3)	21.9 (20.9)	22.6 (20.6)	21.5 (20.1)	1.04^	0.92 - 1.20^	0.489
external oblique - MF	77.4 (37.8)	76.8 (50.3)	63.4 (31.7)	70.6 (38.1)	68.5 (39.4)	0.94^	0.87 – 1.26^	0.151
Low back angle (degrees)								
sagittal mean	-5.9 (15.6)	-2.8 (17.0)	-3.3 (17.4)	-3.7 (14.1)	-0.5 (13.4)	0.98	-0.25 – 2.21	0.117
sagittal std deviation	0.3 (0.3)	0.7 (0.7)	1.0 (1.5)	0.4 (0.4)	0.8 (1.4)	0.09	-0.04 – 0.23	0.172
Pelvis movement (cm/second)								
distance	1.6 (1.0)	1.9 (0.8)	2.3 (1.9)	1.9 (1.0)	2.2 (1.4)	1.11^	0.95 – 1.3^	0.178
Mental state (/100)								
perceived mental state	28.0 (18.8)	32.4 (19.3)	31.1 (16.4)	35.4* (19.6)	37.2*(19.1)	2.16	1.10-3.22	<0.001

Confidence Interval is 95% confidence interval, ^ back transformed

*statistically significant pairwise comparisons from baseline

3.3.1 Correlations

Low back discomfort was substantially negatively correlated with external oblique median frequency (r=-0.533) but not with external oblique amplitude, or erector spinae (amplitude or median frequency), low back angle (mean or standard deviation) or pelvis movement (see Table 3.4). Lower limb discomfort was not significantly correlated with biceps femoris and rectus femoris muscle amplitude or median frequency, or pelvis movement (see Table 3.5). Upper limb discomfort was not correlated with trapezius amplitude or median frequency or pelvis movement (see Table 3.6). Total body discomfort had a moderate correlation with creative problem solving errors (rho=0.480, p=0.032), approached significance with mental state (rho=0.423, p=0.063), however was not significantly correlated with unique designs, No-go success, or reaction time (see Table 3.7).

Table 3.4 Change score correlations (r) for low back discomfort and low back angle, pelvis movement and muscle fatigue amplitude (A) and median frequency (MF) measures over 2 hours prolonged sitting

	Low back discomfort	Usual sit (mean sagittal)	Usual sit (SD sagittal)	Erector Spinae (A)	Erector Spinae (MF)	External Oblique (A)	External Oblique (MF)	Pelvis movement
Low back discomfort, r	1.000							
Usual sit (mean sagittal), r	-0.269	1.000						
(p value)	0.252							
Usual sit (SD sagittal), r	0.297	-0.422	1.000					
(p value)	0.204	0.064						
Erector spinae (A), r	-0.140	-0.290	0.477	1.000				
(p value)	0.569	0.229	0.039					
Erector spinae (MF), r	0.374	-0.175	-0.263	-0.489	1.000			
(p value)	0.115	0.474	0.277	0.034				
External Oblique (A)	0.170	0.153	0.058	0.036	-0.117	1.000		
(p value)	0.530	0.571	0.831	0.894	0.665			
External Oblique (MF)	-0.533	0.427	-0.123	0.058	-0.461	-0.175	1.000	
(p value)	0.028	0.087	0.638	0.824	0.062	0.516		
Pelvis movement, r	0.380	-0.310	0.760	0.582	-0.348	0.079	-0.014	1.000
(p value)	0.098	0.184	<0.001	0.009	0.144	0.772	0.959	

Table 3.5 Change score correlations (r) between lower limb discomfort, muscle fatigue [amplitude (A) and median frequency (MF)] and pelvis movement over 2 hours prolonged sitting.

	Lower limb discomfort	Biceps femoris (A)	Biceps femoris (MF)	Rectus femoris (A)	Rectus femoris (MF)	Pelvis movement
Lower limb discomfort , r	1.000					
Biceps femoris (A), r	-0.114	1.000				
(p value)	0.652					
Biceps femoris (MF), r	0.072	-0.510	1.000			
(p value)	0.799	0.052				
Rectus femoris (A), r	0.288	0.118	0.221	1.000		
(p value)	0.233	0.653	0.447			
Rectus femoris (MF), r	-0.084	-0.291	0.312	-0.595	1.000	
(p value)	0.734	0.258	0.277	0.007		
Pelvis movement, r	0.243	0.729	-0.361	0.310	-0.196	1.000
(p value)	0.301	0.001	0.186	0.196	0.421	

Table 3.6 Change score correlations (r) between upper limb discomfort, muscle fatigue [amplitude (A) and median frequency (MF)] and pelvis movement over 2 hours prolonged sitting.

	Upper limb discomfort	Trapezius (A)	Trapezius (MF)	Pelvis movement
Upper limb discomfort , r	1.000			
Trapezius (A), r	0.101	1.000		
(p value)	0.673			
Trapezius (MF), r	0.102	0.501	1.000	
(p value)	0.668	0.022		
Pelvis movement, r	-0.168	0.234	0.558	1.000
(p value)	0.479	0.281	0.011	

Table 3.7 Change score correlations (rho) between total body discomfort, creative problem solving, sustained attention and mental state over 2 hours prolonged sitting

	Total body discomfort	Creative problem solving		Sustained attention		Mental state
		Unique designs	Errors	No-go success	Reaction time	
Total body discomfort, rho	1.000					
Unique designs, rho	0.157	1.000				
(p value)	0.508					
Errors, rho	0.480	-0.294	1.000			
(p value)	0.032	0.208				
No-go success, rho	-0.121	0.292	0.200	1.000		
(p value)	0.611	0.212	0.397			
Reaction time, rho	-0.053	0.383	0.101	0.795	1.000	
(p value)	0.823	0.096	0.672	<0.001		
Mental state, rho	0.423	-0.226	0.398	0.013	-0.028	1.000
(p value)	0.063	0.338	0.082	0.957	0.906	

3.4 Discussion

The current study examined discomfort, cognitive function, muscle fatigue, low back angle, pelvis movement and mental state over two hours of prolonged sitting. Discomfort increased significantly across all body areas with low back rated highest. There was a deterioration in creative problem solving errors over time and a negative impact on mental state during prolonged sitting. There were no effects on muscle fatigue, low back angle or pelvis movement over time.

In congruence with a number of laboratory studies, discomfort increased with time for the low back (Karakolis *et al.* 2016), lower limb (Winkel and Jorgensen 1986a) and also the upper limb (Kar and Hedge 2016). Clinically meaningful increases were evident for low back (10 participants) and hip/thigh/buttock (nine participants) discomfort. Discomfort related to sitting is thus a potentially important issue for office workers, requiring greater understanding and consideration of interventions.

Low back discomfort had a clinically meaningful increase in discomfort at the end of the 120 minutes of prolonged sitting, suggesting a posture break should be taken before 120 minutes of prolonged sitting. Despite low back discomfort being correlated with an external oblique fatigue indicator (median frequency), there was no evidence of erector spinae or external oblique fatigue (i.e. increased amplitude or decreased median frequency) over the two hours of sitting. While evidence suggests sitting can result in increased erector spinae muscle activation, muscle activity level varies depending on the posture assumed (Harrison *et al.* 1999, Makhsous *et al.* 2009). There was a change in low back angle to less lordosis over time, which is in line with prior evidence (Pope *et al.* 2002, O'Sullivan *et al.* 2012b). Castanharo *et al.* (2014) has previously suggested passive tissue stress to be less with greater anterior tilt and the lumbar spine closer to neutral, resulting in less discomfort. Although not evident in the results from this study, it is postulated that over a longer duration the increase in posterior tilt may contribute to more passive tissue stress and thus discomfort. In contrast, the lack of increase in pelvis movement was not expected. O'Sullivan *et al.* (2012a) found those with discomfort adopted a more static end-range sitting position with less frequent micro-movements, but large infrequent shifts in posture during sitting. This is in line with Fenety *et al.* (2000) who found fidgets increased with sitting time. The data capture sampling period of 10 seconds in the current study may have missed irregular movement and thus not reflected the full amount of movement undertaken. Therefore whilst not evident in our study, the lack of movement may have been a contributor to discomfort. Further research of movement patterns during prolonged sitting preceding discomfort, may help to understand the adoption of preventative movement strategies versus movement to alleviate discomfort.

Hip/thigh/buttock had a clinically meaningful increase in discomfort at 90 minutes which was also statistically significant (which was earlier than for the low back). Discomfort in the hip/thigh/buttock area is postulated to have some relationship with gluteal pressure (Reid *et al.* 2010). Sondergaard *et al.* (2010) separated buttock and thigh regions and found discomfort in the buttock was rated considerably higher than the thigh. This may in part be attributed to the pressure distribution in sitting. Makhsous *et al.* (2009) found a concentration of higher pressure around the ischial region of the buttocks compared to the thigh. In the remainder of the lower limb, although knee and ankle/foot discomfort increased over time neither reached clinically meaningful levels. Winkel and Jorgensen (1986a) studied eight hours of seated work and found increased foot swelling and decreased foot temperature, when there was minimal leg movement in sitting. Lower limb discomfort was not correlated with pelvis movement in the current study. It was postulated that increased pelvis movement may assist to relieve discomfort in the gluteal region (Sondergaard *et al.* 2010) but potentially has less benefit for the lower leg. There may be other factors which were not measured, such as swelling and blood flow, which may help to understand mechanisms underlying lower limb discomfort. Further research which separates thigh and buttock discomfort measures and considers lower limb swelling may help to understand the mechanisms for buttock and lower leg discomfort better.

Despite statistically significant increases in discomfort in all upper limb areas, changes from baseline did not reach clinically meaningful levels. The increase in the neck and shoulder discomfort appeared greater than elbow and wrist/hand increases. Neck discomfort for office workers has been found in a number of studies (Janwantanakul *et al.* 2008, Wærsted *et al.* 2010) and has been associated with neck flexion. For the upper limb, field and laboratory studies have found discomfort to be greater in just-sitting than other work postures such as sit-stand (Roelofs and Straker 2002, Davis and Kotowski 2014). This finding has been postulated to be a result of increased loading on neck and shoulder muscles when sitting (Roelofs and Straker 2002). In the current study participants had autonomy over the tasks undertaken and as a result there may have been individual differences in duration of a specific posture (such as neck flexion) or repetitive movements (e.g. using mouse or keyboard). In the workplace there may be more or less autonomy in task performance and duration which may influence discomfort. As this study was for two hours duration, discomfort may increase more over a longer duration and thus reach clinically meaningful levels. To gain a clear understanding of neck and upper limb discomfort in office workers an accurate description of the pattern of tasks performed may be important.

The current study found a decline in cognitive function over prolonged sitting in the form of increased creative problem solving errors, although performance in generating unique designs did not change over time and there was no change in sustained attention. Mental state was perceived to decline from 90 minutes. The increase in errors is consistent with other evidence showing working in prolonged positions led to poorer cognitive function than working with interruption and adoption of an alternate work position (Mullane *et al.* 2017). On the other hand, some studies have failed to find a significant difference in cognitive function (including executive tasks, memory and attention) over periods of uninterrupted sitting (Wennberg *et al.* 2016) and in studies with shorter periods (Russell *et al.* 2016). It is noted, however, that not all studies of cognitive function have considered the same attributes or over the same length of time which reduces the ability to make direct comparisons (Schraefel *et al.* 2012). The results of the current and other studies show that prolonged uninterrupted sitting can negatively impact cognitive function.

For sustained attention this study found no significant change in reaction time and No-go success. It is known that sustained attention has a tendency to deteriorate with time-on-task (Thomson *et al.* 2015). In the current study, the lack of decrement may have been due to the self-directed tasks performed by participants being able to keep participants relatively alert. Alternatively the testing itself (approximately four minutes every 30 minutes) may have been perceived as a novelty and resulted in an increase in attention. Interestingly although sustained attention was maintained, there was a concurrent finding of deterioration in mental state. However the change in mental state was relatively small given the possible response range. In considering wider measures of attention and perceived mental state, other studies have considered mental fatigue. Wennberg *et al.* (2016) found there was an increase in mental fatigue over four hours of prolonged sitting, along with a decrease in heart rate and altered neuroendocrine biomarkers, potentially reflecting an influence on the autonomic nervous system. It has been suggested that the relatively low energy expenditure and metabolic rate of prolonged sitting (Barone Gibbs *et al.* 2016) has potential to negatively impact brain health (Voss *et al.* 2014) and thus potentially effect cognitive function. In contrast, higher energy expenditure has been linked with changes in metabolism including cerebral blood flow (Perrey 2013) and oxygenation (Rooks *et al.* 2010). It is clear that the factors influencing cognitive function and mental state are likely to be multifaceted. Research comparing just-sitting to alternate work positions with higher energy expenditure may provide greater understanding.

Results of the current study showed a significant moderate correlation between total body discomfort and cognitive function errors and moderate but not statistically significant association with mental state. Pronk *et al.* (2012) found in a field study that by reducing periods of prolonged sitting there was reduced pain and improved productivity and focus. However, studies which have considered the correlation between discomfort and cognitive function are limited and have focused on integrated work productivity tasks such as typing rather than more discrete cognitive function tests (Liao and Drury 2000, Haynes and Williams 2008). A change in physical state, such as discomfort, has been hypothesised to be related to changes in the allocation of attention resources (Tomporowski 2003) although this was not conclusively evident through the measures in this study. Whilst the current study found some evidence of acute deterioration in cognitive function during sitting, there are also concerns that chronic sedentary behaviour has potential to negatively influence cognitive function more substantially (Voss *et al.* 2014, Falck *et al.* 2017). Research of mechanisms not considered in this study, such as autonomic nervous system activity, may assist in understanding the long term effect of chronic uninterrupted seated work on cognition.

3.4.1 Strengths and limitations

This study used a strong design (within participant, repeated measures) and included an elaborate range of variables to characterise the effect of prolonged sitting on discomfort and cognitive function as well as potential mechanisms such as muscle fatigue and lumbar posture and movement. It is acknowledged however that the convenience sample, laboratory setting and test protocol may have influenced the results and thus generalising results should be undertaken with caution. For example the sensors on their low back may have impacted discomfort ratings. In addition data capture may not have been of sufficient duration to show changes for some sporadic or irregular movement. The lightly controlled tasks performed by participants may have increased random variance. One person did stand once (briefly) during the two hours, however their level of discomfort did not influence overall findings. It is also acknowledged that individual factors such as motivation may have influenced cognitive function results. Further it is acknowledged that correlation results outlined which are suggestive of a relationship between variables require further exploration. The number of statistical tests performed raises the issue of type 1 errors, the over interpretation of which was minimised by examining the pattern of response over repeated measures and across multiple dependent variables.

3.5 Conclusion

This study found acute negative effects during two hours of prolonged sitting with clinically meaningful increases in discomfort in the low back and hip/thigh/buttock areas. Regarding cognitive function, some deterioration in creative problem solving was observed, but there was no impact on sustained attention during prolonged sitting. No significant changes in muscle activation, low back angle and pelvis movement were found. Increasing body discomfort had a moderate correlation with cognitive function suggesting potentially important relationship between them. The observed findings suggest sitting for prolonged periods may have consequences for musculoskeletal discomfort and cognitive function in the short term and breaks to change position are recommended.

Chapter 4 Just-sitting and under-desk cycling

This chapter compares the discomfort and cognitive function outcomes for just-sitting and under-desk cycling undertaken in Study 1 and is a verbatim copy of the paper published in Applied Ergonomics:

Baker, R., Coenen, P., Howie, E., Williamson, A., & Straker, L. (2019). The musculoskeletal and cognitive effects of under-desk cycling compared to sitting for office workers. Applied Ergonomics, 79, 76-85.

Discomfort and cognitive function were assessed regularly while participants maintained just-sitting and sitting while under-desk cycling each for a two hour duration. Discomfort intensity was assessed by body location and cognitive function was assessed using tests of sustained attention and creative problem solving. The paper considered the potential mechanisms which may explain the differences in discomfort between the two conditions. For cognitive function mechanisms are considered which may have influenced results including dual task implications and energy expenditure. Mental state ratings are also compared between the two conditions.

The musculoskeletal and cognitive effects of under-desk cycling compared to just-sitting for office workers.

4.1 Introduction

There is an increasing body of evidence supporting a negative association between a sedentary lifestyle and health (Dunstan et al., 2012). Health issues of concern include cardiometabolic risk, type two diabetes (Dunstan et al., 2012), some cancers (Schmid and Leitzmann, 2014) and musculoskeletal discomfort and disorders (Marshall and Gyi, 2010; Straker et al., 2016). For office workers, their work contributes a considerable proportion of their overall sedentary time (Parry and Straker, 2013). As a result there is an interest in considering alternative work positions. The alternative office work positions being promoted include sit-stand desks, use of a treadmill (walking) and cycling (Davis and Kotowski, 2015). It is not clear however, whether a change in work position to another static posture such as standing will sufficiently ameliorate the health risks of sedentary behaviour (Callaghan et al., 2015). A movement work position such as cycling may be a better solution. Studies of office workers performing cycling during their work day are limited and it is therefore not clear what impact it may have on the musculoskeletal system and cognitive performance (Davis and Kotowski, 2015).

The field and laboratory studies which have considered cycling as a work position have not evaluated discomfort as a dependent variable, however discomfort and feasibility issues have been raised. Carr et al. (2013) conducted a field study using a portable pedal device and found participants' knees were hitting the underside of the desk. In a laboratory study using a recumbent cycle, Elmer and Martin (2014) commented that none of the participants reported noticeable seat related discomfort however knee clearance was an issue and an altered upper limb position was required. As a result they expressed concern that having the keyboard higher than usual may result in additional muscle activity to elevate the arms and shoulders. In a further laboratory study, Straker et al. (2009) reported discomfort from an upright cycle seat, however the seat had not been customised for office use. As upright cycles typically do not have a backrest, this may also lead to discomfort if used over an extended period (Davis and Kotowski, 2015). Research is required to identify whether discomfort will be an issue if under-desk cycling is adopted for use in office workplaces.

Cycling, with the movement it creates, may assist in addressing some of the musculoskeletal issues with prolonged static sitting. Field and laboratory studies have found increased discomfort in the low back (Karakolis et al., 2016; Schinkel-Ivy et al., 2013) and the lower limb (Sondergaard et al., 2010) with prolonged sitting. Field studies have also found increased discomfort in the upper limb when working in sitting compared to other work positions (Davis and Kotowski, 2015; Roelofs and Straker, 2002), while laboratory studies have found an increase in neck and shoulder discomfort (de Looze et al., 2003; Sondergaard et al., 2010) associated with prolonged sitting.

In understanding why discomfort may arise during static sitting, hypotheses have suggested muscle fatigue from sustained low level activation and also passive tissue loading (Morl and Bradl, 2013). Other hypotheses suggest postural changes, such as flattening of lumbar lordotic curve with increasing time spent sitting (Le and Marras, 2016), and minimal leg muscle use, which may influence vascular return and swelling (Winkel and Jorgensen, 1986) to be mechanisms for discomfort development. Use of the large leg muscles when cycling, as well as trunk muscles for stabilisation, may unload passive tissues. Additionally muscle pump action may assist with venous return and positively influence trunk and lower limb discomfort. Conversely, too much cycling (time, speed and/or resistance) may fatigue leg and trunk muscles and lead to discomfort. Therefore understanding the correct protocol for use, in order to manage discomfort, is required before implementation in workplaces.

Another potential barrier to implementation of under-desk cycles in office workplaces is the perception of a negative impact on work performance. A number of studies have considered the impact of cycling (of various types) on work performance. Tudor-Locke et al. (2014) undertook a review of cycling studies and concluded there was considerable negative impact on work productivity, in particular in the use of a mouse. This has been postulated to be due to the less stable torso compared to just-sitting (Commissaris et al., 2014).

When considering the influence of cycling on the cognitive function underlying work productivity, evidence to date is mixed and therefore any association remains unclear. Studies have evaluated varying cognitive functions using varying testing protocols and thus comparison between studies is difficult. Torbeyns et al. (2016a) conducted an office workplace study and found no difference in memory and attention. Commissaris et al. (2014) also found there were no significant differences in perceptual performance, attention and executive memory between cycling and just-sitting. An exception was working memory accuracy which declined when performing higher intensity cycling. Further to this, a small (n=9) study by Mullane et al. (2017) found cognitive performance scores were higher in low intensity cycling for psychomotor function, working memory and executive functions compared to just-sitting. In this study the cycling was intermittent (in bouts of 10-30 minutes, totalling 2.5 hours) over an 8 hour day. Torbeyns et al. (2016b) also found cycling had a positive effect however only for attention (but not on memory) compared to just-sitting.

Interestingly, Sliter and Yuan (2015) found while participants (n=192) reported higher arousal when under-desk cycling compared to just-sitting, non-standardised testing (web based search tasks) found no difference between conditions. It has been postulated that, compared to more static work positions such as sitting (John et al., 2015), increased muscle contractions might improve cognitive function due to changes in blood flow and metabolism (Perrey, 2013; Rooks et al., 2010). The influence of movement on brain activation and thus cognitive function is complex (Brümmer *et al.* 2011), with outcomes influenced by duration and intensity of exercise, individual level of fitness and type of cognitive function being assessed (Chang et al., 2012). It is unclear what impact light activity, such as use of an under-desk cycle, may have.

Under-desk cycling may be a feasible tool to reduce sedentary time at work if more evidence is provided to inform industry that discomfort can be managed and productivity maintained. Therefore the current study aims to add to the current evidence base by testing whether the use of an under-desk cycle, compared to just-sitting, influences discomfort and cognitive function over a period of two hours. Muscle fatigue, low back angle, pelvis movement and mental state were also measured to gain a better understanding of underlying mechanisms.

4.2 Method

4.2.1 Participants

Twenty adults were recruited to participate in the study via personal and professional networks. Inclusion criteria were aged between 18 – 65 years, English and computer literate, anticipated physical ability to undertake light activity (under-desk cycling) and prolonged sitting (non-cycling) over two hours. Participants for whom workstation set up was unsuited due to height or girth or who had known pain in response to activity or prolonged sitting were excluded. One potential participant was excluded due to very tall stature. (see Table 4.1 for descriptive statistics).

Table 4.1 Descriptive details of the study sample (just-sitting and under-desk cycling)

Participant provided information	Mean (SD)
Age	35 (8.0)*
Gender	13 female, 7 male
Weight (kg)	69.8 (14.3)*
Height (cm)	171.5 (9.6)*
Occupational Category:	Number of participants
1. Sedentary occupation	18
2. Standing occupation	1
3. Physical work	1

* = data for 19 participants (1 participant chose not to provide descriptive data)

4.2.2 Design and procedure

In the current within-participant laboratory-based study, participants attended two testing sessions where they either just sat or performed under-desk cycling (each for two hours). Participants were able to fidget or stand up briefly if required but were otherwise encouraged to remain sitting. At the commencement of each session measurements of all dependent variables were taken, and then again every 30 minutes (five measures in total). Participants continued cycling whilst completing the measurements and were observed to cycle continuously over the two hours. The dependent variables were musculoskeletal discomfort, cognitive function (creative problem solving and sustained attention), muscle fatigue, spinal kinematics and mental state. Participants undertook the two conditions in a random order (using a coin toss) approximately one week apart, at a similar time of day. The coin toss resulting in a split of 9/11 for order of conditions. Participants were familiarised with the procedure and tests through a visit to the laboratory prior to study commencement.

A height adjustable desk (A7TR78928H, Steelcase, Sydney, Australia) with standard ergonomic adjustable chair was used for both conditions. Optimal desk height for under-desk cycling (lowest level possible whilst still allowing acceptable knee clearance) was used across both conditions (see Figures 4.1 and 4.2). A height adjustable footrest (Z rest, Ergolink, Perth, Australia) was used during just-sitting. A Desk-cycle (Magnetrainer, Sydney, Australia) (see Figure 4.3) was used for the under-desk cycling condition and was set at the lowest resistance level (free-wheeling). Participants were instructed to cycle at a comfortable slow pace (no control over cadence was implemented). Participants undertook self-directed computer or paper-based tasks between the testing periods. Participants were asked to avoid consuming refreshments other than water during the testing.

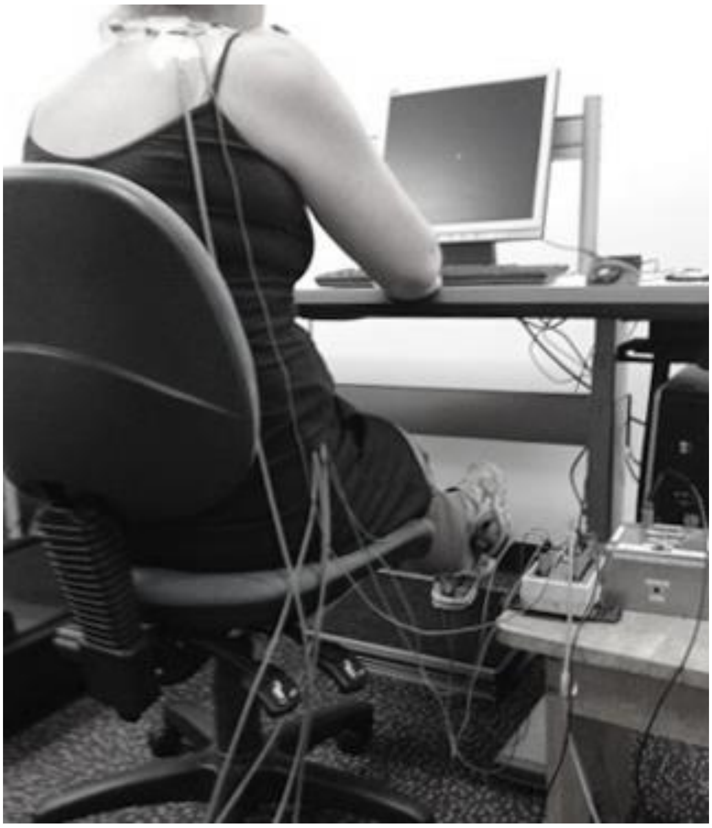

Figure 4.1 Participant position during just-sitting

Figure 4.2 Participant positions during under-desk cycling

Figure 4.3 Under-desk cycle used by participants

4.2.3 Dependent variables

4.2.3.1 Musculoskeletal discomfort

Musculoskeletal discomfort was measured using an electronic (modified) Nordic Musculoskeletal Questionnaire (NMQ) which required participants to rate intensity of musculoskeletal discomfort on a scale with anchors of 0 = 'no discomfort' and 100 = 'discomfort as bad as it could be' across nine bodily areas. The modified NMQ has been used extensively to identify musculoskeletal discomfort and has been considered to have acceptable reliability (Kuorinka et al., 1987). Scores for individual bodily areas and scores for upper limb (averaged over shoulder, elbow, wrist/hand), lower limb (average over hip/thigh/buttock, knee, ankle/feet) and total body (average of all body area scores) discomfort were calculated for analysis.

4.2.3.2 Cognitive function

The Ruff Figural Fluency Test (RFFT) is considered a test of problem solving and executive cognitive function due to the requirement for mental productivity whilst continually monitoring for perseveration errors (Ross et al., 2003). Participants were required to develop as many unique designs as possible using the five dot pattern provided, without repetition. The

RFFT has evidence of convergent validity with executive function tests and inter-rater reliability (intra-class correlation coefficients for unique designs 0.98 and 0.94 for perseveration errors) (Ross et al., 2003). Participants completed two (of five) consecutive parts of the RFFT each testing session using the computer mouse to draw the designs. Number of unique designs (manually tallied by the researcher) and errors were used for analysis. To determine errors the participant needed to follow certain rules and violation of these resulted in an error being recorded. The rules were: a design had to be contained to a box and could not enter a neighbouring box, designs could not interlink with a neighbouring figure and finally a design could not be repeated. Designs with alternate orientation (rotation) were however considered unique.

Sustained attention was measured using the Sustained Attention to Response Test (SART) which requires withholding a response on an infrequent basis (Manly *et al.* 1999), 1999) over four minutes 20 seconds (http://www.millisecond.com/download/library/SART/). Participants used their dominant hand to press the spacebar as quickly as possible to all digits (Go response) except the number three (No-go response), which flashed briefly (250ms) on the screen, while also aiming to minimise errors. Analysis was undertaken of No-go success (%) and response time (milliseconds).

4.2.3.3 Muscle fatigue

Muscle activity was collected for 10 second periods using surface electromyography (EMG) via Octopus AMT-8 EMG Cable Telemetry System (Bortec Electronics Inc., Calgary, Canada) with a sample rate of 2000Hz. Standard skin preparation (shaved, cleaned with alcohol and lightly abraded with fine sand paper) was completed before self-adhesive disposable Ag/AgCl (6mm gel diameter) electrodes (Neuroplus, Vermed, New York, USA) were secured with tape. Muscles from which data was collected were right side upper trapezius (with 20mm centre to centre distance 20mm lateral to the midpoint between the acromion process and C7 vertebra (Veiersted et al., 2013)), external oblique (slightly below the rib cage along the line connecting the most inferior point of the costal margin and the contra-lateral pubic tubercle (Dankaerts et al., 2004)), lumbar erector spinae (at L1 spinous process level equidistant between the midline and the lateral aspect of the participant's body (O'Sullivan et al., 2006b)), rectus femoris (halfway along a line between the anterior superior iliac spine and superior patella border (Rouffet and Hautier, 2008)), biceps femoris (midway laterally on the posterior thigh (Rouffet and Hautier, 2008)) and the common earth electrode was placed over the acromium.

Submaximal voluntary contractions, to allow amplitude normalisation, were held for five seconds and repeated three times for: upper trapezius (participant seated elevating the upper arm to 90 degrees abduction in the scapular plane (Veiersted et al., 2013)), external oblique (participant lying supine with hips flexed to 45° and knees flexed to 90° performing lifted both legs 1cm off the plinth (Dankaerts et al., 2004)), erector spinae and biceps femoris (participant prone lying with the knees bent to 90°, both knees lifted 5cm off the plinth (Dankaerts et al., 2004)) and rectus femoris (while sitting with hips flexed to 90° and a 2kg weight secured around the ankle, the tested knee was extended to 45° (Kollmitzer et al., 1999)). EMG data were high pass (10Hz) and low pass (1000 Hz) filtered by the amplifier. Data was processed using a customised program (LabView, National Instruments Inc., Texas, USA) and visually inspected for artefacts. For statistical analysis muscle fatigue was characterised as normalised (to the middle submaximal contraction) amplitude and median frequency. Outliers (>1.5 times the interquartile range) were removed.

4.2.3.4 Spinal kinematics

Low back angle and pelvis movement were measured for 10 second periods using Space Fastrak (Polhemus Navigation Sciences Division, Vermont, USA) at a 25Hz sample frequency (Pearcy and Hindle, 1989). Sensors were secured over spinous processes at T12, L1 and S2 (based on the protocol by Levine and Whittle (1996)) and used to measure sagittal plane postural angles of the lumbar spine. The previously mentioned LabView program was used to calculate total low back angle (the angle between T12 and S2 sensors in sagittal plane) and pelvis movement (distance in centimetres of transverse plane displacement of the S2 sensor (O'Sullivan *et al.* 2006)), which were used for further statistical analysis.

4.2.3.5 Mental state

Perceived mental state was measured using five visual analogue scales. The five scales used had anchors of: ‘not at all alert/tired/drowsy/fatigued’ to ‘extremely alert/tired/drowsy/fatigued’ and ‘concentrating was no effort at all’ to ‘concentrating was a tremendous chore’ with participants using a mouse to mark their perception. The individual scales selected were designed to give a broad interpretation of mental state rather than just fatigue which was the origin of the scale. The Visual Analogue Scale for Fatigue has evidence for reliability and validity (Lee et al., 1991). Scores from all items were normalised to a 0-100 scale for analysis and averaged to provide a single score for statistical analysis.

4.2.4 Statistical analysis

Data were examined for normality (using histograms, kurtosis and skew statistics). Subsequent analysis was then undertaken of each dependant variable with time (five repeated measures over two hours) and condition (just-sitting and under-desk cycling) as the independent variables and a time*condition interaction using mixed models with participant as random intercept. Linear models were used for normally distributed data (low back angle, cognitive function and mental state), negative binomial models were used for non-parametric data with a count distribution (musculoskeletal discomfort) and logarithmic transformation was undertaken before linear models were used (back transformed data is presented) for skewed data (muscle fatigue, pelvis movement). Beta coefficients (point estimate in linear models) and incident rate ratios (IRR as the point estimate; in negative binomial models) were reported with 95% confidence interval (CI). Discomfort rating changes greater than 10/100 from baseline were considered clinically meaningful based on Hägg et al. (2003), individual body areas increasing more than 10/100 were subsequently tested with pairwise comparisons to baseline discomfort. For the other variables given the lack of a recognised minimum clinically meaningful change, all time points were tested by pairwise comparison to baseline using linear mixed models when there was a significant time effect. Statistical significance was accepted at alpha probability of $p<0.05$. The software used for analysis was STATA (StataCorp 2015, Stata Statistical Software: Release 14. College Station TX: StataCorp LP).

4.3 Results

All 20 participants completed both conditions. Through visual inspection a number of EMG data samples were excluded due to artefacts as a result of signal interference (such as a direct hit of the electrode against the desk or the electrode being partially dislodged due to sweat or tape malfunction). Notes were taken during data collection to correlate these events. EMG data with artefacts were excluded for one participant's erector spinae, seven participants' external oblique and five participants' biceps femoris. Only a couple of participants were observed to stand briefly.

4.3.1 Discomfort

There was an increase in discomfort across all body areas and combined areas (upper limb, lower limb and total body), depicted as statistically significant time effects in Table 4.2. Pairwise comparisons showed that group clinically meaningful discomfort increases from baseline were also statistically significant for; low back (under-desk cycling 120 mins IRR=6.90, $p<0.001$ and just-sitting 120 mins IRR=4.20, $p<0.001$), and hip/thigh/buttock (under-desk cycling 120 mins IRR=43.28, p<0.001 and just-sitting 90 mins IRR=14.67, p<0.001 and 120 mins IRR=19.75, p<0.001). Clinically meaningful differences between conditions at 120 minutes were also statistically significant for ankle/foot (p<0.001). Thus the study had sufficient power to detect clinically meaningful differences in discomfort. Although there was no effect for condition in any of the discomfort sites, there was a time*condition interaction effect for shoulder discomfort (IRR 1.27, CI 1.06 to 1.52) indicating the increase in discomfort over time with under-desk cycling was slightly less than with just-sitting. Pairwise testing found under-desk cycling had statistically and clinically meaningful increases for knee (120 mins IRR=8.38, p<0.001) and ankle/foot (120 mins IRR=19.68, p<0.001), whereas the changes for just-sitting were not clinically meaningful.

Table 4.2 Discomfort [Mean (standard deviation)] over 2 hours prolonged just-sitting (S) and under-desk cycling (C) with incident rate ratio for effects of time, condition and time*condition.

Variable	Minutes - group means (sd)					Time effect			Condition effect			Time*condition interaction		
	0	30	60	90	120	IRR	CI	p value	IRR	CI	p value	IRR	CI	p value
Discomfort(/100)														
Neck - S Neck – C	3.1 (4.2) 3.1 (6.0)	3.6 (3.6) 2.2 (3.1)	8.7 (10.1) 5.2 (7.8)	11.8 (14.9) 6.3 (13.2)	11.6 (17.3) 8.1 (13.6)	1.25	1.05 – 1.48	0.009	1.47	0.66 – 3.29	0.347	1.09	0.86 – 1.38	0.478
Shoulder - S Shoulder - C	2.2 (4.4) 3.7 (6.0)	3.1 (3.4) 3.9 (4.4)	7.9 (10.9) 5.3 (8.7)	10.0 (15.5) 6.8 (13.5)	11.1 (17.6) 9.0 (14.2)	1.18	1.04 – 1.34	0.011	0.56	0.30 - 1.07	0.079	1.27	1.06 – 1.52	0.011
Elbow - S Elbow - C	0.9 (2.4) 0.8 (1.7)	1.9 (2.8) 1.4 (2.9)	2.4 (3.9) 2.1 (2.9)	3.3 (5.0) 3.5 (7.9)	2.4 (3.1) 3.1 (6.3)	1.32	1.10 – 1.60	0.004	1.14	0.46 – 2.86	0.827	0.97	0.75 – 1.26	0.827
Wrist/hand - S Wrist/hand - C	0.7 (1.6) 0.6 (1.2)	1.4 (2.4) 1.7 (3.8)	2.4 (4.8) 2.0 (3.9)	2.3 (4.3) 3.1 (8.4)	2.6 (5.1) 3.1 (6.5)	1.30	1.04 – 1.61	0.020	0.96	0.33 – 2.85	0.950	0.98	0.72 – 1.33	0.899
Upper Back - S Upper back - C	3.5 (7.8) 2.8 (5.5)	4.5 (7.6) 3.8 (6.2)	8.0 (10.1) 5.5 (8.6)	10.8 (15.6) 6.7 (10.5)	11.7 (15.4) 8.0 (12.6)	1.28	1.11 – 1.48	0.001	1.13	0.57 – 2.22	0.727	1.08	0.89 – 1.31	0.423
Low back - S Low back - C	4.8 (7.2) 2.8 (4.6)	5.5 (6.8) 4.4 (6.1)	7.9 (8.4) 7.9 (11.7)	12.2 (12.8) 10.6 (13.1)	16.3 (14.3)[a] 15.7 (15.6)[a]	1.67	1.42 – 1.95	<0.001	2.01	0.96 – 4.19	0.064	0.86	0.70 – 1.07	0.181
Hip/thigh/buttock - S Hip/thigh/buttock - C	1.1 (2.7) 0.8 (2.1)	2.2 (4.8) 5.3 (11.9)	5.8 (8.8) 9.5 (17.2)	11.5 (13.8)a 10.7 (17.0)	14.8 (17.5)[a] 18.6 (19.4)[a]	2.25	1.73 – 2.91	<0.001	0.85	0.24 – 3.04	0.808	0.94	0.66 – 1.35	0.753
Knee - S Knee - C	1.5 (3.1) 1.6 (2.8)	1.7 (3.2) 4.4 (8.0)	3.7 (5.9) 7.8 (16.6)	4.7 (8.5) 9.4 (16.7)	3.8 (6.8) 13.6 (19.6)[a]	1.65	1.36 – 2.00	<0.001	0.88	0.33 – 2.33	0.797	0.81	0.61 – 1.07	0.143
Ankle/foot - S Ankle/foot - C	1.0 (2.9) 1.5 (2.1)	1.5 (2.1) 3.9 (5.5)	2.6 (4.4) 9.9 (15.5)	2.9 (3.9) 11.4 (14.5)	3.7 (5.5)[b] 16.3 (18.2)[ab]	1.76	1.45 – 2.14	<0.001	0.52	0.19 – 1.41	0.197	0.81	0.61 – 1.09	0.163
Upper Limb - S Upper limb - C	1.3 (2.0) 1.7 (2.2)	2.1 (2.0) 2.3 (3.1)	4.2 (5.1) 3.2 (4.8)	5.2 (7.1) 4.5 (9.7)	5.4 (7.0) 5.1 (8.4)	1.25	1.12 – 1.40	<0.001	0.81	0.45 – 1.43	0.466	1.10	0.94 – 1.30	0.222
Lower Limb - S Lower Limb - C	1.2 (2.7) 1.3 (1.8)	1.8 (2.6) 4.5 (6.6)	4.1 (5.2) 9.0 (13.6)	6.3 (7.5) 10.5 (12.4)	7.4 (7.5) 16.2 (16.2)	1.78	1.55 – 2.05	<0.001	0.60	0.29 – 1.24	0.165	0.95	0.78 – 1.17	0.632
Total Body - S Total Body - C	2.1 (2.8) 2.0 (2.2)	2.8 (2.5) 3.4 (4.0)	5.5 (5.0) 6.1 (8.0)	7.7 (7.0) 7.6 (9.8)	8.6 (7.7) 10.6 (11.0)	1.47	1.36 – 1.60	<0.001	1.01	0.66 – 1.54	0.959	0.98	0.87 – 1.10	0.720

S – sitting, C – under-desk cycling, IRR – Incident Rate Ratio, CI - Confidence Interval is 95th ;
a - statistically significant pairwise comparisons of clinically meaningful increases from baseline;
b – statistically significant pairwise comparison of condition for this body area at 120 minutes

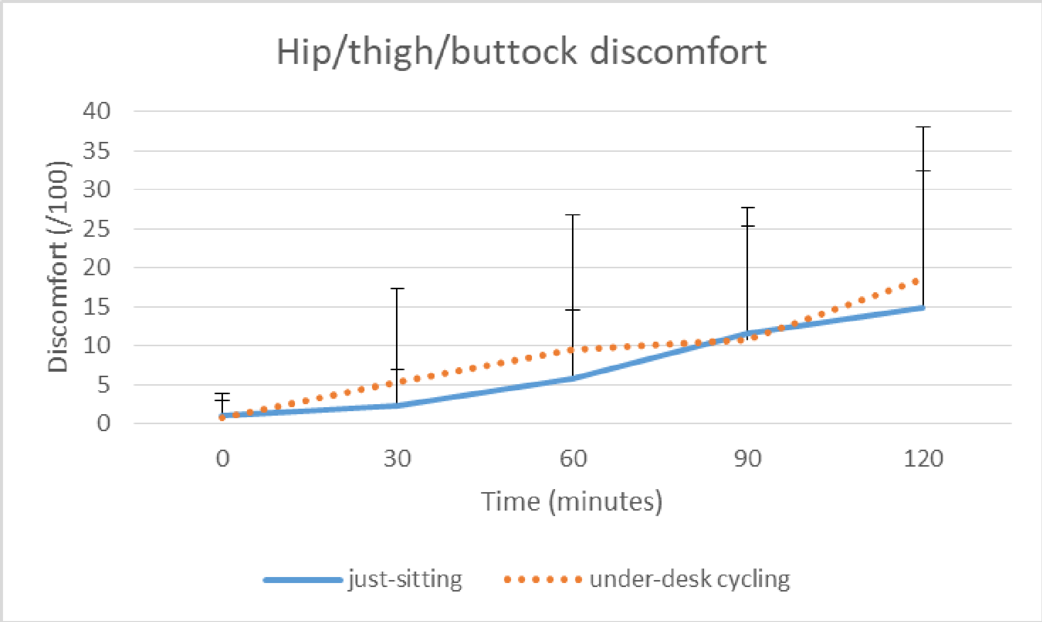

Figure 4.4 Hip/thigh/buttock discomfort (mean and standard deviation) over two hours for just-sitting and under-desk cycling.

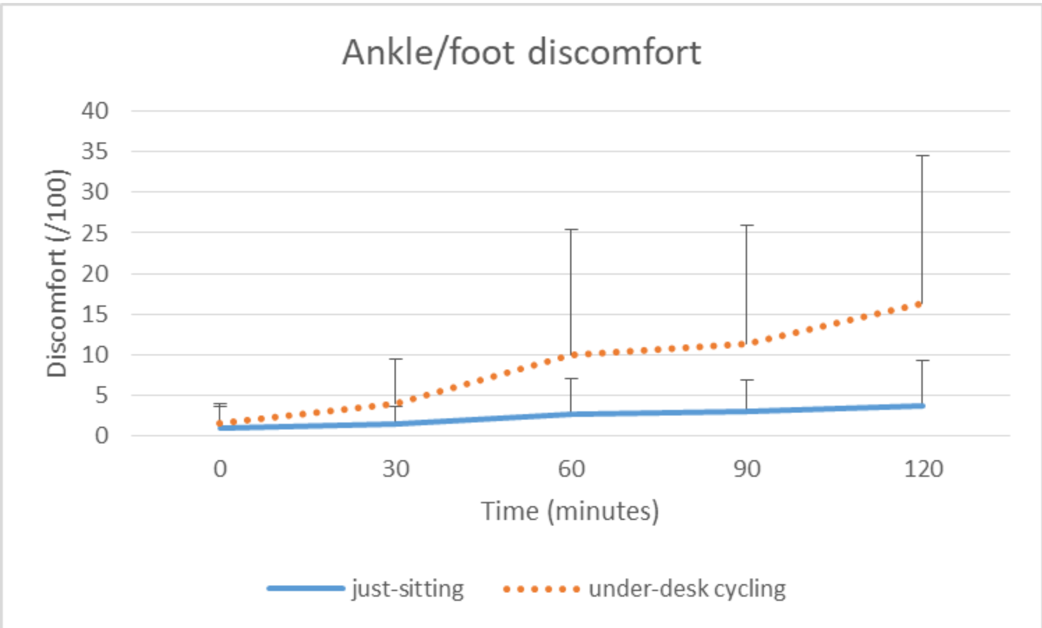

Figure 4.5 Ankle/foot discomfort (mean and standard deviation) over two hours for just-sitting and under-desk cycling.

4.3.2 Cognitive function

RFFT creative problem solving unique designs had non-significant trends for deterioration over time (β=0.50, CI -0.01 to 1.02) and time*condition (β =-0.72, CI -1.45 to 0.01) with no statistically significant effect of condition. For RFFT errors there was a non-significant trend for a time*condition interaction (β=0.26, CI -0.04 to 0.56; under-desk cycling deteriorating earlier but less deterioration later) with no effect of time or condition. SART sustained attention success (percentage) had a non-significant trend toward deterioration for time and no effect for condition or time*condition interaction. SART reaction time had a condition effect, with under-desk cycling slower (β=-34.82, CI -62.12 to -7.53) (see Table 4.3 Figure 4.6). Pairwise analysis found there were no cognitive measures which were statistically different between conditions at 120 minutes. As there is no clear evidence for what constitutes a clinically meaningful difference for the cognitive measures, an assessment of study power for these outcomes was not possible.

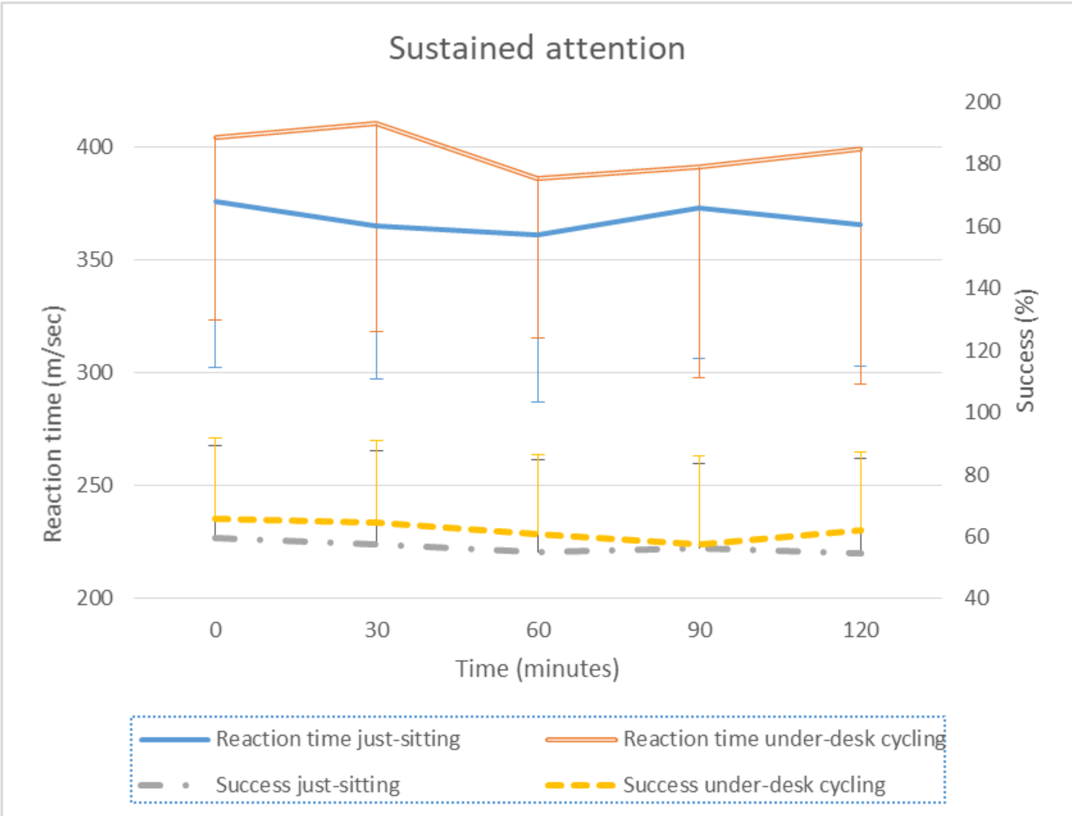

Figure 4.6 Sustained attention (mean and standard deviation) over two hours for just-sitting and under-desk cycling.

Table 4.3 Cognitive function [mean (standard deviation)] over 2 hours of prolonged just-sitting (S) and under-desk cycling (S) with Beta coefficients for effect of time, condition and time*condition.

Variable	Minutes - group means (sd)					Time effect			Condition effect			Time*condition interaction		
	0	30	60	90	120	Beta	CI	p value	Beta	CI	p value	Beta	CI	p value
Sustained attention														
no-go success (%) - S	59.4 (29.7)	57.6 (30.1)	54.8 (30.1)	56.2 (27.5)	54.4 (30.7)	-1.46	-3.16 – 0.24	0.093	-6.56	-14.55 – 1.43	0.108	0.32	-2.09 – 2.72	0.795
no-go success (%) - C	65.8 (25.9)	64.4 (26.6)	60.8 (25.5)	57.4 (28.6)	62.0 (25.3)									
reaction time (msec) - S	375.9 (73.3)	365.4 (68.1)	361.2 (74.1)	373.1 (66.8)	365.5 (62.6)	-2.87	-8.69 – 2.95	0.334	-34.82	-62.12 – (-7.53)	0.012	1.56	-6.66 – (9.79)	0.709
reaction time (msec) - C	404.2 (80.8)	410.5 (92.2)	386.3 (70.7)	391.3 (93.5)	399.4 (104.1)									
Problem Solving														
unique designs (n) - S	42.1 (9.1)	40.2 (8.8)	41.3 (8.5)	43.2 (8.7)	39.6 (8.7)	0.50	-0.01 – 1.02	0.054	0.93	-1.48 – 3.34	0.450	-0.72	-1.45 – 0.01	0.052
unique designs (n) - C	42.2 (8.5)	39.9 (7.7)	43.2 (7.8)	44.8 (8.3)	42.3 (8.0)									
errors (n) - S	1.8 (3.2)	1.8 (2.8)	2.3 (3.6)	2.2 (2.3)	2.8 (3.1)	-0.01	-0.22 – 0.20	0.928	-0.81	-1.82 – 0.20	0.117	0.26	-0.04 – 0.56	0.095
errors (n) - C	1.8 (2.1)	2.8 (3.3)	2.3 (2.6)	1.8 (2.3)	2.4 (2.0)									

S – sitting, C – under-desk cycling, CI - Confidence Interval is 95th

4.3.3 Muscle activity, kinematics and mental state

There were significant effects of condition for muscle activity for rectus femoris (β=0.33, CI 0.18 to 0.60) and biceps femoris (β=0.22 , CI 0.11 to 0.46) median frequency being lower in under-desk cycling; and external oblique (β=3.80, CI 1.38 to 10.72), rectus femoris (β=6.16, CI 2.04 to 18.60) and biceps femoris (β=4.26, CI 1.86 to 9.55) amplitude being higher in under-desk cycling. There were no other statistically significant effects for time, condition and time*condition, see Table 4.4.

There were non-significant time, condition and/or interaction trends for low back (sagittal mean) angle and low back (sagittal standard deviation) angle movement. Pelvis movement had a condition (β 2.75, 1.51 to 5.13) and interaction effect (β=0.82, CI 0.69 to 1.00) with more movement in under-desk cycling decreasing over time.

Mental state deteriorated over time (β=2.96, CI 1.54 to 4.37), with pairwise comparison showing a statistically significant difference from 60 mins (β=5.47, p=0.003; 90 mins β=9.74, p<0.001; 120 mins β=10.6, p=<0.001) for under-desk cycling and 90 mins for sitting (β=7.47, p=0.002; 120 mins β=9.29, p=<0.001).

Table 4.4 Muscle fatigue, low back angle, pelvis movement and mental state [mean (standard deviation)] over 2 hours of prolonged sitting (S) and under-desk cycling (C) with coefficient (Beta) for effect of time, condition and time*condition.

Variable	**Minutes - group means (sd)**					**Time effect**			**Condition effect**			**Time*condition interaction**		
	0	**30**	**60**	**90**	**120**	**Beta**	**CI**	**p value**	**Beta**	**CI**	**p value**	**Beta**	**CI**	**p value**
Muscle Fatigue [A – Amplitude (% reference contraction), MF- Median Frequency (hertz)]														
erector spinae - A - S	25.6 (48.3)	24.3 (30.3)	20.8 (19.0)	18.2 (16.0)	18.1 (18.3)	0.89^	0.74 – 1.05^	0.161	0.52^	0.23 – 1.20^	0.125	1.07^	0.83 – 1.38^	0.569
erector spinae - A - C	16.2 (12.4)	14.1 (10.6)	15.1 (11.4)	14.8 (10.4)	13.4 (9.1)									
erector spinae - MF - S	84.4 (40.1)	82.7 (38.0)	87.7 (44.4)	100.0 (49.0)	99.3 (55.2)	1.10^	1.00 – 1.20^	0.052	1.55^	1.00 – 2.40^	0.050	0.91^	0.79 – 2.40^	0.122
erector spinae - MF - C	94.9 (49.2)	100.5 (47.6)	94.6 (43.3)	91.7 (40.0)	96.1 (52.9)									
external oblique – A – S	17.2 (15.7)	24.9 (28.3)	21.9 (20.9)	22.6 (20.6)	21.5 (20.1)	1.07^	0.85 – 1.32^	0.558	3.80^	1.38 – 10.72^	0.009	0.89^	0.66 – 1.23^	0.484
external oblique – A - C	25.8 (20.6)	39.8 (62.2)	41.0 (77.4)	36.2 (44.5)	37.4 (86.2)									
external oblique – MF – S	77.4 (37.8)	76.8 (50.3)	63.4 (31.7)	70.6 (38.1)	68.5 (39.4)	0.93^	0.81 – 1.05^	0.275	0.87^	2.09 – 1.58^	0.624	1.10^	0.91 – 1.32^	0.337
external oblique – MF - C	70.1 (30.6)	73.2 (35.7)	82.6 (36.4)	64.0 (25.7)	78.2 (34.5)									
trapezius - A – S	47.6 (124.6)	36.1 (86.7)	46.8 (113.1)	41.2 (112.6)	31.1 (49.8)	0.98^	0.79 – 1.20^	0.752	0.87^	0.33 – 2.29^	0.782	1.12^	0.85 – 1.51^	0.420
trapezius - A – C	21.3 (13.8)	24.2 (15.5)	24.5 (14.4)	24.5 (14.6)	26.4 (19.3)									
trapezius - MF – S	73.3 (16.2)	71.3 (15.5)	70.2 (14.1)	68.4 (13.2)	72.0 (15.5)	0.98^	0.93 – 1.05^	0.557	1.05^	0.81 – 1.32^	0.725	1.02^	0.95– 1.10^	0.712
trapezius - MF – C	74.1 (19.9)	74.3 (10.1)	72.4 (12.6)	73.6 (13.9)	73.3 (14.9)									
rectus femoris - A - S	20.2 (36.7)	19.2 (36.8)	23.2 (38.2)	21.2 (52.2)	25.3 (48.0)	0.98^	0.76 – 1.26^	0.800	6.16^	2.04 – 18.60^		1.00^	0.72 – 1.41^	0.955
rectus femoris - A - C	35.9 (51.2)	35.8 (52.6)	37.1 (52.7)	38.5 (55.5)	39.7 (69.9)						0.001			

Variable	Minutes - group means (sd)					Time effect			Condition effect			Time*condition interaction		
	0	30	60	90	120	Beta	CI	p value	Beta	CI	p value	Beta	CI	p value
rectus femoris - MF – S	107.4 (68.7)	105.6 (72.5)	99.4 (67.9)	120.3 (81.0)	92.6 (51.6)	0.98^	0.87–1.12^	0.766	0.33^	0.18 – 0.60^	<0.001	1.02^	0.85–1.20^	0.865
rectus femoris - MF – C	58.1 (12.6)	52.4 (7.1)	53.4 (8.9)	53.7 (7.4)	57.0 (13.3)									
biceps femoris - A – S	10.1 (8.2)	11.3 (8.1)	12.7 (14.3)	9.9 (7.7)	12.5 (16.4)	0.95^	0.81 – 1.12^	0.619	4.26^	1.86 – 9.55^	0.001	0.98^	0.76 – 1.23^	0.799
biceps femoris - A – C	23.9 (20.8)	22.1 (16.9)	22.0 (15.9)	19.8 (13.6)	18.8 (13.4)									
biceps femoris - MF – S	164.7 (63.1)	158.9 (68.0)	151.1 (82.0)	186.7 (63.4)	152.0 (64.1)	1.00^	0.85 – 1.17^	0.958	0.22^	0.11 – 0.46^	<0.001	1.00^	0.81–1.26^	0.946
biceps femoris - MF – C	80.1 (50.7)	96.4 (62.4)	88.7 (62.4)	98.1 (69.9)	90.9 (67.7)									
Low back angle (degrees)														
sagittal mean – S	-5.9 (15.6)	-2.8 (17.0)	-3.3 (17.4)	-3.7 (14.1)	-0.5 (13.4)	0.98	-0.16 – 2.1	0.093	5.06	-0.03 – 10.4	0.065	-1.26	-2.88 – 0.37	0.129
sagittal mean – C	-2.8 (12.6)	-1.4 (13.3)	-0.5 (13.4)	-0.5 (12.2)	-4.6 (15.7)									
sagittal std deviation – S	0.3 (0.3)	0.7 (0.7)	1.0 (1.5)	0.4 (0.4)	0.8 (1.4)	0.10	-0.01 – 0.20	0.082	0.43	-0.07 – 0.93	0.095	-0.13	-0.28 – 0.02	0.097
sagittal std deviation – C	0.8 (0.5)	0.8 (0.6)	0.5 (0.3)	0.7 (0.8)	0.6 (0.4)									
Pelvis movement (cm/sec)														
distance – S	1.6 (1.0)	1.9 (0.8)	2.3 (1.9)	1.9 (1.0)	2.2 (1.4)	1.12^	0.98 – 1.26^	0.104	2.75^	1.51 – 5.13^	0.001	0.82^	0.69 – 1.00^	0.047
distance – C	2.5 (1.7)	2.4 (1.0)	2.2 (1.0)	2.0 (0.7)	2.2 (0.9)									
Mental State (/100)														
perceived mental state - S	28.0 (18.8)	32.4 (19.3)	31.1 (16.4)	35.4[a] (19.6)	37.2[a] (19.1)	2.96	1.54 – 4.37	<0.001	5.28	-1.35 – 11.9	0.119	-0.80	-2.80 – 1.20	0.436
perceived mental state – C	24.5 (15.8)	25.9 (17.2)	29.9[a] (16.2)	34.2[a] (16.4)	35.1[a] (16.9)									

S - sitting, C – under-desk cycling, CI - Confidence Interval is 95th, ^ back transformed data
[a] - statistically significant pairwise comparisons from baseline

4.4 Discussion

The current study compared discomfort, cognitive function, muscle fatigue, spinal kinematics and mental state between just-sitting and under-desk cycling over two hours. Discomfort increased significantly across all body areas over time with knee and ankle/foot discomfort reaching clinically meaningful levels over time during under-desk cycling but not during just-sitting. Sustained attention reaction time was slower for under-desk cycling. Muscle activity amplitude was higher in under-desk cycling for external oblique, rectus femoris and biceps femoris and pelvis movement was greater in under-desk cycling and reduced over time while just-sitting increased over time. Mental state deteriorated over time in both conditions, becoming significant earlier in just-cycling. There were no other substantial differences.

4.4.1 Discomfort

As expected there was an increase in discomfort for a number of body areas for prolonged just-sitting, consistent with previous studies (Karakolis et al., 2016; Sondergaard et al., 2010). Under-desk cycling also had increases in discomfort. While statistically significant, the change in total body discomfort did not reach clinically meaningful levels for either condition. There were however clinically meaningful increases in discomfort for both conditions in the low back and hip/thigh/buttock and for only under-desk cycling in the knee and ankle/foot.

For the low back, discomfort had clinically meaningful increases at the end of 120 minutes for both conditions. Under-desk cycling was not beneficial in preventing or managing low back discomfort. In understanding why this was the case, the potential mechanisms measured through the current study were examined including muscle fatigue and kinematics. There were no significant differences between under-desk cycling and just-sitting in erector spinae median frequency or amplitude changes over time, suggesting fatigue did not occur and therefore was not a factor driving low back discomfort. Low back angle (sagittal mean) in under-desk cycling changed into more lordosis (from group mean-2.8 degrees [SD 12.6] more lordotic than usual sitting at baseline to -4.6 degrees [15.7] at 120 mins) while just-sitting changed into less lordosis (from -5.9 degrees [15.6] to -0.5 degrees [13.4]), although this apparent interaction did not reach statistical significant (p=0.065) and neither did low back angle standard deviation (i.e. movement) (p=0.095). As far as we are aware, no other studies have considered the impact of under-desk cycling on low back posture to allow comparison. The literature is not clear on what an optimal lumbar posture is for sitting, however it is hypothesised that the further the deviation from neutral the greater likelihood of discomfort (O'Sullivan et al., 2012b). Should under-desk cycling assist in maintaining low back posture near neutral over greater durations, it may have potential to beneficially influence discomfort. Another difference between conditions was pelvis movement. Under-desk cycling started at a higher level of movement that decreased a little over the two hours (2.5cm/sec to 2.2cm/sec) while just-sitting tended to result in increasing movement over time (1.6cm/sec at baseline to 2.2cm/sec at 120 mins). Studies of sitting have suggested that with increasing time there is a tendency for larger infrequent postural shifts while with more dynamic sitting there are regular inherent spinal micro-movements which may assist with managing discomfort (O'Sullivan et al., 2012a). The under-desk cycling, with greater movement from commencement, had potential to reduce passive loading on tissues, however this was not evident in the discomfort ratings. Whilst there was insufficient evidence in the current study of two hours duration, the kinematic changes (posture and postural movement) may be important in their contribution to discomfort over a longer duration.

In the lower limb, the hip/thigh/buttock area had clinically meaningful increases in discomfort at 90-120 minutes for just-sitting and under-desk cycling. These results suggest interrupting just-sitting and under-desk cycling before 90-120 minutes may help to reduce discomfort. Previous studies have reported increased discomfort in the buttock area with prolonged sitting (Sondergaard et al., 2010) which has been postulated to be related to tissue pressure (Reid et al., 2010). It was hypothesised that the movement during under-desk cycling would provide some static pressure relief evident during just-sitting. The finding of discomfort reaching a clinically meaningful level at a later stage in the under-desk cycling condition provides some support for this hypothesis. Separate mechanisms may have led to an increase in discomfort during under-desk cycling and reduced the between condition difference, such as friction and pressure over a smaller surface area. Further, as the hip/thigh/buttock were grouped for discomfort rating it is unclear if the specific location of discomfort varied during under-desk cycling from just-sitting. In contrast, the lower limb areas of knee and ankle/foot were rated worse during under-desk cycling with both areas reaching clinically meaningful levels by 120 minutes, whereas during just-sitting neither knee nor ankle/foot areas reached a clinically meaningful level of discomfort. Under-desk cycling had higher amplitudes of rectus femoris and biceps femoris compared to just-sitting from commencement. This was expected due to the increased leg muscle use during under-desk cycling. There was however no evidence of an increase in amplitude nor a decrease in median frequency over time, suggesting that while there was a higher average amplitude during under-desk cycling it did not contribute to muscle fatigue. The variable pattern of muscle contractions during cycling may have reduced the development of fatigue (Srinivasan and Mathiassen 2012). Discomfort at the ankle during under-desk cycling may have been due to participants' feet being positioned under a strap which may have caused pressure. Further the under-desk cycle had a set height and pedal crank lengths for all participants. Consideration of other designs including those without foot straps may help reduce discomfort, particularly in the ankle/foot.

For upper limb discomfort none of the areas reached a clinically meaningful level suggesting that while discomfort increased over time it was less of a concern than the other body areas. Shoulder discomfort ratings increased slightly more over time during just-sitting compared to under-desk cycling. Muscle fatigue does not appear to be the cause as trapezius muscle activity levels were not significantly different between conditions. Post-hoc analysis for a correlation between upper limb discomfort and pelvis movement in under-desk cycling indicated a weak correlation ($r=-0.167$, $p=0.495$), suggesting the greater pelvis movement associated with cycling in this and prior reports (Elmer and Martin, 2014; Sliter and Yuan, 2015) may have helped reduce discomfort in the shoulder. Further research which should include measures of upper body postural sway may help to clarify how this influences upper limb discomfort.

4.4.2 Cognitive

Sustained attention reaction time was faster in just-sitting than under-desk cycling, suggesting a dual task load, with the slower reaction time enabling accuracy to be maintained. In comparison, whilst there were trends for interactions for both creative problem number of designs and errors, neither condition had a clear pattern of better performance. With only two studies previously considering the use of an under-desk cycle in the workplace (Carr et al., 2012; Torbeyns et al., 2017) understanding of the impact on performance is limited. Neither study objectively measured cognitive performance or work productivity. Carr et al. (2012) found it did not impact the subjective quality of work or productivity (e.g. reading), although there were mixed responses to anticipated ability to complete computer tasks suggesting some dual task interference. Torbeyns et al. (2017) found the majority of participants perceived either a positive or no effect on work performance while two thirds indicated a positive influence on motivation. Research has identified that there is a complex relationship between activity level (in particular exercise) and specific cognitive functions (Tomporowski, 2003). Evidence also suggests there may be a tendency for a larger effect size for executive tasks than alertness or attention tasks (McMorris and Hale, 2012). The impact of using an alternate work position may thus not impact all cognitive functions uniformly.

Based on previous studies it is clear that a number of factors have potential to influence cognitive function including the time chosen for the testing (during or after activity), and the activity duration, frequency and intensity. Mullane *et al.* (2017) found cognitive performance (in a test battery consisting of psychomotor function, working memory and attention and executive functions) was better in a protocol which included intermittent bouts of low intensity cycling over a longer duration (6 hours) compared to just-sitting however their testing was conducted after bouts of cycling had been completed and therefore there were no dual task implications. Increased overall activity level has been postulated to influence cognitive performance through changes in brain activity level. Bailey et al. (2008) found an increase in brain activity, measured using electroencephalography, following higher intensity cycling. In the current, study cognitive testing occurred during the under-desk cycling and thus it is not clear whether dual task interference may have impacted results. Another factor which may have influenced results is the intensity of cycling. Previous studies have found protocols which required maintaining a set speed distracting (Straker et al., 2009). Participants in the current study were instead instructed to undertake low intensity cycling and choose their own speed, as would be expected in a natural work setting. As a result there would have been differences between participants in their activity intensity. It is unclear whether light activity such as the current study is likely to give the same benefits for cognitive function as higher intensity activity (Chang and Etnier, 2009; Wollseiffen et al., 2016). Given the postulated benefits from increased activity, further research which considers bouts of higher intensity of cycling during periods of prolonged sitting may provide greater insight.

Mental state deteriorated over time for both conditions. It was anticipated there would be less decrement with under-desk cycling than just-sitting due to the increased movement and influence on metabolism, however the results do not support this. It has previously been found that under-desk cycling (over a 35 minute period) had a negative association with performance and satisfaction (Sliter and Yuan, 2015). These authors noted that ideal positioning may not have been achieved, which may have influenced mental state. In the current study, increasing discomfort particularly in the lower limb may have been a reason why under-desk cycling did not appear to have a positive impact on mental state, or cognitive performance. Cognitive function monitoring over several months or years, with discomfort better managed, would assist in clarifying if under-desk cycling does provide benefit.

4.4.3 Strengths and limitations

The strengths of the current study included using a within-participants design, an under-desk equipment design potentially feasible for current standard sitting workstations, as well as a rich data collection protocol with individual body area discomfort ratings, objective and standardised measures of important aspects of cognitive function. This is the first study to investigate discomfort, posture and cognitive function in a setting applicable to office workers. Further the duration of two hours was representative of standard working time before some form of break (e.g. for meal, refreshment or bathroom break). The study limitations include a lack of control over the cycling movement (cadence) and the self directed activities participants undertook during two hours however this could be considered realistic. The duration (10 seconds) and frequency (30 minutes) of capturing pelvic movement may have been insufficient to capture infrequent fidgeting type movements. A larger sample size may have allowed statistical detection of observed trends for condition differences after two hours. Further research should determine what constitutes a clinically meaningful difference in the RFFT and SART measures. The desk was set to allow optimal positioning for under-desk cycling however this may not have been optimal for all participants in just-sitting. Further, the particular design of the strap over the foot on the under-desk cycle device may have adversely affected foot discomfort while the low back sensors may have contributed to discomfort in both conditions. Potential for bias due to novelty effect, motivation or expectations can not be excluded. It is also acknowledged that this study was undertaken for two hours, generalising results to work situations of longer duration should be undertaken with caution.

4.5 Conclusion

The current study compared just-sitting to sitting while using an under-desk cycle over two hours. Clinically meaningful increases in discomfort for the low back and hip/thigh/buttock occurred in both conditions, while under-desk cycling also had meaningful increases for the knee and ankle/foot. Under-desk cycling resulted in slower sustained attention reaction times, but was similar to just-sitting for problem solving. Under-desk cycling did not help prevent the deterioration in mental state observed in both conditions. Whilst the movement created with under-desk cycling theoretically has the potential to reduce discomfort and increase cognitive function during office work, further research is required to determine optimal equipment design and use protocol to address discomfort and provide clearer evidence of benefits to cognitive function and work productivity before wide scale implementation of under-desk cycling in workplaces can be recommended. For potential positive impact on cognitive function, future research could consider higher intensity cycling over shorter bouts. If discomfort can be better managed, under-desk cycling shows promise as a good alternate work posture to address sedentary behaviour in office workers.

Chapter 5 Just-standing

This chapter reports on the discomfort and cognitive function outcomes for just-standing undertaken in Study 2 and is a verbatim copy of the paper now published in Ergonomics (as below):

Baker, R., Coenen, P., Howie, E., Lee, J., Williamson, A., & Straker, L. (2018). A detailed description of the short-term musculoskeletal and cognitive effects of prolonged standing for office computer work. Ergonomics, 61(7), 877-890.

Discomfort and cognitive function were assessed regularly while participants maintained just-standing for a two hour duration. Discomfort intensity was assessed by body location and cognitive function was assessed using tests of sustained attention and creative problem solving. Mechanisms which may have been responsible for the increases in discomfort were explored including low back angle, movement, muscle fatigue and lower limb swelling. Mental state was also considered for change over time. The paper also considered potential correlations between discomfort and cognitive function.

A detailed description of the short term musculoskeletal and cognitive effects of prolonged standing for office computer work

5.1 Introduction

A rapidly increasing body of evidence supports an association between excessive sedentary behaviour and negative health outcomes including increased risk of all-cause mortality, cardiovascular disorders, diabetes and cancer along with concerns about musculoskeletal disorders (Straker *et al.* 2016). For office workers a large proportion of work time has been shown to be spent sitting (82%), with occupational exposure reported to account for approximately half of an individual's sedentary behaviour (Parry and Straker 2013). In order to reduce occupational sitting exposure, and thereby reduce the possible risks, a common strategy currently being widely promoted is to replace sitting with increased standing through the use of sit-stand workstations (Danquah *et al.* 2017) and stand-biased desks (Benden *et al.* 2014).

However epidemiological studies of occupations requiring prolonged standing (e.g. workers in retail and industrial settings) suggest there may also be negative health issues associated with too much standing. These include perinatal risks (Mozurkewich *et al.* 2000, Magann *et al.* 2005), atherosclerotic progression (Krause *et al.* 2000), chronic venous insufficiency and varicose veins (Beebe-Dimmer *et al.* 2005, Tuchsen *et al.* 2005), and symptoms in the back (Coenen *et al.* 2016) and lower limbs (Leroux *et al.* 2005).

Laboratory studies investigating the short term effects of prolonged standing have also found increased back discomfort (Gregory and Callaghan 2008, Gallagher and Callaghan 2015, Le and Marras 2016). Whilst the mechanisms for the development of back discomfort due to standing remain poorly understood, hypotheses include the role of muscle fatigue and prolonged loading on passive tissues (Callaghan and McGill 2001). Studies relating back discomfort and muscle fatigue have been inconclusive (Balasubramanian *et al.* 2009, Antle and Côté 2013). Studies considering the unloading of passive tissues through movement have reported that participants move from a neutral low back posture into more lumbar flexion during prolonged standing (Gregory and Callaghan 2008) and those who developed pain had less and later lumbar spine movement (fidgets) (Gallagher and Callaghan 2015).

An association between standing and discomfort in the lower limbs has also been found in laboratory studies (Chester *et al.* 2002, Antle and Côté 2013), with possible mechanisms including muscular fatigue (Garcia *et al.* 2015) and lower limb circulation changes (Antle and Côté 2013). Swelling has been linked with lower limb discomfort (Seo *et al.* 1996, Chester *et* *al.* 2002) but the association with lower limb muscle activity and fatigue is unclear (Balasubramanian *et al.* 2009, Antle and Côté 2013).

Most studies on discomfort in standing have focused on the back or lower limbs with a systematic review reporting a lack of conclusive epidemiological evidence for an association between occupational standing and upper limb symptoms (Coenen *et al.* 2016). The mechanisms for discomfort in the upper limbs for computer users during sitting are hypothesised to be linked to static posture and low-level static muscle contractions resulting in muscular fatigue (Wahlstrom 2005). It has been suggested the less constrained posture in standing compared to sitting with the ability to move more and consequent reduction in static muscle contractions may positively influence discomfort (Roelofs and Straker 2002).

In addition to concerns about health issues related to prolonged standing, there are also concerns in the occupational context about productivity. We were not able to locate any epidemiological studies considering the role of prolonged standing on productivity in office workers. The few field studies which have considered productivity in office workers exposed to prolonged standing have found no evidence for changes in objectively measured (Chau *et al.* 2015b) or perceived work productivity (Dutta *et al.* 2014, Brakenridge *et al.* 2016) following interventions to reduce sitting and increase standing in office workers. A number of laboratory studies have considered keyboard and mouse use and found no difference in work productivity between standing and sitting over short durations (Beers *et al.* 2008, Straker *et al.* 2009, Tudor-Locke *et al.* 2014, Russell *et al.* 2016).

A number of laboratory studies have examined aspects of cognitive function thought to be critical for work productivity. Tests of attention and memory, when standing for periods of up to one hour, have found no difference when compared to sitting (Bantoft *et al.* 2016, Russell *et al.* 2016) however in a study of complex attention, with both sitting and standing conditions undertaken within one hour, sitting had better cognitive function compared to standing (Schraefel *et al.* 2012). Creative problem solving, an area less studied, is important to office workers who need to not only maintain attention but address a problem if required. Bluedorn *et al.* (1999) studied standing versus seated meetings and found the quality of decisions made in a standing meeting were no different. Further, Mullane *et al.* (2017) considered reasoning and problem solving in periods of standing (up to 30 mins) alternated with sitting, and found no difference between sitting and standing. Given the relatively short duration (not more than 1 hour) of the majority of studies there is limited understanding of the impact of prolonged standing on cognitive function.

A recent systematic review (MacEwen *et al.* 2015) found mixed evidence of the impact of standing on perceived mental state which included ratings of mood, fatigue and concentration. Some studies included a single assessment of a standing-only condition whilst others assessed multiple-week workplace interventions (where sit-stand desk were used). However none were studies of standing-only over a prolonged period. Whilst a deteriorating mental state was reported by participants in studies with standing conditions (Hasegawa *et al.* 2001, Beers *et al.* 2008) it is not clear how mental state relates to discomfort. Further it is unclear how mental state and discomfort may relate to cognitive function (such as executive functions, working memory and attention). Whilst there have only been a limited number of studies which have considered worker productivity (which cognitive function and mental state would contribute to) with discomfort concerns have been raised (Drury *et al.* 2008, Karakolis and Callaghan 2014).

There are a number of gaps in understanding the impact of prolonged standing during office work. These include the mechanisms for the development of low back and lower limb discomfort, and potential association between standing and upper limb discomfort. Also it remains unclear to what extent cognitive function may be impacted by prolonged standing. This study aimed to provide a more comprehensive overview of musculoskeletal and cognitive function changes during prolonged standing. It was hypothesised that discomfort would increase over 2 hours of prolonged standing in the low back, lower limb and upper limb and there would be a decline in cognitive function. Observed increases in discomfort which exceeded meaningful changes were hypothesised to be not due to chance. A secondary aim was to explore potential mechanisms for the anticipated discomfort and cognitive changes through analysing changes in muscle fatigue, low back posture and movement, lower limb swelling and perceived mental state. Thus a secondary hypothesis was that there would be an association between changes in discomfort and cognitive function, discomfort and muscle fatigue, low back posture and movement and lower limb swelling, and cognitive function and perceived mental state. As the uptake of occupational standing as an alternative work posture in offices is likely to be influenced by the productivity (Gilson *et al.* 2012) and health consequences of standing, results from this study may help inform policy and practice regarding prolonged standing in office work.

5.2 Method

5.2.1 Participants

Twenty adults (7 male, 13 female) were recruited via email from personal and professional networks and had a mean (standard deviation) age of 28.3 (± 9.9) years, while weight and height were 66.1 (± 10.5) kg and 167.5 (±10.5) cm, respectively. Occupational category of the participants was self-reported as sedentary (n=13), primarily standing (n=4) and physical (n=3). Participants were included if they were 18 – 65 years of age and English and computer literate, and had the physical ability to undertake standing for a 2 hour period. Exclusion criteria were current use of a standing work station and known pain in response to activity (e.g. from a pre-existing musculoskeletal condition). Ethics approval was provided by Curtin University (RHS-266-15). Participants provided written, informed consent and were able to withdraw at any time.

5.2.2 Design and Procedure

The study used a repeated measures design over two hours of standing, with measures of each dependent variable taken at baseline and then at 30 minute intervals (five times in total). Standing time was considered an independent variable and discomfort and cognitive function (sustained attention and creative problem solving) as dependent variables, along with muscle fatigue, low back angle and pelvis movement, calf swelling and mental state. Participants attended a familiarisation session at a university research laboratory approximately one week prior to participation, in which they undertook practice of all the cognitive tests. Participants were asked to refrain from vigorous exercise in the 48 hours preceding the testing session.

During the two hour trial, participants undertook self-directed computer activities (including typing, using a mouse to navigate menus and reading). A desk (A7TR78928H, Steelcase, Sydney, Australia) was adjusted to 5cm below standing elbow height (Nelson-Wong *et al.* 2010) and the top of the computer screen (15 inch, Acer, Taiwan) to eye level. Participants were instructed to stand in their usual manner and were advised to rest their forearms, but not lean on the desk surface. Assessment measures took approximately 7 minutes each time with the final assessment commenced at 120 mins. Participants remained standing at the workstation during each assessment. Participants provided their own flat foot wear and were able to drink water at their own discretion but no other refreshments.

5.2.3 Dependent variables

5.2.3.1 Musculoskeletal discomfort

Participants completed a modified electronic version of the Nordic Musculoskeletal Questionnaire (NMQ) rating intensity of bilateral musculoskeletal discomfort in each of 9 body regions (neck, shoulder, elbow, wrist/hand, upper back, low back, hip/thigh/buttock, knee, ankle/foot) on a single visual analogue scale (with anchors of 0 = '*no discomfort'* and

100 = '*discomfort as bad as it could be'*). The modified NMQ has been used extensively and is considered to have acceptable reliability (Kuorinka *et al.* 1987). Composite lower limb and upper limb variables were created with summed average discomfort scores for hip/thigh/buttock, knee and ankle/feet (lower limb) and shoulder, elbow and wrist/hand (upper limb). Composite total body discomfort was created with summed average of all discomfort scores. Participants were asked to report when they would have chosen to cease standing if not in a study. Participants were advised to cease the session if discomfort increased beyond a level they considered to be acceptable.

5.2.3.2 Cognitive Function

The Sustained Attention to Response Test (SART) (*http://www.millisecond.com/download/library/SART/*) is a Go/No-go type test that has been widely used to measure sustained attention aspects of cognitive function (Head and Helton 2014). The 4 minute 20 seconds long computer test requires participants to use their dominant hand to depress the keyboard spacebar to all digits (Go response), except the number 3 (No-go, no response). Digits were flashed briefly (250ms) on the screen, with participants aiming to respond as quickly as possible while also aiming to minimise errors. The No-go success (percent correctly withheld responses) and reaction time were utilised for analysis.

The Ruff Figural Fluency Test (RFFT) was chosen as a test of problem solving and executive cognitive function (Ross *et al.* 2003) which was not overtly novel thereby avoiding altering attentional level (Oken *et al.* 2006). Reliability testing of the RFFT has shown inter-rater reliability of scoring for unique designs of 0.98 and for perseveration errors of 0.94 and there is evidence of convergent validity on executive function tests (Ross *et al.* 2003). The test was computer administered with participants shown squares containing an arrangement of five dots and they were required to use a mouse to draw lines between dots to create unique designs within 60 seconds according to certain rules. Participants completed 2 consecutive parts of the 5 part RFFT every test period. The number of unique designs and errors (repeat of designs or not within rules) were tallied manually by the researcher.

5.2.3.3 Muscle fatigue

Data were collected using surface electromyography (EMG) using a Trigno® Wireless System (Delysys Inc, Boston, USA) with a sampling rate of 2000Hz in 2 minute samples. Standard skin preparation was undertaken before electrodes were secured with tape to collect signals from the following muscles (unilaterally, right side): lumbar erector spinae (iliocostalis lumborum pars thoracis) at the level of the L1 spinous process level midway between the midline and lateral aspect (O'Sullivan *et al.* 2006); rectus femoris midway along a line between the anterior superior iliac spine and superior border of the patella (Rouffet and Hautier 2008); biceps femoris midway laterally on the posterior thigh (Rouffet and Hautier 2008); and tibialis anterior 15 cm below the patella (von Tscharner *et al.* 2003). Unilateral measures were considered adequate based on participant burden and prior evidence with the symmetrical tasks (Fujiwara *et al.* 2006, Lemos *et al.* 2015, Fewster *et al.* 2017). These muscles were chosen in line with prior studies and our hypotheses. Erector Spinae was selected due to being a surface muscle which is commonly used to measure low back activity (O'Sullivan *et al.* 2006, Antle and Côté 2013). Rectus femoris and biceps femoris were captured as it was anticipated that there would be a lack of movement in this work position (Antle and Côté 2013) which was important as this study is part of a series of studies which also include work positions with lower limb movement. Tibilias anterior was selected as it has been commonly used in standing studies relating to muscle fatigue (Antle and Côté 2013, Garcia et al. 2015).

Submaximal voluntary contractions (held for 3 seconds, repeated 3 times for each muscle) for amplitude normalisation were undertaken. For erector spinae and biceps femoris contractions, participants were lying in a prone position with the knees bent to 90° and both knees lifted 5 cm off the supporting surface (Dankaerts *et al.* 2004). For rectus femoris contractions participants were sitting with hips flexed to 90° and the tested knee extended to 45° (Kollmitzer *et al.* 1999) with 2kg weight secured at ankle. For tibialis anterior contractions participants performed dorsiflexion holding their heel ~10 cm off the ground with foot parallel to floor (adapted from Madeleine *et al.* 1998).

A customised program (LabView, National Instruments Inc., Texas, USA) was used to process the EMG data which was demeaned, rectified and high pass filtered at 10Hz (high pass) and 1000Hz (low pass) by the amplifier cut off frequency and visually inspected for artefacts. Muscle fatigue was quantified for further statistical analysis using median frequency and normalised amplitude. Reliability and validity of these measures has previously been demonstrated in our laboratory (Dankaerts *et al.* 2004). Mean median frequency and normalised mean amplitude (percentage of submaximum voluntary reference contraction) were calculated for each 2 minute sample and used for further statistical analysis.

5.2.3.4 Kinematics

Kinematic data were collected using 3-Space Fastrak (Polhemus Navigation Sciences Division, Vermont, USA), at 25Hz in 2 minute samples. Fastrak is an electromagnetic device which generates a low frequency magnetic field and determines the position and orientation of sensors relative to the field source, with reported accuracy of 0.2 degrees (Pearcy and Hindle

1989). Sensors were secured with tape over C7, T12, L3 and S2 spinous processes (based on the protocol by Levine and Whittle (1996)) and measured postural angles of the thorax, and the upper and lower lumbar spine in the sagittal, lateral and coronal planes (for a diagram of sensor placement see Lee et al. (2018)).

The aforementioned LabView program was used to calculate the sagittal mean and standard deviation (both normalised to usual standing posture) of the sagittal plane angle between T12 and S2 sensors via matrix algebra (Burnett et al. 1998, Ng et al. 2015) to use for further analysis. Data over the two minute capture period was averaged with a more negative number indicating an increase in lordosis angle while a smaller negative number and larger positive number indicated more kyphosis. Pelvis movement was measured as the distance (in centimetres) of transverse plane displacement of the S2 sensor over 2 minutes (O'Sullivan *et al.* 2006).

5.2.3.5 Lower limb swelling

Calf circumference was measured using a non-stretch tape with spring tension (Gulick II, Denver, USA) in 3 locations: 10 cm above the medial malleolus, 10 cm below the medial knee joint and the midpoint of these two (te Slaa *et al.* 2011). Consistency training was undertaken across the two researchers conducting the data collection (RB and JL). Reliability of circumferential measurements for limb swelling has been demonstrated (Karges *et al.* 2003). The average of two measures taken at each location was used for further analysis.

5.2.3.6 Mental state

A scale composed of five visual analogue items (perceived alertness, tiredness, drowsiness, fatigue and concentration) was used based on the Visual Analogue Scale for Fatigue which has evidence for reliability and validity (Lee *et al.* 1991). Anchors were: *'not at all alert/tired/drowsy/fatigued'* to *'extremely alert/tired/drowsy/fatigued'* and *'concentrating was no effort at all'* to '*concentrating was a tremendous chore*'). As for discomfort intensity, the scales were computer administered and participants used a mouse to mark their perception. Scores from all items were averaged and normalised to a 0-100 scale for analysis. Higher scores indicated deterioration.

5.2.4 Statistical analysis

Data were tested for normality. For normally distributed data (cognitive function, low back angle, lower limb swelling and perceived mental state) linear mixed models with participant as random intercept were used. Skewed data (muscle fatigue, pelvis movement) were transformed logarithmically and then used in linear mixed models (back transformed data presented in tables). For zero inflated data (discomfort body regions) negative binomial mixed models were used. Analysis was undertaken of each dependant variable in separate models with time (5 repeated measures over 2 hours) as the independent variable. Betas and incident rate ratios (IRR), for linear and negative binominal mixed models respectively, were reported with 95th percent confidence intervals and alpha probabilities.

To address the second research aim, correlations were examined between changes over the 2 hour period for low back discomfort (with erector spinae median frequency and amplitude, deviation from usual standing and pelvis movement in sagittal plane), lower limb discomfort (with biceps femoris, rectus femoris and tibialis anterior median frequency and amplitude, pelvis movement and calf swelling), and cognitive function and mental state (with body discomfort). In order to do so, Pearson and Spearman tests were used for normally and non-normally distributed data respectively. Changes in discomfort greater than 10/100 were considered clinically meaningful based on Hägg et al. (2003) and tested with pairwise comparisons to baseline discomfort using negative binomial mixed models. All other variables with significant time effects (cognitive function, kinematics, swelling and mental) were further tested with pairwise comparisons. Given the lack of a recognised minimum clinically meaningful change for these variables, all time points were tested in comparison to baseline using linear mixed models. In all analyses, statistical significance was accepted at alpha probability of $p=<0.05$. The software used for analysis was STATA (StataCorp 2015, Stata Statistical Software: Release 14. College Station TX: StataCorp LP).

5.3 Results

Of the 20 participants, 19 completed the 2 hours of prolonged standing with one participant withdrawing after 74 minutes due to reporting an unacceptable level of discomfort. For this participant only data from the first 4 test periods were available. Participants reported that they would have ceased the session after 80.5 (range 31 - 120) minutes if not in a study. Based on visual inspection for artefacts and checking outliers (> 1.5 times the interquartile range), EMG data were not included for 3 participants' rectus femoris, 1 participant's biceps femoris and 3 participants' tibialis anterior. Pelvis movement data for 2 participants were also not included in the analysis due to being outliers.

5.3.1 Discomfort

Discomfort significantly increased over the 2 hours for all body areas (see Table 5.1). Figure 5.1 shows the increase in discomfort for the low back, combined lower limb region and combined upper limb region. Ratings at 120 mins were highest in ankle/foot with mean discomfort of 33.1 (SD 22.1), followed by low back 32.0 (28.4), knee 23.8 (24.8) and hip/thigh/buttock 19.9 (24.1). All participants reported a clinically meaningful increase in discomfort greater than 10/100 in at least one body region (16 for low back, 16 for foot/ankle, 13 for knee and 11 for hip/thigh/buttock) with 18 reporting an increase greater than 10/100 in more than 1 body region. Pairwise comparisons showed that group clinically meaningful discomfort increases from baseline, which were also statistically significant, were apparent by 30 or 60 minutes for the: low back (60 mins: IRR=4.18, p<0.001, 90 mins: IRR=5.93, p<0.001, 120 mins: IRR=6.83, p<0.001), hip/thigh/buttock (60 mins: IRR=5.92, p<0.001, 90: IRR=6.66, p<0.001, 120: IRR=9.45, p<0.001), knee (60mins: IRR=5.63, p<0.001, 90: IRR=6.47, p<0.001, 120: IRR=8.87, p<0.001), and ankle/foot (30 mins: IRR=4.22, p<0.001, 60: IRR=5.82, p<0.001, 90: IRR=7.92, p<0.001, 120: IRR=10.60, p<0.001).

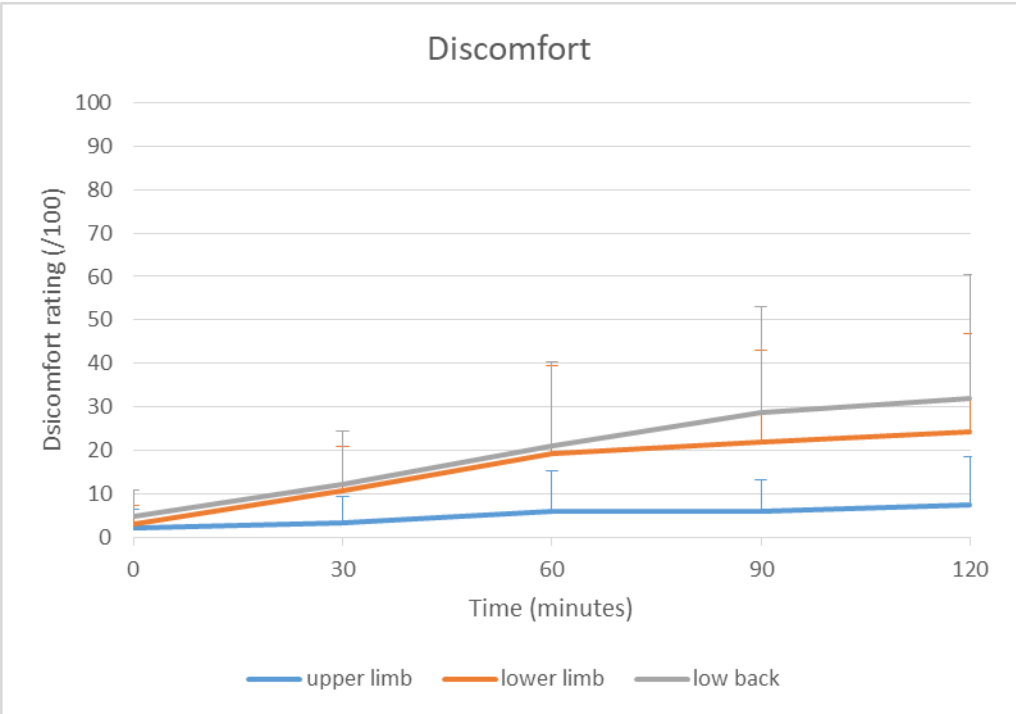

Figure 5.1 Discomfort (mean and standard error) by body regions during 2 hours of prolonged standing

Table 5.1 Mean (standard deviation) in discomfort over 2 hours of prolonged standing with incident rate ratio (IRR) for effect of time.

Variable	Minutes - group means (sd)					IRR	Confidence Interval	p value
	0	30	60	90	120			
Discomfort (/100)								
neck	2.6	4.2	5.3	8.2	9.7	1.36	1.16 – 1.60	<0.001
	(4.4)	(6.8)	(9.4)	(14.8)	(13.0)			
shoulder	3.9	5.0	7.6	7.6	11.2	1.25	1.08 – 1.44	0.002
	(5.7)	(7.1)	(9.5)	(9.0)	(15.9)			
elbow	1.7	2.8	4.7	4.9	7.0	1.51	1.26 – 1.83	<0.001
	(4.0)	(5.9)	(9.8)	(7.5)	(11.0)			
wrist/hand	1.5	2.6	6.3	5.4	5.7	1.64	1.31 – 2.06	<0.001
	(4.0)	(5.8)	(11)	(7.9)	(8.6)			
upper back	2.8	4.9	9.2	10.5	12.0	1.58	1.35 – 1.86	<0.001
	(5.6)	(8.4)	(12)	(14.1)	(15.6)			
low back	5.0	12.4	21.0*	28.8*	32.0*	1.57	1.45 – 1.70	<0.001
	(6.1)	(12.2)	(19.3)	(24.3)	(28.4)			
hip/thigh/buttock	2.6	6.6	15.3*	17.3*	19.9*	1.69	1.53 – 1.87	<0.001
	(4.0)	(10.1)	(19.7)	(22.2)	(24.1)			
knee	3.3	10.6	19.5*	20.2*	23.8*	1.61	1.44 – 1.80	<0.001
	(5.0)	(11.7)	(22.0)	(21.7)	(24.8)			
ankle/feet	3.8	15.0*	23.1*	28.5*	33.1*	1.62	1.47 – 1.79	<0.001
	(4.9)	(12.4)	(22.7)	(22.2)	(22.1)			
upper limb	2.4	3.5	6.2	6.0	7.6	1.34	1.18 – 1.52	<0.001
discomfort	(4.2)	(6.0)	(9.3)	(7.4)	(11.1)			
lower limb	3.3	10.7	19.3	22.0	24.4	1.57	1.44 – 1.72	<0.001
discomfort	(4.2)	(10.2)	(20.4)	(21.1)	(22.4)			
total discomfort	3.0	7.1	12.4	14.6	16.3	1.47	1.36 – 1.59	<0.001
	(3.9)	(7.0)	(12.6)	(12.6)	(15.0)			

Confidence Interval is 95% confidence interval
*statistically significant pairwise comparisons of clinically meaningful increases from baseline

5.3.2 Cognitive function

For cognitive function the SART results showed statistically significant slowing in reaction time by 78 msec over the 2 hour period and although No-go success increased over time (from 36% to 44%), this trend was not statistically significant (Table 5.2 and Figure 5.2). Pairwise comparisons showed that group sustained attention reaction times, compared to baseline, were also statistically significant from 60 minutes (β=54.50, p=0.018; 90 mins β=56.90, p=0.013; 120 mins β=75.43, p=0.001). For creative problem solving the number of unique designs increased by β=0.89 (p=0.004) with no statistically significant change in number of errors (though the trend was for errors to reduce from 4.0 to 2.6). Pairwise comparison showed that group creative problem solving unique designs were significantly different from baseline at 60 mins (β=4.65, p<0.001) and 90 mins (β=5.75, p=,0.001).

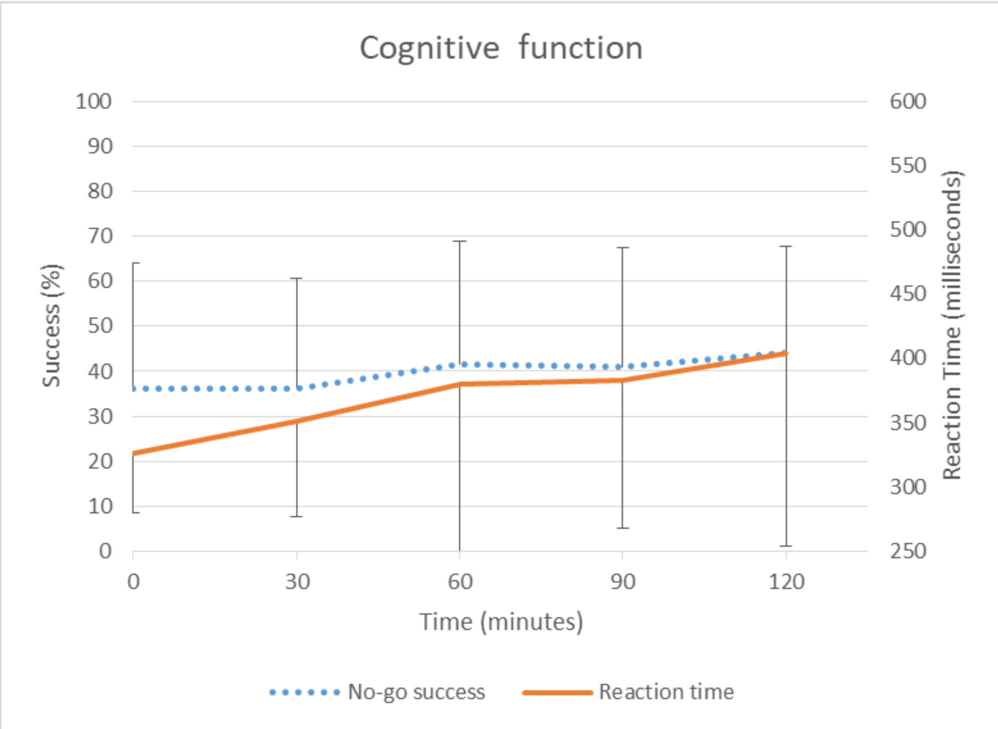

Figure 5.2 Sustained attention no-go success and reaction time(mean and standard deviation) during 2 hours of prolonged standing.

Table 5.2 Mean (standard deviation) in cognitive function over 2 hours of prolonged standing with coefficient (Beta) for effect of time.

Variable	Minutes - group means (sd)					Coefficient (Beta)	Confidence Interval	p value
	0	30	60	90	120			
Sustained attention								
no-go success (%)	36.2 (27.9)	36.2 (24.5)	41.6 (27.2)	41.0 (26.4)	44.0 (23.7)	1.86	-0.09 – 3.82	0.062
reaction time (msec)	325.9 (46.1)	351.6 (74.7)	380.4* (136.9)	382.8* (114.4)	404.3* (150.7)	18.25	8.00 – 28.51	<0.001
Problem solving								
unique designs (n)	40.2 (10.7)	41.0 (8.2)	44.8* (9.6)	46.0* (10.0)	42.9 (9.2)	0.89	0.29 – 1.49	0.004
errors (n)	4.0 (7.1)	2.6 (3.2)	2.2 (2.5)	1.9 (2.0)	2.6 (2.8)	-0.37	-0.79 – 0.06	0.090

Confidence Interval is 95% confidence interval
*statistically significant pairwise comparisons from baseline

5.3.3 Muscle fatigue, kinematics, swelling and perceived mental state

The median frequency and amplitude of erector spinae, rectus femoris, biceps femoris and tibialis anterior muscles did not change significantly over the 2 hours (Table 5.3). Low back angle moved 2.4 degrees away from usual standing (-1.8 to -4.2 degrees) into more lordosis while pelvis movement increased from 4.7cm/sec to 5.6cm/sec over the 2 hours. Pairwise comparison of low back angle sagittal mean from baseline showed a statistically significant difference only at 90 mins (β =-4.02, p=0.008) while sagittal standard deviation had differences at both 90 and 120 mins (90 mins: β=-2.13, p=0.013, 120 mins: β=-1.91, p=0.026). Lower limb swelling increased significantly in all 3 calf locations over the 2 hours (1.2% increase in upper calf, 0.9% middle calf and 0.7% lower calf). Pairwise comparison showed statistical significant when compared to baseline for upper calf from 30 mins (β=0.27, p<0.001), middle calf from 60 mins (β=0.20, p=0.009) and lower calf from 90 mins (β=0.17, p=0.015). Figure 5.3 illustrates the effect of time on Tibialis Anterior muscle activity amplitude (submaximum voluntary reference contraction %) and calf swelling. Mental state deteriorated with pairwise comparison showing a statistically significant difference from 90 mins (β=7.57, p=0.045; 120 mins β=8.36, p=0.027) (Figure 5.4).

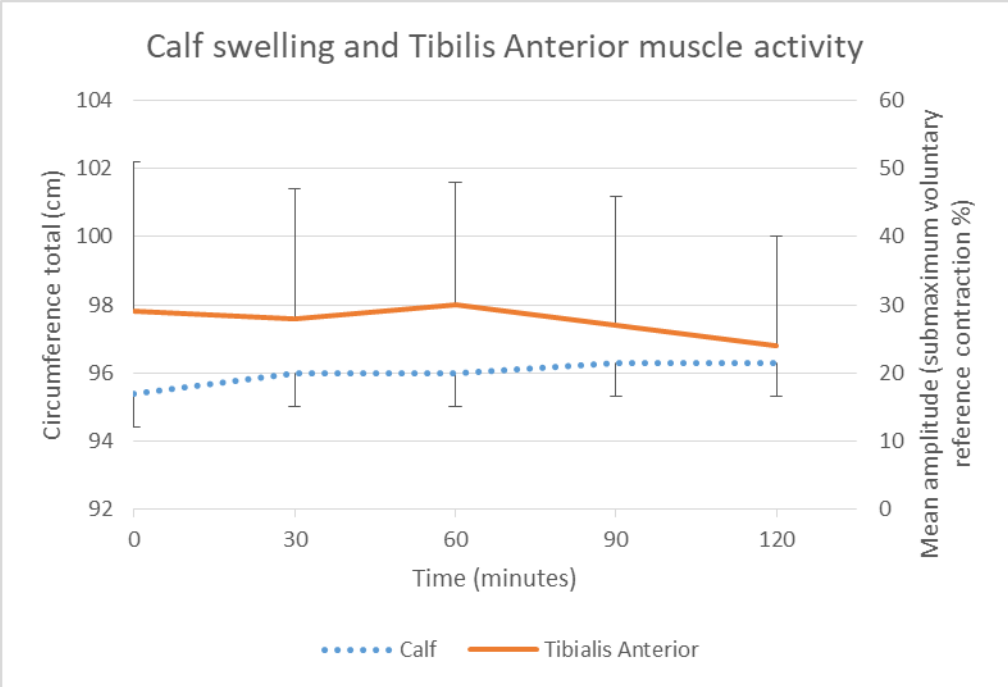

Figure 5.3 Calf swelling and tibilias muscle activity (mean and standard deviation) during 2 hours prolonged standing.

Table 5.3 Mean (standard deviation) in muscle fatigue, low back angle and movement, calf swelling and mental state over 2 hours of prolonged standing with coefficient (Beta) for effect of time.

Variable	Minutes - group means (sd) 0	30	60	90	120	Beta	Confidence Interval	p value
Muscle fatigue (A – Amplitude (% reference contraction), MF- Median Frequency [hertz])								
erector spinae - A	21.5 (16.0)	20.0 (13.0)	18.8 (10.8)	19.8 (11.2)	20.3 (11.3)	1.00^	0.95 – 1.05^	0.996
erector spinae - MF	54.7 (32.3)	52.1 (20.3)	48.6 (14.2)	53.9 (19.2)	54.9 (21.3)	1.02^	0.98 – 1.90^	0.429
rectus femoris - A	15.4 (9.0)	15.0 (8.7)	14.1 (7.5)	16.2 (10.9)	15.0 (7.7)	1.02^	0.95 – 1.07^	0.492
rectus femoris - MF	72.4 (17.2)	76.4 (19.7)	80.4 (22.8)	75.2 (18.6)	76.2 (21.7)	1.02^	0.98 – 1.05^	0.519
biceps femoris - A	33.6 (22.6)	32.0 (21.6)	30.9 (23.0)	37.3 (27.5)	34.9 (23.8)	1.07^	0.98 – 1.17^	0.125
biceps femoris - MF	84.1 (20.6)	91.6 (23.6)	88.5 (21.6)	91.7 (20.4)	88.9 (15.0)	1.02^	0.98 – 1.07^	0.376
tibialis anterior - A	29.0 (22.1)	27.8 (19.4)	29.8 (18.3)	27.4 (19.4)	24.3 (16.2)	0.95^	1.29 – 1.15^	0.607
tibialis anterior - MF	90.7 (30.0)	92.0 (29.7)	91.2 (25.1)	87.4 (29.0)	94.7 (23.4)	1.05^	1.00 – 1.10^	0.128
Low back angle (degrees)								
sagittal mean	-1.8 (4.1)	-2.3 (4.1)	-3.9 (8.1)	-5.7* (7.9)	-4.2 (7.3)	-0.87	-1.55 -(-0.19)	0.012
sagittal std deviation	34.7 (12.4)	35.1 (13.4)	34.7 (12.8)	37.6* (12.2)	37.3* (14.5)	-0.55	-0.94 -(-0.17)	0.005
Pelvis movement (cm/second)								
distance	4.7 (1.5)	4.6 (2.0)	5.0 (2.9)	5.6 (2.4)	5.6 (2.8)	1.10^	1.00 – 1.20^	0.041
Calf swelling (cm)								
upper calf	36.3 (2.9)	36.6* (2.8)	36.6* (2.8)	36.8* (2.7)	36.8* (2.8)	0.10	0.01 – 0.13	<0.001
middle calf	33.9 (2.9)	34.0 (2.8)	34.1* (2.6)	34.2* (2.8)	34.2* (2.8)	0.07	0.04 – 0.11	<0.001
lower calf	25.1 (2.1)	25.3 (2.3)	25.2 (2.2)	25.3* (2.2)	25.4* (2.2)	0.04	0.01 – 0.07	0.021
total calf swelling	95.4 (7.1)	96.0 (7.0)	96.0 (6.8)	96.3 (6.8)	96.3 (6.8)	0.21	0.14 – 0.28	<0.001
Mental state (/100)								
	25.4 (18.0)	30.8 (16.0)	32.8 (17.0)	33.0* (19.1)	33.7* (23.3)	1.89	0.22 – 3.56	0.027

Confidence Interval is 95% confidence interval, ^ back transformed
*statistically significant pairwise comparisons from baseline

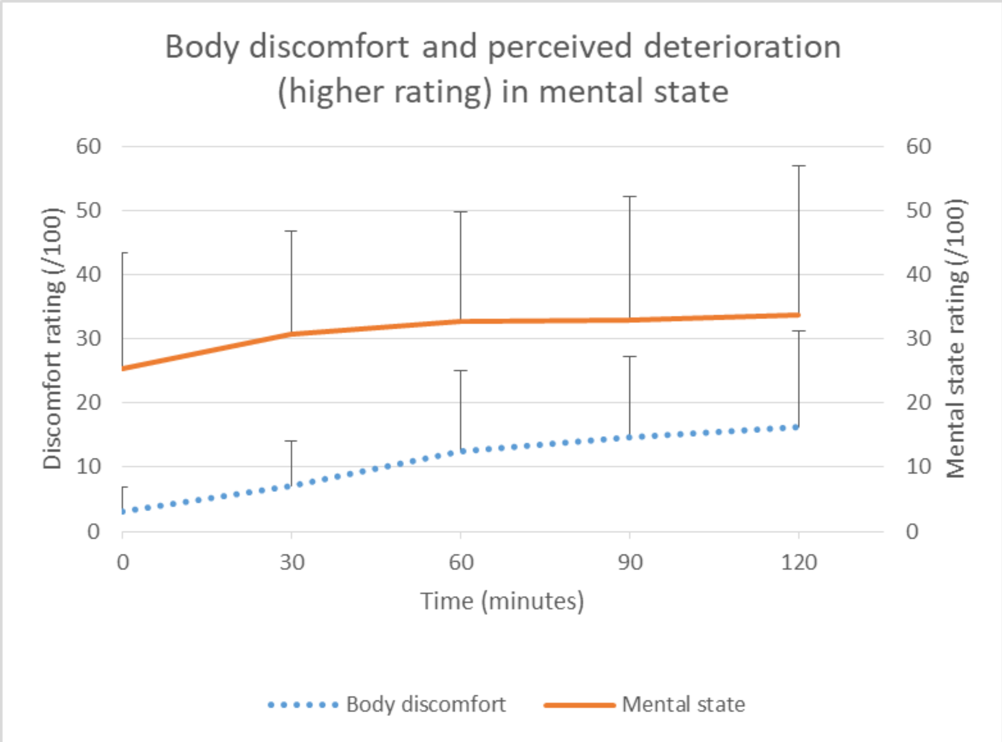

Figure 5.4 Body discomfort and mental state (mean and standard deviation) during 2 hours prolonged standing.

5.3.4 Correlations

Low back discomfort was not significantly correlated with erector spinae fatigue (amplitude or median frequency), deviation from usual standing (mean or standard deviation) or pelvis movement (change in postural sway) (see Table 5.4). Lower limb discomfort was not significantly correlated with lower limb swelling or tibialis anterior, biceps femoris and rectus femoris muscle amplitude or median frequency (see Table 5.5). Total body discomfort was moderately positively correlated with perceived mental state rating (rho=0.670; p= 0.001; see Table 5.6), however had no significant correlation with creative problem solving (number of designs or errors), or sustained attention (accuracy or reaction time).

5.4 Discussion

We investigated a number of variables to provide a detailed overview of musculoskeletal and cognitive changes related to prolonged standing. The results indicated a considerable increase in discomfort and mixed impact on cognitive function. Although there was no evidence of muscle fatigue over the 2 hours of standing, participants were however found to alter their low back posture and their lower limb swelling increased. There was a negative impact of prolonged standing on perceived mental state.

5.4.1 Discomfort

Congruent with other studies, participants reported an increase in discomfort in the low back (Gallagher and Callaghan 2015, Le and Marras 2016) and lower limbs (Chester *et al.* 2002, Antle *et al.* 2013). Less expected was that discomfort increased across all body regions including the upper limbs. During standing, participants generally only used small movements to access the keyboard or mouse potentially leading to static loading and little relief to passive structures of the upper limb. However this study did not measure upper limb muscle fatigue or posture so the mechanisms are unclear. Whilst epidemiological studies have not supported a clear link between standing and discomfort in the upper limb (Coenen *et al.* 2016) previous studies such as Balasubramanian *et al.* (2009) have found more static postures to result in higher discomfort than dynamic postures. The contrasting results of Roelofs and Straker (2002) may have been due to less static upper limb posture when performing bank teller tasks in standing. Whilst prolonged standing showed a moderate increase in discomfort in the upper limbs in the current study, future research could investigate discomfort in upper limbs further to understand mechanisms and develop interventions.

Muscle fatigue is commonly mentioned as a mechanism for discomfort in standing however this was not evident in the muscles analysed. Prior studies which have measured muscle fatigue via EMG have had mixed results. At the low back Antle and Côté (2013) found no change in trunk muscles after 34 mins while Hansen *et al.* (1998) found there were signs of postural fatigue with a significant fall in mean power frequency of left paraspinalis (back) at 2 hours. For the lower limb Cham and Redfern (2001) found no (statistically significant) muscle fatigue over a 4 hour test duration however Garcia *et al.* (2015) measured muscle twitch force and while no fatigue was found over 2 hours, it was evident after 5 hours. Halim *et al.* (2012) conducted a study of production workers taking measurements over 5.75 hours and identified muscle fatigue in erector spinae and tibialis anterior which correlated with ratings of perceived muscle fatigue. Thus the available evidence suggests that muscle fatigue may be more evident following periods of standing greater than 2 hours and therefore research to provide further insight into low back muscle fatigue as a mechanism for discomfort may need to involve standing for longer than 2 hours. Such prolonged exposure may be necessary to create fatigue as the amount of postural muscle activity required in standing is quite low (approximately 2.5 times that of sitting and considerably less than walking (Tikkanen *et al.* 2013)).

The current study found that low back discomfort increased, low back angle changed and pelvis movement increased over time. A number of studies have found low back angle change and fidgets or weight shifts to increase over time (Gregory and Callaghan 2008, Gallagher *et* *al.* 2011, Antle and Côté 2013, Gallagher and Callaghan 2015). It is unclear whether a low back change of 2.4 degrees and an increased movement of 0.9cm/sec is clinically meaningful, although the finding of an increase of 27/100 for low back discomfort is considered to be clinically important (Hägg *et al.* 2003). It is postulated that unloading of passive tissues through movement is used to alleviate or manage discomfort (Gallagher and Callaghan 2015) however further research is required to investigate whether the movement is pre-emptive or reactionary. This information will help to guide industry recommendations to manage discomfort.

Whilst the increase in lower limb discomfort (21/100) is considered to be clinically meaningful (Hägg *et al.* 2003) it is unclear whether calf swelling is an important mechanism, given the lack of statistically significant correlation. The change in calf circumference was congruent with previous studies including Chester *et al.* (2002) who found an increase in circumference of 1.7% after 90 mins. The lack of movement in static standing is postulated to impact lower extremity swelling. Seo *et al.* (1996) found swelling in standing to be less than sitting however the difference was approximately halved when some walking was permitted with the standing. The lack of correlation in the current study of lower limb muscle activity amplitude and median frequency with discomfort may have been due to the lack of consideration of the pattern of muscle activity. Phasic muscle contractions are likely to assist with venous return and reduce swelling however it is unclear whether static contractions provide the same benefit and this should be explored in further research.

5.4.2 Cognitive function

The current study found mixed changes for cognitive function. In the creative problem solving task, the number of unique designs increased over time and the number of errors showed signs of decreasing. Whilst practice effects may have contributed to these results (Ross et al., 2003), there was no evidence of any potential deterioration in performance during standing. Participants were able to withhold responses in the sustained attention task at about the same rate across the 2 hour period however reaction times became significantly slower. It is possible that this pattern of changes on sustained attention task may be due to practice effects in which participants slowed their reaction time in order to maximise accuracy in withholding (No-go) responses. Other studies, although of shorter duration, have not found a deterioration in reaction time between sitting and standing (Bantoft *et al.* 2016) or in speed and accuracy across a range of cognitive tests (Commissaris *et al.* 2014, Russell *et al.* 2016). The reduction in reaction time in the current study may have been due to the longer duration used (2 hours). Although this duration is well short of a standard work day it does capture a typical work period an office worker may perform before some form of break. The results indicate that participants were able to perform creative problem solving and maintain sustained attention accuracy, albeit at a slower pace, during standing for 2 hours. It is unclear whether changes of the magnitude found in this study are likely to be of meaningful detriment or benefit in real occupations.

Perceived mental state was found to deteriorate and to be moderately correlated with body discomfort. The deterioration in mental state is in line with Hasegawa *et al.* (2001) who reported an increase in observed signs of fatigue (such as changing position, stretching, yawning) in standing compared to sitting and Chester *et al.* (2002) who reported a non-significant trend for tiredness to increase with time. Correlations have previously been found for prolonged standing between perceived fatigue and muscle fatigue in production workers (Halim *et al.* 2012) and in a laboratory study between overall tiredness and discomfort (Chester *et al.* 2002). Thus perceptions of discomfort may signal deteriorating broader mental state. Compared to sitting, standing does increase heart rate and energy expenditure although to a modest degree (Barone Gibbs *et al.* 2016). To avoid mental state deterioration, either a lower or higher level of movement (with resultant physiological changes) may be required, and this may also assist with managing discomfort.

5.4.3 Strengths, limitations and implications

The strengths of this study included the multiple concurrent measures taken repeatedly allowing relationships between variables and potential mechanisms to be explored. Assessments of cognitive function and mental state were valuable to provide insight into the participants' performance together with the musculoskeletal data.

Whilst the 2 hours was a reasonable duration for a laboratory study, it was not a whole work day and was not repeated on successive days and for weeks, months and years as may be the case in occupational exposure. Thus some issues may become more obvious and important if observed over a longer period in the work context. A convenience sample was used, with fewer older participants, none with health conditions limiting standing capacity and none were conditioned to a standing work posture. It is unclear if conditioning workers could help maintain performance and minimise short and long term health impacts. We also did not control the computer activities undertaken by participants over the 2 hours, which may have effected results but was intended to provide consistent participant motivation. This may have affected upper limb discomfort results depending of amount of typing/mouse use versus more passive activities (reading, viewing movies). In addition this may have also impacted cognitive function results depending on the cognitive requirements during non-testing periods

Based on the findings of this study and prior studies, it is clear that standing for prolonged periods results in increased discomfort. Further, the effect of standing on low back, knee and ankle/feet discomfort was evident by 60 minutes, assuming a minimal clinically meaningful increase in discomfort of 10/100 (Hägg *et al.* 2003). This suggests the changes are of a magnitude that may have important implications for occupations with exposure to prolonged standing. Therefore interventions such as movement or posture variety are likely to be an important risk control measure to implement in order to minimise occupational standing for periods of longer than 60 minutes. However, the exact time of when to break from sustained standing requires further clarification.

The only adverse effect of prolonged standing on cognitive function was delayed reaction time, however it is possible that practice-induced changes may have obscured any performance deterioration. Further research using prolonged practice to eliminate these effects before the study or use of seated controls would help to clarify this point. It is also acknowledged that results were not compared to another prolonged posture condition such as sitting.

5.5 Conclusion

This study found acute negative health effects during 2 hours of prolonged standing including increases in discomfort in the low back, lower and upper limbs (to varying degrees) and lower limb swelling. Participants increased their low back movement however it is unclear if this was preventative or following increases in discomfort. Whilst there were significant increases in discomfort the variables studied did not clearly establish responsible mechanisms. Cognitive function results suggest mixed effects of prolonged standing, with increased creative problem solving and accurate but slower attention task responses. Exploration of associations between the variables showed a moderate correlation between total body discomfort and perceived mental state. The observed findings suggest replacing office work sitting with standing should be done with caution.

Chapter 6 Just standing and standing-with-movement

This chapter compares the discomfort and cognitive function outcomes for just-standing and standing-with-movement undertaken in Study 2 and is a verbatim copy of the paper now published in Human Factors (as below):

Baker, R., Coenen, P., Howie, E., Lee, J., Williamson, A., & Straker, L. (2018). Musculoskeletal and cognitive effects of a movement intervention during prolonged standing for office work. Human Factors, 60 (7), 947-961.

Discomfort and cognitive function were assessed regularly while participants maintained just-standing or standing-with-movement each for a two hour duration. Discomfort intensity was assessed by body location and cognitive function was assessed using tests of sustained attention and creative problem solving. The paper considers the potential mechanisms which may explain the differences in discomfort between the two conditions. For cognitive function differences in sustained attention and creative problem solving between conditions are considered alongside mechanisms which may have influenced results including dual task implications and energy expenditure. Mental state ratings are also compared between the two conditions.

Musculoskeletal and cognitive effects of a movement intervention during prolonged standing for office work

6.1 Introduction

Many office workers have a high exposure to sedentary time from their work (Parry and Straker 2013). Given the potential impact of this sedentary time on overall health (Dunstan *et al.* 2012, Straker *et al.* 2016) and work performance (Buckley *et al.* 2015), alternative office work positions (Huysmans *et al.* 2015) integrating movement are being promoted (Davis and Kotowski 2015). Alternate office work positions which allow more movement include treadmill and cycling workstations. There are concerns regarding the use of a treadmill work position around feasibility due to cost, footprint, noise and falls (McAlpine *et al.* 2007, Wieczer 2013) as well as impact on productivity due to dual task demands (Straker *et al.* 2009, Davis and Kotowski 2015). The limited studies on recumbent and under desk cycling have reported impact on work productivity, in particular while using a mouse (Straker *et al.* 2009, Tudor-Locke *et al.* 2014), and difficulty accommodating knee clearance without impacting the position of other body parts such as the upper limbs (Elmer and Martin 2014). Standing is being encouraged as a substitute for sitting (van der Ploeg *et al.* 2014, Buckley *et al.* 2015), but does not create much movement and has health risks including low back and lower limb discomfort in addition to lower limb swelling (Antle and Côté 2013, Coenen *et al.* 2016). Adding some movement to standing, such as alternating use of a footrest, may be a useful alternative. Footrests are easily accessible and low cost and therefore feasible for large scale implementation. A standing work system which enables computer work but also encourages movement, even to only a limited extent, may address some of the health and productivity issues.

There are a limited number of laboratory studies on the use of a footrest in standing. Rys and Konz (1994) had college students (n=9) stand for six hours using a 100mm flat platform (alternating foot position every seven minutes or just standing) and determined using a footrest had benefits for discomfort. Satzler *et al.* (1993) found standing aids were preferred, compared to regular standing, by 16 participants who stood for two hours (on each of 4 days undertook 30 minutes for each condition). Of the standing aids used (platform, angled platform and bar [each 100mm from the floor]) the two platforms rated most favourably. Whilst these few studies provide some indication that use of a footrest may be beneficial, there is a lack of evidence to support the optimal footrest design and use protocol.

6.1.1 Discomfort

Research specifically considering discomfort when using a footrest is limited. Whistance *et al.* (1995), in a short duration study (10 minutes) found standing with a footrail did not reduce discomfort for the trunk and there was increased discomfort in the supporting leg. This was congruent with Rys and Konz (1994) who found a decrease in lower leg, ankle and foot comfort when using a footrest compared to regular standing. There has been less attention to discomfort in the upper body, with Rys and Konz (1994) finding neck comfort to be better when using a footrest compared to regular standing and Satzler *et al.* (1993) who found comfort reduced for all body parts except the neck.

A footrest has been postulated to assist with low back discomfort due to the impact on pelvic tilt and lumbar posture (Ganesan *et al.* 2015). In a study of 30 staff and students the use of a 250mm footrest during standing was found to reduce anterior pelvic tilt by 4-5 degrees (Bridger and Orkin 1992). Whistance *et al.* (1995) found there was more posterior and laterally downward (toward the flexed leg) pelvic tilt during footrest use. It has been suggested that reducing anterior tilt may assist with low back discomfort (Levine and Whittle 1996), potentially by reducing tissue loading. Another hypothesis is that reducing *static* loading on tissues will reduce discomfort (Callaghan and McGill 2001). Use of a footrest allows regular movement during posture changes and increases postural sway (Ganesan *et al.* 2015). In considering the lower limb, the use of a footrest has been shown to result in considerably increased weight bearing by the supporting leg (up to 80% of body weight) (Ganesan *et al.* 2015), swelling (Rys and Konz 1994) and lower limb discomfort (Rys and Konz 1994, Whistance *et al.* 1995). Whilst there is the potential to positively influence discomfort by unloading the unsupporting leg and passive tissues, the movement needs be regular enough to pre-empt discomfort in the supporting leg. Another factor which may contribute to discomfort across all body regions is muscle fatigue (Callaghan and McGill 2001). Stationary standing has been found to fatigue lower limb muscles quicker than a dynamic posture over an hour (Balasubramanian *et al.* 2009). The introduction of some movement while standing, like through the use of a footrest, may be able to reduce discomfort arising from static loading and muscle fatigue.

6.1.2 Cognitive function

There are no field or laboratory studies we are aware of which considered cognitive function of office workers while using a footrest. There is a limited number of laboratory studies of movement work positions and cognitive function however the majority are of only short duration (up to 60 mins). While several studies have found no significant difference

(Commissaris *et al.* 2014, Bantoft *et al.* 2016, Russell *et al.* 2016) between sitting and a movement work position, Mullane *et al.* (2017) reported improved performance for memory, attention and problem solving while Sliter and Yuan (2015) found increased arousal levels in a movement work position. Hypotheses for improved cognitive function with increased activity levels include changes to brain blood flow, metabolism and oxygenation (Rooks *et al.* 2010). While studies of high energy expenditure exercise have found improvements in cognitive function (Colcombe and Kramer 2003, Chang and Etnier 2009, Wollseiffen *et al.* 2016), standing only slightly increases energy expenditure compared to sitting (Barone Gibbs *et al.* 2016). Although energy expenditure may further increase (slightly) for standing with movement (Beers *et al.* 2008) the impact on cognitive function is not known.

This study aimed to test whether standing-with-movement (using a footrest protocol), compared to regular standing, influenced discomfort and cognitive function over a period of prolonged standing. Muscle fatigue, low back angle, pelvis movement, lower limb swelling and mental state were also measured to gain further understanding of how these factors may be associated.

6.2 Method

6.2.1 Participants

Twenty adults (7 males, 13 female) were recruited from personal and professional networks with inclusion criteria of anticipated ability to stand for a two hour period, English and computer literacy and aged between 18 and 65 years. Those who used a standing work station or had pain in response to light activity (i.e. pre-existing musculoskeletal condition) were excluded. Informed signed consent was obtained and participants were able to withdraw at any time. Ethics approval for this study was provided by Curtin University Human Research Ethics Committee (RHS-266-15).

6.2.2 Design

Participants first attended a familiarisation session (one week prior to testing) and were asked not to undertake vigorous exercise in the 48 hours before the testing session. Participants attended a research laboratory at Curtin University for two testing sessions, undertaking two hours of either just standing or standing-with-movement (use of footrest). For standing-with-movement participants rotated every five minutes between right foot raised on a 100mm footrest (Z rest, Ergolink, Perth Australia) followed by left foot, then both feet on the floor. For the just standing condition participants continuously stood with both feet on the floor and were instructed to stand normally. During the just standing condition participants had to keep their feet on the floor, that is not use the footrest, but were free to move their feet and shift their weight at will. Participants were instructed to stand in their usual manner but were not instructed, nor otherwise constrained in foot position and wore flat shoes for both conditions. Participants undertook conditions approximately one week apart at a similar time of day in a balanced random order. During each of the two conditions, five repeated measures were taken (at baseline and then at 30 minute intervals). Condition and time were considered as independent variables and discomfort, cognitive function (sustained attention and creative problem solving), muscle fatigue, low back angle, pelvis movement, calf swelling and perceived mental state as dependent variables. During the standing-with-movement condition, cognitive testing was completed with the right foot on the footrest. Kinematics readings were taken after the cognitive testing while both feet were on the ground. Participants completed a brief questionnaire at the conclusion of each session with an additional question at the end of the second session ascertaining which work position they preferred.

During the sessions participants undertook self-directed computer activities (such as use of the internet and answering emails) and clerical tasks, and ceased this while undertaking testing (which was administered via the same computer). Test duration was approximately 7 minutes with the final testing undertaken after completion of the 120 minutes (while still standing). Participants stood with their abdomen touching the desk, or within a couple of centimetres of the desk edge, with elbows by their side allowing for consistent distances to keyboard and screen. They were asked not to lean on the desk surface but were able to rest their forearms. The desk (A7TR78928H, Steelcase, Sydney, Australia) was set to 5cm below standing elbow height (Nelson-Wong, Howarth and Callaghan, 2010) with the top of the computer screen (15 inch, Acer, Taiwan), approximately arms length in front, at eye level.

6.2.3 Dependent variables

6.2.3.1 Musculoskeletal discomfort

Participants rated intensity of musculoskeletal discomfort in each of nine body regions on a visual analogue scale (anchors: 0 = '*no discomfort'* and 100 = '*discomfort as bad as it could be'*) using an electronic version of the modified Nordic Musculoskeletal Questionnaire (NMQ). The NMQ has been widely used and is considered to have acceptable reliability (Kuorinka *et al.* 1987). Combined scores were created by averaging body region scores to create *upper limb* (shoulder, elbow and wrist/hand), *lower limb* (hip/thigh/buttock, knee and ankle/foot) and *total body* (all scores) discomfort. Participants reported to the researchers when they would have voluntarily chosen to cease standing if not in a study. Participants ceased the session if discomfort increased beyond the level considered by the participant to be acceptable.

6.2.3.2 Cognitive function

Sustained attention. A Go/No-go type test was used to measure sustained attention. The Sustained Attention to Response Test (SART) (*http://www.millisecond.com/download/library/SART/*) has been widely used (Head and Helton 2014) and requires participants to use their dominant hand to depress the keyboard spacebar to all digits which flash briefly (250ms) on the monitor (Go response), except the number three (No-go response), aiming to respond as quickly as possible while also minimising errors over four minutes and 20 seconds. Analysis was undertaken of No-go percentage success (correctly withheld response) and overall reaction time.

Creative Problem Solving. The Ruff Figural Fluency Test (RFFT) was selected for a creative problem solving test (Ross *et al.* 2003) as it was considered to be not overtly stimulating thereby avoiding substantially altering attentional level (Oken *et al.* 2006). The RFFT has been tested for test-retest reliability (unique designs intraclass correlation coefficients of 0.98 and perseveration errors 0.94) and has evidence of convergent validity with executive functions tests (Ross *et al.* 2003). Participants used the computer mouse to draw lines between dots creating unique designs over a 60 second period, with the total number of unique designs and errors (repeat of designs or not within rules) tallied manually by the researcher. At every test period participants completed two consecutive parts of the five part RFFT (1&2, 3&4, etc).

6.2.3.3 Muscle fatigue

Surface electromyography (EMG), via Trigno® Wireless System (Delsys Inc, Boston, USA), was used to collect muscle activity data (with a sampling rate of 2000Hz) in two minute samples. Muscle fatigue was characterised using median frequency and amplitude. These measures have previously had reliability demonstrated in our laboratory (Dankaerts *et al.* 2004). Standard skin preparation was completed before electrodes were secured with tape to the following muscles: lumbar erector spinae (iliocostalis lumborum pars thoracis) at L1 spinous process level midway between the midline and lateral aspect (O'Sullivan *et al.* 2006); rectus femoris midway along a line between the anterior superior iliac spine and superior border of the patella (Rouffet and Hautier 2008); biceps femoris midway laterally on the posterior thigh (Rouffet and Hautier 2008); and tibialis anterior 15 cm below the patella (von Tscharner *et al.* 2003).

Submaximal voluntary contractions were held for three seconds and repeated three times for each muscle, completing the following: erector spinae and biceps femoris - lying in a prone position with the knees bent to 90° and lifting both knees 5cm off the supporting surface (Dankaerts *et al.* 2004), rectus femoris - sitting with 2kg weight secured at ankle and with hips flexed to 90° and the tested knee extended to 45° (Kollmitzer *et al.* 1999); tibialis anterior – with the foot parallel to floor dorsiflexion contraction holding heel ~10 cm off the ground (adapted from (Madeleine *et al.* 1998)).

EMG data were processed using a customised program (LabView, National Instruments Inc., Texas, USA) and was demeaned, rectified and high pass filtered using a 4Hz cut off frequency and visually inspected for artefacts. Median frequency and amplitude (normalised to the middle submaximal contraction) were calculated and used for statistical analysis.

6.2.3.4 Kinematics

3-Space Fastrak (Polhemus Navigation Sciences Division, Vermont, USA) was used to collect two minute samples (at 25Hz) of kinematic data. Fastrak determines the position and orientation of sensors, relative to the field source, via a low frequency magnetic field and has a reported accuracy of 0.2 degrees (Pearcy and Hindle 1989). Sensors were secured over spinous processes with tape at the level of C7, T12, L3 and S2 (based on the protocol by Levine and Whittle (1996)). As with EMG, kinematics were collected when participants had both feet on the ground to allow comparison between conditions.

The average and standard deviation of the sagittal low back angle sagittal between T12 and S2 sensors, calculated using the LabView program, was used for further analysis (both normalised to usual standing posture – group mean low back angle was -30.1 degrees). Pelvis movement was measured as distance in centimetres of transverse plane displacement of the S2 sensor over two minutes (O'Sullivan *et al.* 2006) and converted to cm/sec for further analysis.

6.2.3.5 Lower limb swelling

Calf circumference was measured using a Gulick II (Denver, USA) non stretch tape with spring tension, in three locations: 10 cm above the medial malleolus, 10 cm below the medial knee joint and the midpoint of these (te Slaa *et al.* 2011). The average of two measures taken at each location was used for analysis. Consistency training was undertaken across the two researchers. Reliability of circumferential measurements for limb swelling has been demonstrated (Karges *et al.* 2003).

6.2.3.6 Mental state.

Perceived mental state was measured using five computer administered visual analogue scales with anchors: *'not at all alert/tired/drowsy/fatigued'* to '*extremely alert/tired/drowsy/fatigued'* and '*concentrating was no effort at all'* to *'a tremendous chore*', adapted from the Visual Analogue Scale for Fatigue which has evidence for reliability and validity (Lee *et al.* 1991). Data were reverse scored where needed then summed, averaged and normalised to a single 0-100 scale for further analysis.

6.2.4 Statistical analysis

Data were examined for normality using histograms, kurtosis and skew statistics. Analysis was undertaken of each dependant variable with time (five repeated measures over two hours) and condition (standing-with-movement and just standing) as the independent variables and a time*condition interaction using mixed models with participant as random intercept. For normally distributed data (cognitive function, low back angle, lower limb swelling and mental state) linear mixed models were used; for data with a count distribution (discomfort body regions) negative binomial mixed models were used; and for skewed data (muscle fatigue, pelvis movement) logarithmic transformation was undertaken then linear mixed models were used (back transformed data is presented). Unstandardised beta coefficients (in linear models) and incident rate ratio (IRR; in negative binominal models) were reported with 95% confidence interval and p values. Statistical significance was accepted at alpha probability of p=<0.05. The software used for analysis was STATA (StataCorp 2015, Stata Statistical Software: Release 14. College Station TX: StataCorp LP).

Discomfort ratings with change from baseline greater than 10/100 were considered clinically meaningful based on Hägg *et al.* (2003) and increases greater than 10/100 from baseline were tested with pairwise comparisons. Given the lack of a recognised minimum clinically meaningful change for the other variables (cognitive function, kinematics, swelling and mental state), all time points were tested in comparison to baseline using linear mixed models if there was a significant time effect.

6.3 Results

Nineteen participants completed the full two hours just standing condition and 18 completed the standing-with-movement condition. See Table 6.1 for descriptive statistics. One participant withdrew after 74 minutes in the standing condition and two participants withdrew from the standing-with-movement condition, at 59 and 108 minutes respectively, reporting an unacceptable level of discomfort. For these participants data from the available test periods were used. Following visual inspection for artefacts, EMG data was not included for three participants' rectus femoris (for one of the conditions) and one participant's rectus femoris (for both conditions), one participant's biceps femoris (for one of the conditions) and four participants' tibialis anterior (for one of the conditions). For low back movement two participants were extreme outliers (greater than 1.5 times the interquartile range) and were excluded from analysis. Participants reported 'if they were free to sit at any time' they would have done so on average after 80 (range 31 - 120) minutes for just standing and 77 (10-120) minutes for standing-with-movement.

Table 6.1 Descriptive information of the study sample for just-stand and standing-with-movement

	Mean (SD)
Age (years)	28.3 (9.9)
Weight (kg)	66.1 (10.5)
Height (cm)	167.5 (10.5)
Occupational Category	**Number of participants**
Sedentary occupation	13
Standing occupation	4
Physical work	3
Heavy manual work	0

Table 6.2 Discomfort [mean (standard deviation)] over 2 hours prolonged standing (S) and standing-with-movement (SWM) with incident rate ratio (IRR), and 95th percentile Confidence Interval (CI), for effect of time, condition and time*condition

Variable	Minutes - group means (sd)					Time effect			Condition effect			Time*condition interaction		
	0	30	60	90	120	IRR	CI	p value	IRR	CI	p value	IRR	CI	p value
Discomfort /100)														
Neck - S	2.6 (4.4)	4.2 (6.8)	5.3 (9.4)	8.2 (14.8)	9.7 (13.0)	1.32	1.14 - 1.53	<0.001	1.19	0.58 - 2.44	0.643	0.98	0.79 - 1.20	0.821
Neck – SWM	2.9 (5.2)	4.5 (8.0)	7.0 (9.5)	9.0 (16.4)	11.0 (18.3)									
Shoulder - S	3.9 (5.7)	5.0 (7.1)	7.6 (9.5)	7.6 (9.0)	11.2 (15.9)	1.22	1.06 - 1.41	0.004	0.77	0.39 - 1.50	0.440	1.07	0.88 - 1.30	0.440
Shoulder - SWM	4.5 (8.2)	4.5 (7.3)	7.3 (10.1)	11.3 (18.2)	13.1 (19.1)									
Elbow - S	1.7 (4.0)	2.8 (5.9)	4.7 (9.8)	4.9 (7.5)	7.0 (11.0)	1.42	1.23 - 1.65	<0.001	1.31	0.64 - 2.68	0.460	0.96	0.78 - 1.17	0.691
Elbow - SWM	1.7 (2.4)	2.9 (3.8)	5.0 (6.7)	5.7 (8.4)	9.0 (15.0)									
Wrist/hand - S	1.5 (4.0)	2.6 (5.8)	6.3 (11)	5.4 (7.9)	5.7 (8.6)	1.56	1.29 - 1.90	<0.001	2.12	0.87 - 5.19	0.098	0.81	0.62 - 1.06	0.128
Wrist/hand - SWM	1.5 (2.1)	3.6 (4.8)	6.7 (7.4)	5.2 (9.2)	5.4 (7.4)									
Upper Back - S	2.8 (5.6)	4.9 (8.4)	9.2 (12)	10.5 (14.1)	12.0 (15.6)	1.50	1.28 - 1.74	<0.001	0.92	0.44 - 1.92	0.821	1.04	0.82 - 1.29	0.743
Upper back - SWM	2.0 (4.7)	5.1 (6.7)	8.2 (9.5)	12.4 (18.1)*	12.9 (18.7)*									
Low back - S	5.0 (6.1)	12.4 (12.2)	21 (19.3)*	28.8 (24.3)*	32.0 (28.4)*	1.60	1.42 - 1.81	<0.001	0.87	0.49 - 1.55	0.639	0.97	0.82 - 1.16	0.745
Low back - SWM	4.4 (7.0)	10.5 (10.6)	17.6 (16.5)*	22.7 (23.3)*	23.4 (25.6)*									
Hip/thigh/buttock - S	2.6 (4.0)	6.6 (10.1)	15.3 (19.7)*	17.3 (22.2)*	19.9 (24.1)*	1.73	1.49 - 2.01	<0.001	1.74	0.86 - 3.50	0.121	0.88	0.71 - 1.08	0.215
Hip/thigh/buttock - SWM	3.4 (6.2)	7.8 (9.5)	14.0 (16.0)*	17.1 (21.7)*	19.0 (25.6)*									
Knee - S	3.3 (5.0)	10.6 (11.7)	19.5 (22.0)*	20.2 (21.7)*	23.8 (24.8)*	1.65	1.44 - 1.89	<0.001	0.83	0.43 - 1.60	0.572	0.97	0.79 - 1.18	0.741
Knee - SWM	2.6 (4.9)	8.6 (10.0)	13.0 (15.3)*	18.6 (24.7)*	17.7 (22.3)*									
Ankle/foot - S	3.8 (4.9)	15 (12.4)	23.1 (22.7)*	28.5 (22.2)*	33.1 (22.1)*	1.61	1.43 - 1.80	<0.001	1.89	1.10 - 3.23	0.020	0.90	0.77 - 1.06	0.207
Ankle/foot - SWM	8.9(11.6)	16.5 (11.0)	26.7 (15.9)*	37.3 (27.4)*	36.6 (25.7)*									
Upper Limb - S	2.4 (4.2)	3.5 (6.0)	6.2 (9.3)	6.0 (7.4)	7.6 (11.1)	1.31	1.18 - 1.46	<0.001	1.15	0.67 - 1.98	0.611	0.97	0.83 - 1.13	0.678
Upper limb - SWM	2.6 (3.6)	3.6 (4.5)	6.3 (7.6)	7.0 (11.4)	8.3 (12.9)									
Lower Limb - S	3.3 (4.2)	10.7 (10.2)	19.3 (20.4)	22.0 (21.1)	24.4 (22.4)	1.57	1.41 - 1.76	<0.001	1.52	0.90 - 2.56	0.119	0.90	0.77 - 1.05	0.194
Lower Limb - SWM	5.0 (5.8)	11.0 (9.1)	17.9 (14.4)	23.1 (22.7)	22.0 (23.1)									
Whole body - S	3.0 (3.9)	7.1 (7.0)	12.4 (12.6)	14.6 (12.6)	16.3 (15.0)	1.47	1.35 - 1.61	<0.001	1.20	0.78 - 1.84	0.413	0.93	0.83 - 1.06	0.278
Whole body - SWM	3.5 (4.3)	7.1 (6.4)	11.7 (9.8)	14.7 (15.8)	14.8 (16.0)									

6.3.1 Discomfort

Discomfort increased over time in both conditions across all body regions and combined regions (upper limb, lower limb and total body) (see Table 6.2). There was an effect for condition for ankle/foot (p = 0.020), with higher discomfort levels in the standing-with-movement condition (see Figure 6.1), but in no other regions. There was no time*condition interaction effect for body discomfort in any of the nine regions. Pairwise comparisons showed that group clinically meaningful discomfort increases from baseline were also statistically significant from 60mins for; low back (standing-with-movement 60mins; IRR=3.96, p<0.001, 90mins; IRR=5.37, p<0.001, 120mins; IRR=6.54, p<0.001 and standing 60mins IRR=4.18, p=<0.001; 90mins IRR=5.93, p<0.001; 120mins IRR=6.83. p<0.001), hip/thigh/buttock (standing-with-movement 60mins IRR=3.53, p<0.001, 90mins IRR=4.18, p<0.001, 120mins IRR=5.53, p<0.001 and standing 60mins IRR=5.92, p<0.001; 90mins IRR=6.66, p<0.001; 120mins IRR=9.45. p<0.001), knee (standing-with-movement 60mins; IRR=5.53, p<0.001, 90mins; IRR=8.00, p<0.001 , 120mins: IRR=8.37, p<0.001 and standing 60mins IRR=5.63, p=<0.001; 90mins IRR=6.47, p<0.001; 120mins IRR=8.87. p<0.001) and ankle/foot (standing-with-movement 60mins; IRR=3.48, p<0.001, 90mins; IRR=5.01, p<0.001, 120mins; IRR 4.85, p<0.001 and standing 60mins IRR=5.82, p=<0.001; 90mins IRR=7.92, p<0.001; 120mins IRR=10.60. p<0.001). Standing-with-movement also had group clinically meaningful discomfort increases from baseline for the upper back from 90mins; IRR = 6.29, P<0.001 (120mins; IRR= 6.79, p<0.001).

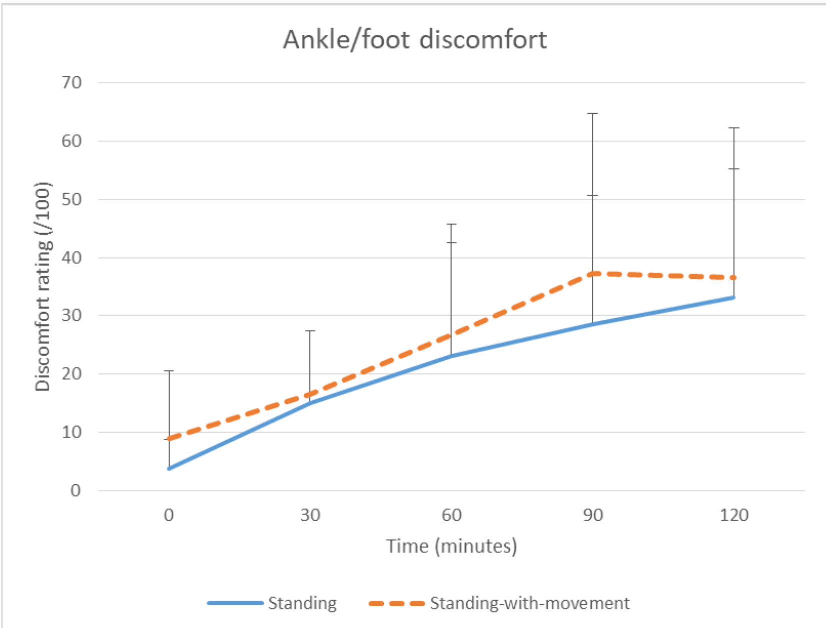

Figure 6.1 Ankle/foot discomfort (mean and standard deviation) for standing and standing-with-movement over 2 hours

6.3.2 Cognitive function

Reaction time in the sustained attention test slowed in both conditions over time (β=18.22, p=<0.001 see Table 6.3). Whilst there was no significant interaction effect, pairwise comparisons showed that group sustained attention reaction times significantly slowed from baseline from 60 minutes but only for standing (β=54.5, p=0.018; 90 mins β=56.90, p=0.013; 120 mins β=75.43, p=0.001). Sustained attention No-go success (percentage) appeared to improve over time across both conditions however this was not statistically significant (p=0.104). There was no significant condition or time*condition effect for No-go success. Creative problem solving unique designs had an effect for time (β =0.90, CI 0.12 to 1.69) with the number of designs increasing (see Figure 6.2) over the 2 hours, however no significant effect for condition or time*condition. Pairwise comparison showed that group creative problem solving unique designs were significantly increased from baseline at 60 mins (β=4.65, p=<0.001) and 90 mins (β=5.75, p=0.001) but only for standing. For creative problem solving errors there was no significant effect for time or condition however there was a time*condition interaction (β=0.64, CI 0.10 to 1.18) with errors in standing tending to decrease over time while standing-with-movement increased.

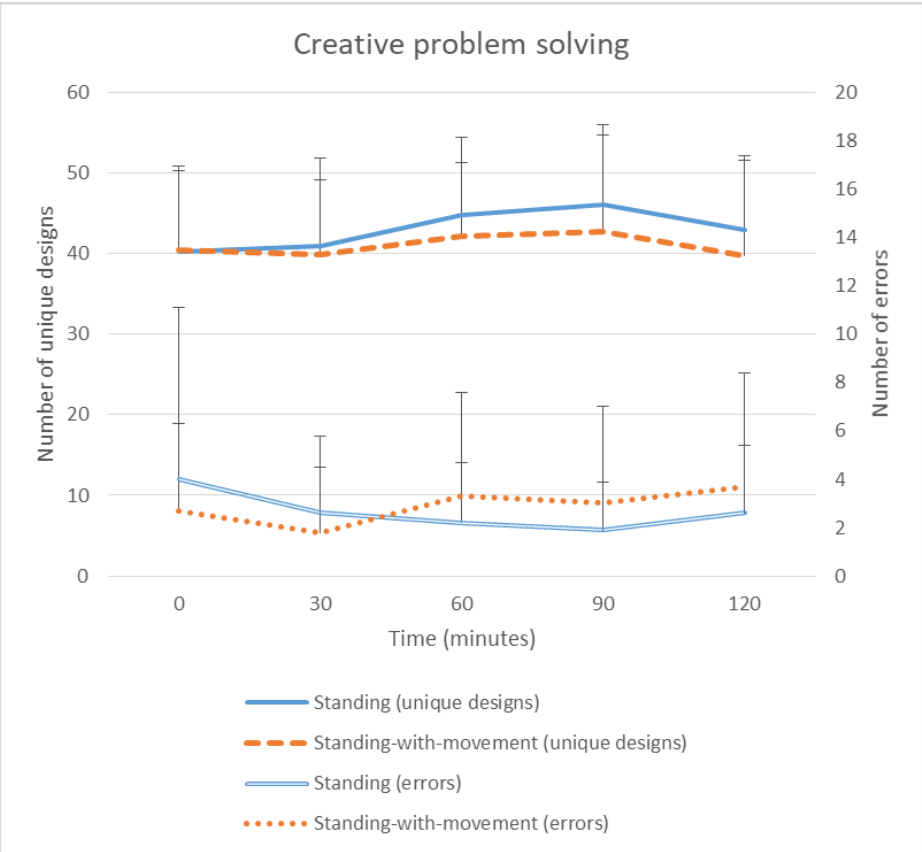

Figure 6.2 Creative problem solving (mean and standard deviation) for standing and standing-with-movement over 2 hours

Table 6.3 Cognitive function [mean (standard deviation)] over 2 hours of prolonged standing (S) and standing-with-movement (SWM) with coefficient (Beta) for effect of time, condition and time*condition

Variable	Minutes - group means (sd)					Time effect			Condition effect			Time*condition interaction		
	0	30	60	90	120	Beta	CI	p value	Beta	CI	p value	Beta	CI	p value
Sustained attention														
No-go success (%) - S	36.2 (27.9)	36.2 (24.5)	41.6 (27.2)	41.0 (26.4)	44.0 (23.7)	1.85	-0.38 - 4.09	0.104	1.78	-8.65 - 12.21	0.738	-0.74	-3.92 - 2.44	0.646
No-go success (%) - SWM	36.8 (29.4)	41.6 (23.2)	34.4 (23.2)	40.6 (25.6)	45.6 (27.8)									
reaction time (msec) - S	325.9 (46.1)	351.6 (74.7)	380.4* (136.9)	382.8* (114.4)	404.3* (150.7)	18.22	8.27 - 28.16	<0.001	29.22	-17.17 - 75.62	0.217	-8.08	-22.23 - 6.07	0.263
reaction time (msec) - SWM	354.1 (112.0)	360.8 (95.4)	376.3 (131.7)	384.1 (133.2)	396.3 (124.4)									
Problem Solving														
unique designs (n) - S	40.2 (10.7)	41.0 (8.2)	44.8* (9.6)	46.0* (10.0)	42.9 (9.2)	0.90	0.12 - 1.69	0.024	0.51	-3.14 - 4.16	0.784	-0.87	-1.98 - 0.24	0.127
unique designs (n) - SWM	40.4 (9.9)	39.8 (12.1)	42.2 (9.1)	42.7 (12.0)	39.7 (11.8)									
errors (n) - S	4.0 (7.1)	2.6 (3.2)	2.2 (2.5)	1.9 (2.0)	2.6 (2.8)	-0.37	-0.75 - 0.01	0.059	-1.73	-3.51 - 0.44	0.056	0.64	0.10 - 1.18	0.020
errors (n) - SWM	2.7 (3.6)	1.8 (2.7)	3.3 (4.3)	3.0 (4.0)	3.7 (4.7)									

S – standing without footrest, SWM- standing-with-movement with footrest, CI = 95th percentile Confidence Interval
**statistically significant pairwise comparisons from baseline*

6.3.3 Muscle activity, kinematics and mental state

There were no significant effects in muscle activity median frequency or amplitude in any of the muscles for time, condition or time*condition, except for greater rectus femoris amplitude in standing-with-movement (β=2.82, CI 1.26 to 6.46; see Table 6.4). Low back mean angle time*condition interaction was significant (β=1.28, CI 0.20 to 2.36), changing from -1.8 degrees (SD 4.1) to -4.2 (7.3) during standing and -3.5 (4.1) to -2.3 (5.9) during standing-with-movement. Pairwise comparison of low back angle sagittal mean showed a significant move away from usual standing posture at 90 mins (β =-4.02, p=0.008) for standing only. However low back angle standard deviation had no differences. Pelvis movement mean (SD) appeared to increase over the 2 hours in standing (4.7cm/sec (1.5) to 5.6cm/sec (2.8)) and decrease during standing-with-movement (5.2cm/sec (2.9) to 4.6cm/sec (1.4)) although the interaction effect did not quite meet significance threshold (p=0.085). Calf swelling had an effect for time for upper calf only (p=0.018) but no effect for condition or time*condition. Pairwise comparison showed significantly increased upper calf girth when compared to baseline from 60mins for standing-with-movement (β=0.65, p=0.001) and from 30mins for standing (β=0.27, p=<0.001). Total swelling (pooled across the three locations) showed no significant effects. Mental state had an effect of time (p=0.003), condition (p=0.018) and time*condition (p=0.031), with greater deterioration in the standing-with-movement condition. Pairwise comparison showed significant differences from 60mins for standing-with-movement (β=12.76, p<0.001; 90mins β=12.60, p<0.001; 120 mins β=14.51, p<0.001) and 90mins for standing (β=7.57, p=0.045; 120 mins β=8.36, p=0.027).

Table 6.4 **Muscle fatigue, low back angle, pelvis movement, calf swelling and mental state [mean (standard deviation)] over 2 hours of prolonged standing (S) and standing-with-movement (SWM) with coefficient (Beta) for effect of time, condition and time*condition.**

Variable	Minutes - group means (sd)					Time effect			Condition effect			Time*condition interaction		
	0	30	60	90	120	Beta	CI	p value	Beta	CI	p value	Beta	CI	p value
Muscle Fatigue A – Amplitude (% reference contraction), MF- Median Frequency [hertz])														
erector spinae - A - S	21.5 (16.0)	20 (13.0)	18.8 (10.8)	19.8 (11.2)	20.3 (11.3)	1.00^	0.91 – 1.10^	0.998	1.35^	0.91 – 2.00^	0.133	0.95^	0.85 – 2.00^	0.410
erector spinae - A - SWM	21.2 (6.7)	19.6 (6.6)	18.8 (8.4)	17.6 (5.8)	17.5 (5.9)									
erector spinae - MF - S	54.7 (32.3)	52.1 (20.3)	48.6 (14.2)	53.9 (19.2)	54.9 (21.3)	1.02^	0.98 – 1.07^	0.453	1.02^	0.79 – 1.32^	0.891	0.98^	0.91 – 1.05^	0.585
erector spinae - MF - F	47.7 (13.7)	53.2 (11.2)	49.5 (16.4)	51.5 (15.2)	49.4 (13.2)									
rectus femoris - A - S	15.4 (9.0)	15.0 (8.7)	14.1 (7.5)	16.2 (10.9)	15.0 (7.7)	1.02^	0.85 – 1.20^	0.827	2.82^	1.26 – 6.46^	0.013	0.98^	0.76 – 1.23^	0.788
rectus femoris - A - SWM	28.0 (18.6)	26.3 (16.4)	26.4 (16.6)	24.9 (17.3)	25.0 (12.2)									
rectus femoris - MF - S	72.4 (17.2)	76.4 (19.7)	80.4 (22.8)	75.2 (18.6)	76.2 (21.7)	1.02^	0.95 – 1.07^	0.649	1.12^	0.83 – 1.51^	0.464	0.98^	0.89 – 1.86^	0.576
rectus femoris - MF - SWM	76.2 (22.1)	79.9 (19.9)	78.2 (13.6)	76.6 (15.4)	74.3 (14.6)									
biceps femoris - A - S	33.6 (22.6)	32.0 (21.6)	30.9 (23.0)	37.3 (27.5)	34.9 (23.8)	1.07^	0.91 – 1.29^	0.408	0.72^	0.32 – 1.62^	0.429	1.02^	0.81 – 1.32^	0.835
biceps femoris - A - SWM	30.3 (28.7)	35.1 (29.2)	29.8 (26.5)	41.3 (41.3)	31.6 (29.5)									
biceps femoris - MF - S	84.1 (20.6)	91.6 (23.6)	88.5 (21.6)	91.7 (20.4)	88.9 (15.0)	1.41^	0.98 – 1.10^	0.294	1.23^	0.93 – 1.66^	0.152	0.95^	0.87 – 1.05^	0.366
biceps femoris - MF - SWM	86.4 (12.2)	91.3 (19.0)	88.2 (18.0)	87.2 (24.3)	89.9 (18.7)									
tibialis anterior - A - S	29.0 (22.1)	27.8 (19.4)	29.8 (18.3)	27.4 (19.4)	24.3 (16.2)	0.95^	0.78 – 1.15^	0.578	1.00^	0.41 – 2.45^	0.995	1.02^	0.78 – 1.35^	0.878
tibialis anterior - A - SWM	39.6 (40.3)	36.1 (30.8)	34.9 (30.0)	39.6 (33.2)	40.0 (39.1)									
tibialis anterior - MF – S	90.7 (30.0)	92 (29.7)	91.2 (25.1)	87.4 (29.0)	94.7 (23.4)	1.03^	0.95 – 1.12^	0.364	0.95^	0.68 – 1.35^	0.804	1.02^	0.91 – 1.12^	0.691
tibialis anterior - MF - SWM	90.3 (41.9)	90.6 (40.6)	87.8 (24.2)	99.0 (48.2)	95.0 (57.6)									

Variable	Minutes - group means (sd)					Time effect			Condition effect			Time*condition interaction		
	0	**30**	**60**	**90**	**120**	**Beta**	**CI**	**p value**	**Beta**	**CI**	**p value**	**Beta**	**CI**	**p value**
Low back angle (degrees)														
sagittal mean - S	-1.8 (4.1)	-2.3 (4.1)	-3.9 (8.1)	-5.7* (7.9)	-4.2 (7.3)	-0.88	-1.63 - (-0.12)	0.022	-3.67	-7.21 - - 0.14	0.042	1.28	0.20 - 2.36	0.020
sagittal mean - SWM	-3.5 (4.1)	-4.8 (7.0)	-3.7 (4.3)	-2.9 (6.0)	-2.3 (5.9)									
sagittal std deviation - S	-34.7 (12.4)	-35.1 (13.4)	-34.7 (12.8)	-37.6 (12.2)	-37.3 (14.5)	-0.71	-1.79 - 0.36	0.194	-3.25	-8.29 - 1.79	0.206	0.41	-1.13 - 1.95	0.601
sagittal std deviation - SWM	-36.9 (10.5)	-37.4 (10.5)	-38.4 (11.0)	-38.9 (10.7)	-38.5 (10.4)									
Pelvis movement (cm/sec)														
distance - S	4.7 (1.5)	4.6 (2.0)	5.0 (2.9)	5.6 (2.4)	5.6 (2.8)	1.10^	1.00 – 1.17^	0.044	1.20^	0.81 – 1.78^	0.381	0.89^	0.80 – 1.02^	0.085
distance - SWM	5.2 (2.9)	4.4 (1.7)	5.0 (2.5)	4.4 (1.4)	4.6 (1.4)#									
Calf swelling (cm)														
upper calf - S	36.3 (2.9)	36.6* (2.8)	36.6* (2.8)	36.8* (2.7)	36.8* (2.8)	0.10	0.02 - 0.18	0.018	-0.02	-0.40 - 0.37	0.922	0.04	-0.07 - 0.16	0.459
upper calf - SWM	36.3 (3.0)	36.6 (2.7)	36.9* (2.6)	37.0* (2.7)	36.8* (2.6)									
middle calf - S	33.9 (2.9)	34.0 (2.8)	34.1 (2.6)	34.2 (2.8)	34.2 (2.8)	0.07	-0.07 - 0.22	0.306	-0.52	-1.18 - 0.14	0.126	0.02	-0.18 - 0.22	0.824
middle calf - SWM	33.3 (3.4)	33.7 (3.4)	33.7 (3.4)	33.7 (3.5)	33.7 (3.5)									
lower calf - S	25.1 (2.1)	25.3 (2.3)	25.2 (2.2)	25.3 (2.2)	25.4 (2.2)	0.03	-0.13 - 0.20	0.669	0.28	-0.47 - 1.03	0.461	-0.03	-0.26 - 0.19	0.765
lower calf - SWM	25.2 (2.4)	25.9 (3.4)	25.3 (2.4)	25.4 (2.5)	25.4 (2.5)									
total calf swelling - S	95.4 (7.1)	96.0 (7.0)	96.0 (6.8)	96.3 (6.8)	96.3 (6.8)	0.21	-0.07 - 0.49	0.144	-0.26	-1.56 - 1.05	0.701	0.03	-0.36 - 0.43	0.871
total calf swelling - SWM	94.8 (8.1)	96.2 (8.4)	95.9 (7.8)	96.1 (8.0)	95.9 (8.1)									
Mental State (/100)														
perceived mental state - S	25.4 (18.0)	30.8 (16.0)	32.8 (17.0)	33.0* (19.1)	35.5* (22.5)	2.39	0.83 - 3.94	0.003	-8.79	-16.0 - (-1.52)	0.018	2.44	0.23 - 4.66	0.031
perceived mental state - SWM	20.2 (16.6)	23.8 (16.4)	33.0* (17.3)	34.6* (18.7)	38.6* (19.3)									

S – standing without footrest, SWM- standing-with-movement with footrest, CI = 95th percentile Confidence Interval, ^ back transformed.
*statistically significant pairwise comparisons from baseline; # non statistically significant pairwise comparison from baseline

Following completion of both conditions 13 participants preferred the use of the footrest, six preferred just-standing and one had no preference. Those who preferred standing-with-movement commented that there was "less aching in legs with movement less pain in lower back with movement/weight shift" and that it gave an "easier position to lean on other leg". Of those who preferred standing the reasons given included ability to shift weight and position when desired and not being limited to one position while standing.

6.4 Discussion

This study compared standing and standing-with-movement to investigate changes in discomfort and cognitive function. Whole body discomfort increased over the two hours with results in both conditions and showed no beneficial effect from use of the footrest (and in the ankle/foot discomfort was even higher for standing-with-movement compared to standing). Cognitive function results showed no difference between conditions in sustained attention reaction time or No-go success. Creative problem solving errors tended to increase during standing-with-movement and decrease during standing while unique designs had no difference between conditions.

6.4.1 Impact of movement intervention on discomfort

The standing-with-movement condition did not benefit discomfort ratings in the low back. In terms of potential factors influencing discomfort, the findings from this study indicated there was no difference in erector spinae muscle activity however there was a difference in low back angle between the conditions. In regular standing participants moved toward less lordosis over the two hours while in standing-with-movement there was a trend toward more lordosis and increased anterior pelvis tilt. These findings were not congruent with Whistance *et al.* (1995) who found there was more posterior pelvic tilt and reduced lordosis when participants were able to self moderate use of the footrest, noting their study was over a shorter duration. The foot alternating protocol chosen may have impacted the results of the current study. Gallagher *et al.* (2011) found movement, through body weight shifts, increased over time in unconstrained standing with the average duration spent in each new position reduced. In the current study pelvis movement had a trend toward more movement over time in standing than standing-with-movement (during the periods when both feet were on the ground) which may suggest an increasing attempt to alleviate discomfort. In the current study the standing-with-movement protocol restricted foot switch movements to five minute intervals. The period of five minutes before switching legs was chosen as being between the seven minutes in the only other study with a fixed protocol and 90 seconds mean measured in an unconstrained study. This timing aimed to allow for adjustment to the position with an opportunity to still focus on the task. As Satzler *et al.* (1993) reported use of a standing aid was preferred with more frequent movement than in the current study, more frequent foot switching may be needed. Further investigation of an optimal movement protocol could consider the frequency of movement, whether this frequency should vary over time and whether it should be individually flexible. Future studies should also consider continuous measurement of movement to allow direct comparisons between conditions. The design of the footrest also requires further research. Evidence from prior studies suggested a platform would be best, but perhaps use of a fixed or movable rail would encourage more movement.

Lower limb discomfort was slightly higher for standing-with-movement, which is consistent with Whistance *et al.* (1995) report of increased discomfort in the supporting leg. The potential mechanism for this discomfort may be increased static loading on the supporting leg, with asymmetrical posture and locking of knee for stability. Rys and Konz (1994) found little muscle activity in static standing of leg muscles (soleus and rectus femoris). We found greater rectus femoris muscle activity during standing-with-movement suggesting muscle fatigue may have been a contributing mechanism for the discomfort. However, we found no difference in lower leg muscle activity (tibialis anterior) between conditions, which may explain the lack of difference in total calf swelling. With more movement the muscle circulatory pump action (Seo *et al.* 1996) may have assisted with venous return. An alternate protocol of shorter periods between movements to reduce static loading and assist blood flow, could be considered in future studies.

In the upper limb whilst there was an increase in discomfort over time the footrest provided no substantial benefit. The only other study to comment on upper body discomfort found neck comfort was better when using a footrest (Rys and Konz 1994). With altered pelvic position it was anticipated there may have been increased spinal muscle activation (Dolan *et al.* 1988) to maintain posture and stability. Other studies have reported increased sway (Ganesan *et al.* 2015) which allows for slight variation in position of the upper body as a result of the movement thus reducing static loading. In our study neither pelvic movement or muscle activity were considerably different thereby potentially explaining the lack of condition effect.

Satzler *et al.* (1993) and Bridger (2003) both found a preference of standing with a foot raised compared to regular standing and within industry there is an assumed benefit in using a footrest. Safe Work Australia (2016) suggest a footrest should be provided to workers undertaking standing. Findings from the current study provide no support for this policy. In determining why standing-with-movement was not beneficial in reducing discomfort levels; the design of the footrest may not have been optimal and the forced protocol of set five minute changes may have reduced the opportunity for movement to prevent or manage discomfort effectively. There is a need to assess alternate designs and protocols to determine whether there are footrest use benefits relating to discomfort to support policy and practice for those workers who must stand.

6.4.2 Impact of movement intervention on cognition

Cognitive function was similar for standing and standing-with-movement, with the only difference being a decrease in creative problem solving errors over time in standing and an increase in standing-with-movement and slower reaction time. The differences observed, for example a difference between conditions in success rate of 1.78%, and in reaction time of 29 msec, may or may not be of practical importance in a workplace. A factor to consider when introducing movement is both the implications on physically performing tasks and any additional cognitive demands which may affect productivity. Studies have previously reported that standing without movement has little or no impact on the ability to perform manual office tasks; however with more movement, such as cycling and walking, mouse dexterity and key board use have been negatively impacted (Beers *et al.* 2008, Straker *et al.* 2009, Commissaris *et al.* 2014, MacEwen *et al.* 2015). Standing with limited movement, like the use of a footstool, has a more stable upper body than some other movement oriented work positions yet still requires some information processing for posture and movement control (Tudor-Locke *et al.* 2014). The current study asked participants to participate in a novel work position by including limited movement and a set protocol which may have added distraction. Russell *et al.* (2016) suggested performing a familiar task (such as standing) under unfamiliar conditions might result in increased self-monitoring which may in turn impact performance on complex cognitive tasks. This is in line with current results given creative problem solving is a more complex cognitive task than sustained attention. Schraefel *et al.* (2012) have suggested specific tasks may benefit from specific work positions. In addition the increasing discomfort experienced by participants may have been a distractor and influenced results. Broader cognitive function tests over a longer duration, to allow participants to get accustomed to the work position, would be beneficial to consider how work position with movement influences cognitive function.

When considering how work position may impact cognition another consideration is how mental state is influenced. Hasegawa *et al.* (2001) reported that undertaking a static work position increased mental dullness or drowsiness over time and a change of position was useful to moderate this perception. Changing work position has been postulated to assist in attenuating deterioration in mental state as a result of the physiological changes associated with activity (Russell *et al.* 2016, Wennberg *et al.* 2016). In the current study, mental state (including arousal) deteriorated more over two hours for standing-with-movement. Whilst it is unclear why standing-with-movement was worse than standing, the low-intensity movement may have been insufficient to influence physiological pathways such as cerebral blood flow, oxygenation and metabolic changes needed assist cognitive function. Further considerations may include the attention to the test protocol and the increased discomfort in the ankle/foot creating an additional drain on mental resources and influencing mental state.

6.4.3 Strengths/limitations

This study used a strong within subject design and a standardised protocol. Whilst the study had a duration of two hours rather than a whole work day, it covered a period of time comparable to what an office worker might spend before taking a break. It is acknowledged that the protocol may have been distracting which may have impacted the ability to prevent/manage discomfort. More frequent movement and a different footstool design, including height or angle adjusted to suit the participant, and protocol may yield different results. If optimal conditions can be identified there is potential for evidence to support use of a footrest when standing; as despite the objective measures of this study 13 of the 20 participants preferred the use of the footrest. It is further acknowledged that participants were recruited who did not already use a stand-biased desk and/or a footrest. With footrest use over an extended period, and potential conditioning, results may differ. Measurement of movement was not continuous which impacted our ability to compare the amount of movement between conditions. Participants were able to undertake self-selected computer based tasks between testing and this may have impacted results, particularly cognitive function and mental state, through task variation. Cognitive changes over time may also have been impacted by practice effects, in addition to other time dependent factors such as boredom.

6.5 Conclusion

Standing-with-movement by using a footrest provided no advantage in discomfort or cognitive function, and even some negative effects on discomfort at ankle/foot and creative problem solving. The results of this study suggest use of a footrest may not be useful to assist with managing discomfort while standing. It is acknowledged that other footstool designs and use protocols may be able to assist in managing discomfort.

Chapter 7 Discussion

7.1 Summary of key findings

The aim of this thesis was to investigate the impact of prolonged sitting and alternate work positions on musculoskeletal discomfort and cognitive functions. Two studies were conducted. In the first study, 20 participants undertook two hours of prolonged sitting (just-sitting*)* and two hours of under-desk cycling. In the second, a different group of 20 participants undertook two hours of prolonged standing (just-standing) and two hours of standing while alternating raising a foot on a footrest (standing-with-movement). Both studies examined outcomes of discomfort and cognitive functions.

Discomfort

In both studies, each of the work positions resulted in increased discomfort across all body areas with time. These increases were statistically significant (see Table 7.1 below). Further, each of the work positions had at least one body area which reached clinically meaningful levels of discomfort. Clinically meaningful discomfort was defined as a change of greater than 10/100 in discomfort rating compared to baseline. This threshold was chosen based on similar recent studies which have also used 10mm (Coenen et al. 2017). It is acknowledged as a conservative threshold given the healthy population, rather than clinical populations, which had been used in earlier studies by Hägg et al. (2003).

In Study 1 (Chapters 3 and 4) participants under-desk cycling reported higher total body discomfort than just-sitting. At 120 minutes, participants under-desk cycling had four body areas with clinically meaningful levels of discomfort compared to two areas for just-sitting. For only the low back, discomfort reached clinically meaningful levels by 120 minutes in both conditions. For the lower limb, during under-desk cycling, participants had greater discomfort of hip/thigh/buttock, knee and ankle/foot areas with each also reaching clinically meaningful levels. In contrast, for the upper limb no body areas reached clinically meaningful levels for either condition.

For Study 2 (Chapters 5 and 6), participants standing-with-movement reported lower total body discomfort than just-standing. However, at 120 minutes, participants standing-with-movement had more body areas (five) with clinically meaningful levels of discomfort while just-standing had four body areas. For the low back, both conditions reached clinically meaningful levels. Hip/thigh/buttock, knee and ankle/foot all reached clinically meaningful levels for both conditions. Once again, none of the upper limb body areas reached clinically meaningful levels for either condition. Of all the body areas, the lower limb areas had the highest reported discomfort level for both standing conditions.

There was an intention to analyse differences between pain-developers and non pain-developers across both Study 1 and Study 2. However, this was not viable due to 19 out of 20 participants being classified as pain-developers when considering any body area. For the low back, results of pain-developers and non pain-developers were analysed (for Study 2 only) and results reported in Appendix N (this was undertaken as a substudy).

Cognitive functions

Across both studies, cognitive functions results were inconsistent over time (see Table 7.2). There was no clear substantial decrement or improvement for any cognitive functions measure for each of the alternate work positions. There were however both trends and statistically significant differences for individual variables, which may have real-world importance. However as there is currently no threshold to determine clinical significance (Brisswalter *et al.* 2002), interpretation of the cognitive functions results should be undertaken with caution.

In Study 1 there were trends for differences between work positions for sustained attention and creative problem solving, however neither condition had consistently better outcomes. There may have been a dual task cost during under-desk cycling for sustained attention. While reaction time was able to maintained for under-desk cycling, reaction time sped up over the two hours for just-sitting with a statistically significant effect for condition. In comparison, percentage success deteriorated for under-desk cycling while just-sitting had a more stable percentage success. For creative problem solving, there was a non-significant trend for an increase in unique designs for under-desk cycling, with just-sitting remaining more stable. There was a non-significant trend, reduction in number of errors, during under-desk cycling compared to just-sitting.

In Study 2, neither standing condition was markedly better than the other. For sustained attention percentage success, there was no significant difference between conditions. Reaction time for both standing conditions got slower with time and this effect was statistically significant. Creative problem solving errors had a trend for errors to increase over time for just-standing and reduce over time for standing-with-movement. Participants' creative problem solving unique designs had an increase in number of designs over time for both standing conditions however there was no effect of condition.

There were no significant correlations between total discomfort and cognitive measures. Investigation of mechanisms resulted in no clear explanation for the discomfort and cognitive findings. Mental state deteriorated across both seated conditions, with participants rating under-desk cycling higher (deteriorated more than just-sitting). Participants’ mental state also deteriorated for both standing conditions with standing-with-movement having a higher rating (greater deterioration) than just-standing. Qualitative feedback, which was only obtained for Study 2, suggested participants preferred standing-with-movement to just-standing.

Table 7.1 Summary of findings from Studies 1 and 2 - mean (standard deviation) in discomfort over 2 hours prolonged sitting, under-desk cycling, standing and standing with movement with incident rate ratio (IRR) for effect of time, condition and time*condition.

Variable	Minutes - group means (sd)					Time effect			Condition effect			Time*condition interaction		
	0	30	60	90	120	IRR	CI	p value	IRR	CI	p value	IRR	CI	p value
Discomfort (/100)														
Low back - S	4.8 (7.2)	5.5 (6.8)	7.9 (8.4)	12.2 (12.8)	16.3 (14.3)	1.67	1.42 – 1.95	<0.001	2.01	0.96 – 4.19	0.064	0.86	0.70 – 1.07	0.181
Low back - C	2.8 (4.6)	4.4 (6.1)	7.9 (11.7)	10.6 (13.1)	15.7 (15.6)									
Low back - St	5.0 (6.1)	12.4 (12.2)	21 (19.3)	28.8 (24.3)	32.0 (28.4)	1.60	1.42 - 1.81	<0.001	0.87	0.49 - 1.55	0.639	0.97	0.82 - 1.16	0.745
Low back - SWM	4.4 (7.0)	10.5 (10.6)	17.6 (16.5)	22.7 (23.3)	23.4 (25.6)									
Upper limb - S	1.3 (2.0)	2.1 (2.0)	4.2 (5.1)	5.2 (7.1)	5.4 (7.0)	1.25	1.12 – 1.40	<0.001	0.81	0.45 – 1.43	0.466	1.10	0.94 – 1.30	0.222
Upper limb - C	1.7 (2.2)	2.3 (3.1)	3.2 (4.8)	4.5 (9.7)	5.1 (8.4)									
Upper limb - St	2.4 (4.2)	3.5 (6.0)	6.2 (9.3)	6.0 (7.4)	7.6 (11.1)	1.31	1.18 - 1.46	<0.001	1.15	0.67 - 1.98	0.611	0.97	0.83 - 1.13	0.678
Upper limb - SWM	2.6 (3.6)	3.6 (4.5)	6.3 (7.6)	7.0 (11.4)	8.3 (12.9)									
Lower limb - S	1.2 (2.7)	1.8 (2.6)	4.1 (5.2)	6.3 (7.5)	7.4 (7.5)	1.78	1.55 – 2.05	<0.001	0.60	0.29 – 1.24	0.165	0.95	0.78 – 1.17	0.632
Lower limb - C	1.3 (1.8)	4.5 (6.6)	9.0 (13.6)	10.5 (12.4)	16.2 (16.2)									
Lower limb - St	3.3 (4.2)	10.7 (10.2)	19.3 (20.4)	22.0 (21.1)	24.4 (22.4)	1.57	1.41 - 1.76	<0.001	1.52	0.90 - 2.56	0.119	0.90	0.77 - 1.05	0.194
Lower limb - SWM	5.0 (5.8)	11.0 (9.1)	17.9 (14.4)	23.1 (22.7)	22.0 (23.1)									
Total body - S	2.1 (2.8)	2.8 (2.5)	5.5 (5.0)	7.7 (7.0)	8.6 (7.7)	1.47	1.36 – 1.60	<0.001	1.01	0.66 – 1.54	0.959	0.98	0.87 – 1.10	0.720
Total body - C	2.0 (2.2)	3.4 (4.0)	6.1 (8.0)	7.6 (9.8)	10.6 (11.0)									
Total body - St	3.0 (3.9)	7.1 (7.0)	12.4 (12.6)	14.6 (12.6)	16.3 (15.0)	1.47	1.35 - 1.61	<0.001	1.20	0.78 - 1.84	0.413	0.93	0.83 - 1.06	0.278
Total body - SWM	3.5 (4.3)	7.1 (6.4)	11.7 (9.8)	14.7 (15.8)	14.8 (16.0)									

S - sitting, C – under-desk cycling, St – Standing, SWM – Standing with movement, IRR – Incident Rate Ratio, CI - Confidence Interval is 95th

Table 7.2 Summary of findings from Studies 1 and 2 - mean (standard deviation) in cognitive functions over 2 hours of prolonged sitting, under-desk cycling, standing and standing with movement with coefficient (Beta) for effect of time, condition and time*condition.

Variable	Minutes - group means (sd)					Time effect			Condition Effect			Time*condition interaction		
	0	30	60	90	120	Beta	CI	p value	Beta	CI	p value	Beta	CI	p value
Sustained attention														
no-go success (%) - S	59.4 (29.7)	57.6 (30.1)	54.8 (30.1)	56.2 (27.5)	54.4 (30.7)	-1.46	-3.16 – 0.24	0.093	-6.56	-14.55 – 1.43	0.108	0.32	-2.09 – 2.72	0.795
no-go success (%) - C	65.8 (25.9)	64.4 (26.6)	60.8 (25.5)	57.4 (28.6)	62.0 (25.3)									
no-go success (%) - St	36.2 (27.9)	36.2 (24.5)	41.6 (27.2)	41.0 (26.4)	44.0 (23.7)	1.85	-0.38 - 4.09	0.104	1.78	-8.65 - 12.21	0.738	-0.74	-3.92 - 2.44	0.646
no-go success (%) - SWM	36.8 (29.4)	41.6 (23.2)	34.4 (23.2)	40.6 (25.6)	45.6 (27.8)									
reaction time (msec) - S	375.9 (73.3)	365.4 (68.1)	361.2 (74.1)	373.1 (66.8)	365.5 (62.6)	-2.87	-8.69 – 2.95	0.012	-34.82	-62.12 – (-7.53)	0.012	1.56	-6.66 – (-7.53)	0.012
reaction time (msec) - C	404.2 (80.8)	410.5 (92.2)	386.3 (70.7)	391.3 (93.5)	399.4 (104.1)									
reaction time (msec) - St	325.9 (46.1)	351.6 (74.7)	380.4 (136.9)	382.8 (114.4)	404.3 (150.7)	18.22	8.27 - 28.16	<0.001	29.22	-17.17 - 75.62	0.217	-8.08	-22.23 - 6.07	0.263
reaction time (msec) - SWM	354.1 (112.0)	360.8 (95.4)	376.3 (131.7)	384.1 (133.2)	396.3 (124.4)									
Problem Solving														
unique designs (n) - S	42.1 (9.1)	40.2 (8.8)	41.3 (8.5)	43.2 (8.7)	39.6 (8.7)	0.50	-0.01 – 1.02	0.054	0.93	-1.48 – 3.34	0.450	-0.72	-1.45 – 0.01	0.052
unique designs (n) - C	42.2 (8.5)	39.9 (7.7)	43.2 (7.8)	44.8 (8.3)	42.3 (8.0)									
unique designs (n) - St	40.2 (10.7)	41.0 (8.2)	44.8 (9.6)	46.0 (10.0)	42.9 (9.2)	0.90	0.12 - 1.69	0.024	0.51	-3.14 - 4.16	0.784	-0.87	-1.98 - 0.24	0.127
unique designs (n) - SWM	40.4 (9.9)	39.8 (12.1)	42.2 (9.1)	42.7 (12.0)	39.7 (11.8)									
errors (n) - S	1.8 (3.2)	1.8 (2.8)	2.3 (3.6)	2.2 (2.3)	2.8 (3.1)	-0.01	-0.22 – 0.20	0.928	-0.81	-1.82 – 0.20	0.117	0.26	-0.04 – 0.56	0.095
errors (n) - C	1.8 (2.1)	2.8 (3.3)	2.3 (2.6)	1.8 (2.3)	2.4 (2.0)									
errors (n) - St	4.0 (7.1)	2.6 (3.2)	2.2 (2.5)	1.9 (2.0)	2.6 (2.8)	-0.37	-0.75 - 0.01	0.059	-1.73	-3.51 - 0.44	0.056	0.64	0.10 - 1.18	0.020
errors (n) - SWM	2.7 (3.6)	1.8 (2.7)	3.3 (4.3)	3.0 (4.0)	3.7 (4.7)									

S – sitting, C – under-desk cycling, St – Standing, SWM – Standing with movement, CI - Confidence Interval is 95th

7.2 Examining discomfort during prolonged sitting

Results of Study 1 for just-sitting gave evidence of increasing discomfort with time. Hip/thigh/buttock discomfort reached a clinically meaningful level at 90 minutes while low back discomfort reached a clinically meaningful threshold at 120 minutes. These findings were not unexpected, with previous studies also finding increased discomfort for the thigh and buttock region with prolonged sitting (Makhsous *et al.* 2009, Sondergaard *et al.* 2010). Pressure on the ischial tuberosities as a result of relatively static sitting has been postulated to be a cause for discomfort when sitting (Makhsous *et al.* 2009) and is discussed further in Section 7.4.2. For the low back, the results of the current study align with findings from previous studies that increased low back discomfort occurs over time when undertaking prolonged sitting (Sondergaard *et al.* 2010, Schinkel-Ivy *et al.* 2013, Sheahan *et al.* 2016). Mechanisms for the increase in discomfort are further discussed in Section 7.4.

Currently, implementation of alternative work positions for office based workers is often an attempt to address sedentary behaviour rather than an attempt to reduce discomfort when sitting. As a result there is a bias toward assessing discomfort in the alternate work positions without considering a comparison to sitting. It is important to recognise that prolonged sitting also can result in discomfort.

7.3 Factors influencing discomfort

One of the mechanisms postulated to have an impact on discomfort and considered throughout this thesis is movement. Each of the work positions studied for this thesis allowed different types of movement as outlined in Section 2.5.1. These were categorised as very limited (just-sitting), low intensity rhythmic (under-desk cycling), sporadic (just-standing) and intentional non-rhythmic weight shift (standing-with-movement). It was anticipated that just-sitting would have the least amount of movement followed by just-standing (John et al. 2015). The intentional movement required in standing-with-movement was designed to increase the amount of movement compared to just-standing (Beers *et al.* 2008). Meanwhile under-desk cycling with the associated rhythmic movement was anticipated to have the most movement (Straker et al. 2009, Carr et al. 2012, Huysmans et al. 2015). For alternative work positions, positively influencing discomfort is usually the primary focus of intervention protocols and equipment design. Discomfort is one of the most cited factors (Karakolis and Callaghan 2014, Huysmans et al. 2015) influencing user acceptance and feasibility.

The impact of the equipment selected for trials of alternate work positions has been apparent across a number of studies. Laboratory studies have used cycle equipment not designed or typically accepted for office use. For instance Straker et al. (2009) used an upright cycle not designed for office use, and its use resulted in hip/gluteal discomfort. Other studies have used an office chair without a backrest (Sondergaard et al. 2010, Karakolis et al. 2016). This has also impacted on the ability to generalise findings to real world settings. The current study only used equipment which could be readily adopted in a workplace. During under-desk cycling participants used a standard office chair, height adjustable desk and portable cycle machine; just-standing participants used only a height adjustable desk while for standing-with-movement participants used the height adjustable desk and a footrest. The under-desk cycle equipment chosen to use in Study 1 may however have negatively impacted results. The design of the Desk-cycle™ requires a strap over the mid-foot, which although adjustable, required a snug fit to allow cycling to be undertaken. The strap may have resulted in increased foot discomfort. A different design may have yielded different results in regard to foot discomfort. The equipment chosen for Study 2 did not present any obvious design issues which increased discomfort.

Protocols also influence the impact of movement on discomfort when using an alternative work position. Currently there is a lack of guidance available to industry on which ratio of use will positively influence discomfort. Studies of cycling as a work position are limited. Protocols have included set bout lengths of varying duration (Wollseiffen et al. 2016, Mullane et al. 2017) and also bouts of unknown length (Torbeyns et al. 2017). Recommendations for use of cycling work positions are currently lacking and need to be addressed. Study 1 was aimed at addressing this gap for discomfort and cognitive functions when undertaking prolonged continuous cycling. For standing, protocols have previously investigated ratios of standing to sitting and found varying results (Coenen *et al.* 2017b). Currently there is no recognised optimal ratio (Callaghan *et al.* 2015). A recent systematic review has however found standing for greater than 40 minutes may result in increases in pain of greater than 9 out of 100, in vulnerable people (Coenen *et al.* 2017b). Study 2 allowed assessment of discomfort at 30 minute intervals however also compared results of just-standing to standing-with-movement. In previous standing-with-movement studies participants have interacted with the equipment in both an unconstrained (Satzler *et al.* 1993, Carr *et al.* 2012, Karakolis and Callaghan 2014) and constrained manner (Rys and Konz 1994, Son *et al.* 2018). Study 2 had a set protocol to reduce confounders, and also provides findings which add to the evidence base for discomfort and cognitive functions outcomes when alternative work positions are used over prolonged periods.

Study results have demonstrated the importance of finding the optimal ratio of use of alternative work positions with some interventions having a greater positive effect on reducing discomfort. For example Rys and Konz (1994) used a protocol of placing a foot on a footrest for one minute in every seven (over 6 hours) and found nine out of 12 body areas had less discomfort when using the footrest compared to just-standing. In contrast, Whistance et al. (1995) had an unconstrained protocol over 10 minutes and found use of a footrest in standing did not result in significantly less discomfort. It is not described though how often, if at all, participants alternated feet. In Study 1, a protocol of five minutes was chosen for alternation of feet. Given the desire to be able to provide findings which could be used for industry guidance, it was important to trial a protocol which may be realistically implemented, noting regular prompts to change feet would be required. Thus, longer than one minute (Rys and Konz 1994) and shorter than 10 minutes (Whistance et al. 1995) appeared optimal based on prior studies. Whilst standing-with-movement was preferred over just-standing in the current study, the discomfort ratings were not impacted sufficiently to support recommendation of this protocol for implementation and further research on the protocol for footstool use is required.

In investigating the use of alternative work positions it is important that equipment which would suit an office environment and a study design which would allow application to a real world setting are used. It is also important to ensure comparison to sitting is undertaken to address criticisms of discomfort in the alternate work position. That is, while sitting may have less discomfort than other alternatives trialled to date, is not without discomfort. Further, while discomfort appears to be a primary influencer of perceptions of feasibility and acceptance other factors may also have a role.

7.4 Potential mechanisms for discomfort in various work positions

To understand mechanisms which may have influenced discomfort, the regions of the body (back, lower limb and upper limb) were addressed separately given the different physiological factors which may be an influence in each region. Low back angle and pelvis movement, in addition to muscle fatigue, were investigated for impact on discomfort in the low back region. For the lower limb, pelvis movement, muscle fatigue and swelling (in Study 2) were explored. Finally for the upper limb, pelvis movement (indicative of associated upper torso movement) and muscle fatigue were examined.

7.4.1 Low back

Not all individuals in the current studies experienced levels of low back discomfort which could be considered clinically meaningful, based on Hägg *et al.* (2003). This is congruent with other studies which have categorised individuals into pain-developers and non-pain developers

(Nelson-Wong and Callaghan 2014). Pain developers have previously been defined as those who rated a change of 10mm or greater on a 100mm visual analogue scale, while non-pain developers had less than 10mm increase from baseline (Nelson-Wong *et al.* 2010). For those who do develop higher levels of discomfort or pain there have been a number of postulated mechanisms. These include low back angle, static positioning and subsequent loading of passive tissues, muscle fatigue, intervertebral disc pressure and compressive tissue creep (Adams and Dolan 2005, Sorensen *et al.* 2015, Karakolis *et al.* 2016).

In Study 1, low back discomfort ratings reached clinically meaningful levels at 120 minutes for both just-sitting and under-desk cycling (based on group mean). There was a non-significant trend for just-sitting to have marginally higher low back discomfort than under-desk cycling. Discomfort for the low back with prolonged sitting was not unexpected and aligns with previous evidence (Claus *et al.* 2008, Sondergaard *et al.* 2010, Schinkel-Ivy *et al.* 2013). Sondergaard et al's (2010) study of prolonged sitting was 90 minutes in duration and showed a modest increase in low back pain. Schinkel-Ivy *et al.* (2013) meanwhile compared pain developers and non-pain developers over two hours of sitting and collected discomfort ratings for a larger area of the back (including thoracic spine). A significant difference in the level of reported discomfort was found between each group's baseline and rating at two hours. For under-desk cycling, as there is a lack of studies which have investigated discomfort with use of under-desk cycling, results of Study 1 could not be compared to other findings. Further, separation and analysis of pain developers and non-pain developers was not undertaken for the current study due to participant numbers. In the current study, it is not known if under-desk cycling would have continued to trend lower than just-sitting if continued after two hours. Further research over a longer duration would be beneficial.

During Study 2, just-standing and standing-with-movement reached meaningful levels of low back discomfort by 60 minutes. These findings for just-standing were not unexpected, although it had been hypothesised that there would be reduced discomfort with standing-with-movement due to postural change. Other research has also found that, when exposed to prolonged standing, approximately 50% of people experience back pain (Callaghan *et al.* 2015). In the current study, standing-with-movement did appear to have some positive influence on low back discomfort compared to just-standing. This was evident by the lower group mean at 60 minutes for standing-with-movement suggesting there may have been benefit for some participants, noting however there was no statistically significant difference between conditions. The qualitative feedback outlined in Section 7.9 also supports this inference. Satzler *et al.* (1993) also found discomfort increased over time in the low back over two hours of standing however also found there was no significant difference between the three standing aids (which included various types of footrest). In the current studies, both standing conditions had higher levels of low back discomfort compared to both seated conditions. Of note the participants differed for Study 1 and Study 2 and this may also been a factor which contributed to the difference.

Low back angle

One possible explanation for lower discomfort may have been differences in low back angle. During Study 1 just–sitting resulted in a change of the low back angle (sagittal mean) over time toward less lordosis compared to usual sitting. At commencement there was a difference between the conditions in sagittal mean angle, with under-desk cycling having less lordosis than just-sitting. Under-desk cycling then progressed toward even less lordosis with time, as did just-sitting. However, at 120 minutes under-desk cycling changed to more lordosis. With under-desk cycling participants had the lowest group mean for low back discomfort at 120 minutes across all four conditions (noting the participants differed between Study 1 and Study 2). Previous studies of low back angle during prolonged sitting have found mixed results. Sondergaard et al. (2010) found lumbar curvature increased over 96 minutes, as did the variability in lumbar curvature. It was postulated by Sondergaard *et al.* (2010) that with discomfort there was increased variability in an attempt to provide relief to musculo-ligament tension and relieve pressure on passive tissues. Study participants were not able to access to a backrest, which is in contrast to Study 1, and this may explain the difference in lordosis findings. In contrast, Schinkel-Ivy et al. (2013) found lumbar flexion increased for both pain developers and non-pain developers over two hours, again with no access to a back rest. Only nine (Sondergaard et al. 2010) and 10 (Schinkel-Ivy et al. 2013) participants were recruited for each of the respective studies. Further, studies with a backrest and larger sample size may provide greater clarity on movement patterns and associated mechanisms. Evidence suggests there may be different strategies for low back posture which may work for different people (Callaghan and McGill 2001), which may partially explain the mixed findings indicated above. While some individuals may tend to have a more static low back posture, others may use a greater amount of low back range of motion and thus have 'many' low back angle postures of varying duration (Callaghan and McGill 2001). For greater understanding of low back angle, concurrent analysis of movement is important. The current studies' findings for low back movement are discussed further below.

In Study 2, the low back angle (sagittal mean) for just-standing progressed toward more lordosis (compared to usual standing) over time. The posture at commencement for standing-with-movement had more lordosis than just-standing and moved toward less lordosis over time. This finding is consistent with Whistance et al. (1995) who found more posterior pelvic tilt and reduced lordosis when participants were able to self-moderate use of a footrest. The current study findings were also consistent with Sorensen et al. (2015) who found more lordosis in standing on level ground. Sorensen et al. (2015) compared pain developers and non-pain developers and found pain developers had a larger lumbar lordosis than non-pain developers. During standing-with-movement the use of the footrest and change of low back angle to less lordosis may have been the mechanism which assisted management of discomfort for some participants, who indicated a preference for this position compared to just-standing. Given low back discomfort overall still reached clinically meaningful levels during standing-with-movement, the potential benefit does not appear to be sufficient for this position to be a viable work alternative over prolonged periods.

There are a number of hypotheses describing how a change of low back angle may impact discomfort. One hypotheses is that moving away from a neutral lumbar lordosis position may contribute to discomfort (O'Sullivan *et al.* 2012b). Small changes in low back angle, as would be expected to occur with prolonged sitting, result in changes of the orientation of one vertebrae to another resulting in altered load distribution (Sorensen *et al.* 2015). The definition of neutral for the low back continues to be debated as does the ideal position when sitting (O'Sullivan *et al.* 2012b). Thus, the point at which the lordotic curve is sufficiently maintained, or neutral, to minimise discomfort versus being deviated to a point which increases discomfort is not known. The movement away from usual sitting toward less lordosis, for just-sitting in Study 1, suggests the lordotic curve change may have decreased loading on soft tissues. Given the slightly lower discomfort reported by under-desk cycling participants, the change in low back angle may be important in understanding strategies to moderate discomfort with prolonged sitting. If over time under-desk cycling was able to attenuate the drift into a slumped lordotic lumbar posture, as is common with prolonged sitting (Dankaerts *et al.* 2006), a positive impact on discomfort may occur. No other studies were able to be located which have examined low-back angle while performing under-desk cycling to compare results from Study 1 and low back angle change. It remains unclear why under-desk cycling resulted in a trend toward more lordosis over time. It is evident though that just-sitting resulted in the low back angle moving toward more lordosis over time, while under-desk cycling resulted in low back angle changing from less to more lordosis over time. Of interest is that just-sitting trended in a singular direction and had greater discomfort, while under-desk cycling changed direction part-way through the prolonged condition and had less discomfort. Whether the change in discomfort is associated with the timing or extent of the change in direction of low back angle, potentially oscillating around an optimal position, would be beneficial to investigate further.

In the study by Whistance *et al.* (1995) participants did not report the footrest to be beneficial for managing low back discomfort during standing. This was in contrast to the current study where a greater number of participants preferred standing-with-movement to just-standing (based on qualitative feedback), although low back discomfort ratings did not support this with no statistical difference between conditions. The current study, however, did not ask preference relating to specific body areas, rather a holistic opinion. Other studies where a footrest has been used, did not measure the impact on low back angle compared to a control condition (Satzler *et al.* 1993, Rys and Konz 1994). One of the hypotheses for the lack of quantitative evidence of benefit in the current study was the five minute protocol used for alternating feet on the footrest, in which these bouts may have been too long. Whilst it was postulated that there would have been some movement at the low back when alternating feet, it is not known if this was sufficient to offset passive loading. In the study by Satzler *et al.* (1993) the protocol of unconstrained use of the footrest resulted in participants changing feet every 90 seconds, and standing aids were preferred. Therefore, a protocol with more rapid foot alternation, or more participant initiated alternation, may have positively influenced low back discomfort results in the current study.

Another factor postulated to influence discomfort is the impact of asymmetrical positioning on soft tissue structures. With one foot raised on the footrest the pelvis may move laterally with a tendency for the pelvis to drop on the raised leg side (Whistance *et al.* 1995). This may have a subsequent effect of asymmetrical loading of zygapophyseal joints and intervertebral discs. With asymmetrical loading, passive tissues will have a greater load for a period, followed by off-loading while the other side bears the load. It is unclear if this potentially shorter, but higher, loading pattern is beneficial or whether it induces discomfort more quickly. The current study did not measure lateral pelvis position and thus did not explore how this may have impacted results. Further, the placement of the footrest may also impact posture. There may be an effect on pelvis position if the footrest is placed further away, or laterally. The footrest positioning may for example alter the level of body instability and lateral pelvis symmetry with muscle fatigue potentially also playing a role over time. Further research of pelvis movement laterally, concurrent to footrest position, would assist in addressing this issue.

Movement

Another possible explanation for a reduction in discomfort with prolonged positioning is movement. During Study 1, kinematic data collection occurred for periods of 10 seconds every three minutes based on prior evidence (Gallagher and Callaghan 2015) and was restricted by system capability to store data. When analysing the results of Study 1 it was determined that data capture over a longer period may provide more insight. The data capture was increased to two minutes per sample for Study 2 using newer instrumentation. From the data which was collected in Study 1, there was an effect of condition for pelvic movement (measured through the Fastrak sensor positioned at S2). Movement during just-sitting starting lower but increased over time while under-desk cycling started higher and was more stable over time. However, from a cumulative perspective, given the limitations above it is not known if the movement during under-desk cycling was greater than just-sitting over the entire two hours although results suggest it is likely under-desk cycling did have more movement.

The link between timing and type of movement during sitting and relationship to discomfort has been investigated. Studies have suggested that, while sitting for a prolonged period of time, in-chair movement will tend to increase with time (Fenety *et al*. 2000) and that not moving as much while sitting is a potential cause of discomfort (Vergara and Page 2002). Where sitting occurs on a standard chair there is a tendency for pain developers to use larger infrequent postural shifts (O'Sullivan *et al.* 2012a). Studies of static positions have found pain developers tend to delay movement and perform larger movements while non-pain developers tend to move earlier with higher amounts overall (Gallagher and Callaghan 2015). As no studies were able to be located of under-desk cycling which have objectively measured pelvis movement it is not known how much movement occurs, nor when this occurs.

Interestingly, in Study 1, it is anticipated that the non-significantly earlier and consistently higher amount of movement seen during under-desk cycling may have assisted in preventing discomfort. Other studies that have addressed sitting on unstable surfaces have found dynamic sitting results in regular spinal micro-movements (O'Sullivan *et al.* 2012a). Callaghan and McGill (2001) have suggested that fidgeting helps to provide relief to passive structures via change of loading. Based on the current study results, discomfort levels during under-desk cycling were marginally better than just-sitting. Discomfort levels were still too high though to suggest under-desk cycling should be recommended as a work position alternative for wide scale implementation. Dynamic sitting is not an approach which can be used to address low back discomfort in isolation (O'Sullivan et al. 2012a). However, dynamic sitting or chairs, with potential for increased movement, may be a part of the solution to prevent increasing discomfort over time. There may be merit in exploring under-desk cycling further if other issues such as the postulated buttock/thigh pressure which may be contributing to discomfort, are able to be adequately addressed. Thereafter studies of under-desk cycling, likely as bouts of cycling, and over longer periods is required to ensure discomfort is manageable.

In Study 2, pelvis movement increased over time during just-standing and decreased during standing-with-movement. Participants' low back discomfort during just-standing reached clinically meaningful levels by 60 minutes and trended higher than standing-with-movement through to 120 minutes. Gallagher et al. (2011) found body weight shifts increased over time in unconstrained standing with the average duration spent in each new position reduced over time. Study 2 findings of a trend toward more pelvic movement in just-standing and higher discomfort, could suggest the movement was employed to address discomfort. The early intentional movement in standing-with-movement may have helped to moderate the development of discomfort. Studies of movement during standing such as Gallagher and Callaghan's (2015) study support this finding. Non-pain developers were found in the aforementioned study to have earlier and higher frequency lumbar spine flexion/extension fidgets, and large body weight transfers. Gallagher and Callaghan (2015) proposed that the movement might assist in reducing passive loading.

In Study 2, there were some participants who preferred just-standing to standing-with-movement as was the case with Whistance *et al.* (1995). In just-standing, movement is able to occur freely based on proprioceptive feedback and potentially before discomfort reaches higher levels. Passive loads can therefore be shifted as required, muscles are able to contract and relax thus not be constantly activated and these factors may also have played a role (Le and Marras 2016) in why just-standing was preferred for some participants. Standing-with-movement, which is less stable, may have resulted in participants moving their trunk less when a foot was raised. Based on the qualitative feedback from Study 2 participants appeared to have a desire to move in an unconstrained way. Thus, if a participant has a requirement due to discomfort to shift position early and frequently, they may prefer timing of movement to be unconstrained. Arguably, this may be more frequently than the 5 minute protocol used in Study 2. The amount of movement during the period of having one foot raised may have been less than during just-standing. If this was the case, whilst there was movement to off load tissues when changing feet on the footrest, more static positioning during use of the footrest may have been counter-effective for passive loading of tissues.

Pelvic movement data collection during the two standing conditions was taken when participants had both feet on the ground. The cumulative difference of total movement over 120 minutes was not measured. The data samples chosen, with both feet on the ground, allowed direct comparison between conditions but also missed the amount of movement when making the change to access the footrest. Continuous measurement of movement would capture the movement to place a foot on the footrest in addition to sporadic movement. The current study also did not measure movement to allow categorisation of shifts (fast displacement) versus drifts (slow continuous displacement) versus fidgets (fast and return to original position) but rather was a measure of any movement that occurred during the data capture periods. Greater understanding of how the use of a footrest influences movements both cumulatively and at a more specific level over time may be important and provide greater understanding of mechanisms for discomfort.

Muscle fatigue

There was no definitive evidence in Study 1 of trunk muscle fatigue during just-sitting or under-desk cycling. Given the lack of previous research it was not known how under-desk cycling would affect muscle fatigue. For just-sitting there was no evidence of fatigue, which was not unexpected. The level of lumbar muscle activation during sitting with access to a backrest, has previously been found to be low (Callaghan and McGill 2001, Le and Marras 2016). Low muscle activation may have other chronic effects which could contribute to fatigue onset. Evidence suggests posture impacts the muscle activation level (Morl and Bradl 2013). Where there is slumped sitting, as occurred in Study 1 for just-sitting with less lordosis over time, there is little to no activity of lumbar muscles. If prolonged sitting is undertaken habitually there is concern that it may lead to muscle deconditioning (Morl and Bradl 2013). In contrast, a more neutral posture requires increased use of muscles to maintain the posture (Morl and Bradl 2013). Alternatives such as under-desk cycling, where flattening of lordosis and subsequent low lumbar muscle activity can be attenuated, may help in the longer term to prevent deconditioning. A potential outcome of muscle deconditioning may be a vicious cycle of poor posture due to early muscle fatigue, leading to an increase in discomfort as outlined in Section 2.3.5.3 with loading of passive tissues.

In Study 1 there was a finding of discomfort being correlated to muscle activity for just-sitting. Low back discomfort was negatively correlated with external oblique fatigue (median frequency) which was not expected and may be a random chance finding given the number of analyses undertaken. While external oblique median frequency did have a trajectory of reduction over time this was not statistically significant, and thus, external oblique amplitude findings did not show evidence of fatigue. McGill *et al.* (2006) found activation levels of abdominal muscles including external oblique to be low (1-2.8% of maximum voluntary contraction) when sitting and back extensor muscles only slightly higher (1.3-4.8%). Given there was no statistically significant evidence of muscle fatigue during just-sitting, the correlation between external oblique muscle activity and discomfort does not support the hypothesis that external oblique muscle fatigue caused the discomfort reported.

The measurement of abdominal muscle activity (external oblique) was primarily undertaken to compare muscle activation levels between just-sitting and under-desk cycling. It was anticipated there would be higher activation levels during under-desk cycling based on earlier research (Peterman *et al.* 2012). The results from Study 1 supported these findings with external oblique amplitude higher in under-desk cycling than just-sitting. However these findings do not suggest there was any fatigue of abdominal muscles during under-desk cycling. Given the lack of prior evidence specifically for under-desk cycling, previous research which has investigated unstable sitting was explored to compare trunk muscle use. McGill *et al.* (2006) found unstable sitting (on a stability ball) over 30 minutes did not result in trunk muscle fatigue. The participants did not use a backrest (McGill *et al.* 2006) while those in Study 1 did. It was suggested by McGill *et al.* (2006) that use of backrest would reduce low-load long duration contractions. Thus the small dynamic movements with intermittent varying contractions of the trunk muscles while under-desk cycling, and the ability to use the backrest in during just-sitting and under-desk cycling, may have attenuated discomfort via preventing passive tissue loading.

During Study 2, again there was no evidence of muscle fatigue of erector spinae during just-standing or standing-with-movement. Thus, the level of muscle activation required to maintain an upright posture over two hours did not appear to be a primary a mechanism for discomfort. Further, there was no evidence of a correlation between discomfort and muscle amplitude or median frequency. Findings of muscle fatigue during standing have been mixed. Antle and Côté (2013) found no evidence of trunk muscle fatigue (rectus abdominis, external oblique or erector spinae) during standing. A postulated reason for this was the relatively short study duration of 34 minutes. Another study which compared prolonged sitting to alternation between sitting and standing for one hour per condition, also found no noticeable change in muscle activation levels and thus the authors concluded there was no evidence of muscle fatigue (Sheahan *et al.* 2016). They suggested however that deeper trunk muscle (lumbar multifidus and internal oblique) activity, which was not measured, may play a greater role in maintaining posture. In contrast, other evidence has found there was postural muscle fatigue of the paraspinal muscles, after one hour, during standing (Balasubramanian *et al.* 2009) and for erector spinae over two hours standing (Hansen et al. 1998). Given both studies (Balasubramanian *et al.* 2009, Sheahan *et al.* 2016) were for one hour duration, and Study 2 was for two hours duration without evidence of fatigue, it is not known when fatigue would be expected to be present. Evidence suggests low levels of back muscle activity can be sustained for long periods before fatigue occurs (van Dieën *et al.* 2009). Further investigation of the fatigue of deeper trunk muscles during prolonged standing may need to be explored in future research.

Based on the findings from both current studies' muscle fatigue does not seem to be a primary cause of low back discomfort for any of the work positions trialled. It is not clear why in previous studies some have found evidence of fatigue while others have not. Duration seems to be a key factor with greater durations (more than two hours) having higher likelihood of fatigue for standing work positions although this was not evident in Study 2 (by two hours). Individual factors also may play a role with variations in posture, such as more or less lordosis or amount of movement, potentially impacting results. Finally the activity level of superficial versus deeper trunk muscles may differ and requires further investigation.

7.4.2 Lower limb

Discomfort ratings for just-sitting for the combined lower limb region did not reach clinically meaningful levels. In contrast, under-desk cycling did reach a clinically meaningful level for the combined lower limb at 90 minutes. To further understand this finding, examination of the individual body areas which make up the combined lower limb (hip/thigh/buttock, knee, ankle/foot) is important. During just-sitting, only the hip/thigh/buttock area reached a clinically meaningful level of discomfort while the knee and ankle/foot did not reach clinically meaningful levels. In contrast, under-desk cycling had clinically meaningful levels of discomfort across all three areas: hip/thigh/buttock, knee and ankle/foot. The level of discomfort for the single areas (hip/thigh/buttock) in just-sitting reached clinically meaningful levels at 90 minutes which was sooner than any of the three areas (hip/thigh/buttock, knee, ankle/foot) for under-desk cycling.

Hip/thigh/buttock reached clinically meaningful levels for both just-sitting and under-desk cycling by 120 minutes. As the hip/thigh/buttock were grouped, the specific location of discomfort (hip compared to thigh or buttock or a combination) may have differed between conditions. The finding of increased discomfort at the buttock (hip/thigh) in just-sitting, which was occurred earlier than for under-desk cycling, was not unexpected. Previous studies of prolonged sitting have reported increased discomfort in the buttock area (Sondergaard et al. 2010), extending to the thigh (Makhsous et al. 2009). This discomfort has been postulated to be related to tissue pressure (Reid et al. 2010). It was hypothesised that the movement during under-desk cycling would provide some static pressure relief to the buttock and thigh areas compared to just-sitting. As discomfort only reached a clinically meaningful level at a later stage during under-desk cycling there is some support for this hypothesis. It is not known though, if more discrete areas of discomfort were responsible for the reports of discomfort during under-desk cycling and were therefore different to just-sitting. Mechanisms such as friction and pressure over a smaller surface area could also be reasons for discomfort during under-desk cycling.

Knee and ankle/foot discomfort increased during just-sitting in the current study but did not reach clinically meaningful levels. This finding is in line with the study by Sondergaard et al. (2010) who also found that the knee and leg discomfort increased over 90 minutes of sitting. Although the level of discomfort reported for knee and leg was less than that reported for the buttock region (it was not clarified what *legs* represented, however it is assumed to be the lower leg given thigh is identified separately) in the Sondergaard *et al.* (2010) study. During Study 1 under-desk cycling knee and ankle/foot discomfort reached clinically meaningful levels (at 120 minutes) while for just-sitting neither knee or ankle/foot discomfort reached clinically meaningful levels. Under-desk cycling was undertaken at a pace controlled by the participant with no resistance on the cycle (essentially free-wheeling). It is postulated that based on the resistance free self-directed pace the level of muscle activity required was therefore not excessive. Further, the current study found no evidence of leg muscle fatigue (rectus femoris and biceps femoris) during under-desk cycling. Thus, muscle fatigue is unlikely to be a mechanism for the lower limb discomfort reported. Another factor which may help to explain the higher discomfort during under-desk cycling was the participants' feet being positioned under a strap which may have caused pressure. As other studies to date have not investigated discomfort when using under-desk cycle for office based work it is not known whether discomfort was related only to equipment in the Study 1 or another cause such as swelling, circulatory impairment or footwear.

For Study 2, both standing conditions had higher levels of lower limb discomfort than in the seated conditions of Study 1 (noting again the participants were different). Both just-standing and standing-with-movement had clinically meaningful levels of discomfort for the combined lower limb (hip/thigh/buttock, knee and ankle/foot) by 60 minutes. Sixty minutes was also the earliest onset of clinically meaningful levels of discomfort being reached in individual areas of the lower limb for both just-standing and standing-with-movement. The body part with the highest magnitude of discomfort was the ankle/foot during standing-with-movement. Foot discomfort with prolonged standing has been found by a number of previous studies (Laperriere *et al.* 2006, Lin *et al.* 2012a, Karimi *et al.* 2016).

In exploring mechanisms for lower limb discomfort, leg and foot swelling has been previously raised by numerous authors (Winkel and Jorgensen 1986a, Seo *et al.* 1996, Chester *et al.* 2002, Reid *et al.* 2010, Lin *et al.* 2012b). Evidence suggests that during prolonged sitting the minimal leg muscle activity may contribute due to reduced muscle pump action and thus swelling (Reid et al. 2010). Hypothetically, given the anticipated increase in muscle pump action during under-desk cycling swelling would be expected to be lower than during just-sitting. As Study 1 did not measure swelling, study results do not provide data to support this hypothesis. Seo *et al.* (1996) compared leg swelling during sitting and standing and found sitting had greater swelling than standing. This finding appears counter-intuitive as the effect of gravity and venous pooling would could be expected to be higher in standing. It has been postulated however that the sway and minor movements of the feet which occurs during just-standing may have some beneficial impact on swelling (Hansen *et al.* 1998). Study 2 did not have any significant difference in total calf swelling between the two standing conditions. The amount of pelvic movement (representing sway) was greater in just-standing based on the available data (measured only when both feet were on the ground). It is not known what the cumulative movement over the two hours was for each condition, in particular the movement to switch raised feet when the using the footrest. Whilst the sway and sporadic movement in just-standing, and movement to alternate raising a foot during standing-with-movement, were not large it was hypothesised this may have assisted venous return compared to just-sitting. Results from Study 2 suggest the amount of movement undertaken in the two conditions was not sufficient to prevent swelling. Discomfort in the lower limb is likely to be the result of multiple pathways, of which circulatory (venous insufficiency) may be one. Other pathways may include pressure on internal tissues, muscle tissue disruption (Reid *et al.* 2010) and muscle fatigue over longer durations (Garcia *et al.* 2015).

The movement undertaken in unconstrained just-standing and standing-with-movement resulted in significantly more swelling in the calf for both conditions. Prevention of swelling is important given the link with chronic health conditions including chronic peripheral vascular disorders (Beebe-Dimmer *et al.* 2005, Raffetto and Khalil 2008, Bahk *et al.* 2012). Further research of the use of a standing work position is required to define optimal use and avoid swelling at levels which are deemed clinically important. Given the health risks of too much standing, including discomfort and swelling, development of guidelines for industry is necessary before wide scale implementation.

7.4.3 Upper limb

There have been fewer studies of discomfort in the upper limb when using alternative work postures for office workers compared to the low back and lower limb discomfort. There were no studies able to be located which have investigated discomfort in the upper limb and under-desk cycling, and limited information is available for discomfort in the upper limb and standing-with-movement. For Study 1 and Study 2, upper limb discomfort increased over time for all of the conditions, however, discomfort did not reach a clinically meaningful level by 120 minutes for any condition. In Study 1, shoulder discomfort increased more for just-sitting than under-desk cycling. There a number of potential hypotheses for this discomfort increase, including the more static positioning of just-sitting compared to under-desk cycling. A number of studies have mentioned the upper torso postural sway evident when cycling (Elmer and Martin 2014, Koren et al. 2016). This sway may have positively impacted static posture and therefore loading on passive tissues.

Sliter and Yuan (2015) describe an alternative theory, which does not align with the Study 1 findings. Sliter and Yuan (2015) suggested cycling may affect the upper limb in performing tasks due to interdependence between the arms and legs. They projected this would increase the difficulty of holding the arms still during circular leg movements. Based on this, one could hypothesise an increase in the physical demands on trunk stabilising muscles when cycling to manage the postural sway, compared to sitting.

In Study 1 the only upper body muscle which was measured was trapezius. Muscle activity levels measured via EMG found no evidence of fatigue of upper trapezius, suggesting it is unlikely to have been a cause for the higher discomfort found in the shoulder in just-sitting. A study by Luttmann et al. (2010) did however find there was evidence of muscle fatigue for some office workers. The authors undertook an analysis of muscle activity over a full day (of office work) for the trapezius, deltoid and extensor carpi ulnaris muscles. The shoulder muscles had the highest activity during paper work, while there was less activity for keyboard use, and the least activity during mouse use. This was different for hand extensor muscles, which had the highest average activity during keyboard use. In Study 1 and Study 2, tasks were primarily mouse and keyboard use. If measurement of forearm muscle activity instead of shoulder, been undertaken in the current studies, this may have shown greater likelihood of fatigue noting the levels of muscle activity found by Luttmann *et al.* (2010) for the respective tasks chosen. In a real work setting additional tasks would also be expected of office workers including use of telephone (hand held or hands free), potentially handling of paper/files and reaching (into drawers, shelves, across desk). Depending on the mix of these tasks, muscle load and potential fatigue will vary and thus the impact on upper limb discomfort may differ.

The design of the under-desk cycle and impact on work position has potential to impact upper limb position and therefore function. As noted in earlier studies, such as Elmer and Martin (2014), leg clearance required for cycling influenced desk height. In their study the upper limb position was impacted through the use of a purpose built tray whereby the participants' forearms rested on the tray (Elmer and Martin 2014). Other studies such as those where upright cycles have been positioned under a height adjustable desk, have used a position where participants' forearms rested on the desk surface (Commissaris *et al.* 2014) and were not being able to float freely. In Study 1 the desk height was also constrained by the leg clearance required to perform under-desk cycling. As a result, the desk was still higher, relative to the elbows, than a typical set up and resulted in the participants' forearms resting on the desk surface. In order to minimise confounders, the same desk height was used for just-sitting. This ability to rest on the desk surface may have contributed to a lower level of shoulder muscle activity compared to if forearms were able to free float. Given the variation from typical positioning, if used over a longer duration under-desk cycling may have a greater impact on the upper limb and this would need to be further investigated.

During Study 2 upper limb discomfort did not vary between just-stand and standing-with-movement. No upper limb area reached a clinically meaningful level by 120 minutes. Although there were different participants in Study 1 and Study 2, combined upper limb discomfort ratings (shoulder, elbow and wrist/hand) were higher during standing than the seated conditions. Working while standing has previously been found to be preferable to sitting from an upper limb discomfort perspective, postulated to be related to having less constraint on movement and reach (Roelofs and Straker 2002). In Study 2, participants undertook keyboard and mouse work only, and did not need to perform repetitive reaching movements as the bank tellers did in the study by Roelofs and Straker (2002). Task appears to be an important consideration in measuring discomfort of the upper limb. Ebara *et al.* (2008) found an effect of condition with increased discomfort of right forearm and wrist/hand in sit-stand compared to just-sit. The authors of that study suggested the finding of only the right upper limb experiencing discomfort may have been due to dominance, however it was also noted the equipment may not have been correctly set up for each participant.

Discomfort in the neck did not reach clinically meaningful levels for any of the conditions. Ariëns *et al.* (2001) found the main risk factors for the neck were static postures and repetitive neck movements particularly neck flexion. In Study 1 and Study 2, participants used a desktop computer and viewed content on the screen adjusted to approximately eye-level. There were between participant differences in chosen activities, from watching online videos (thus minimal neck flexion however potential for sustained positioning) compared to typing. The activity of typing also had potential for between participant differences with varying levels of touch typing skill and thus varying amounts of repetitive neck flexion in adjusting gaze between screen and keyboard and these differences may have influenced ratings. It is postulated though that the tasks undertaken in Study 1 and Study 2 resulted in minimal sustained neck flexion and thus the results were not unexpected.

7.5 Factors influencing cognitive functions

Prolonged sitting of a habitual nature has potential to negatively impact cognitive functions, however impacts on short term cognitive functions have not been clear (Voss *et al.*

2014, Falck *et al.* 2017). The alternate work positions and types of movement assessed through Study 1 and Study 2 for this thesis had potential to impact cognitive functions both negatively and positively. For acceptance by industry there needs to be evidence that an alternative work position will at the least not result in reduction in work performance, although enhanced performance is desirable.

Research on cognitive functions across the full range of alternative work positions currently available previously had a number of gaps. The majority of the studies had not investigated movement interventions, rather the focus had been on sit-stand workstations only. Thus, there are limited previous studies which can be used to compare results with the work positions explored in this thesis to understand how different types of movement may influence cognitive functions.

Research to date has also been unable to clarify how specific cognitive functions are affected with increased activity level and/or the type of activity (Labonté-LeMoyne *et al.* 2015, Mullane *et al.* 2017). Therefore, it is unclear whether cycling or standing will have similar effects on cognitive functions, or if activity level impacts cognitive functions differently (Lambourne and Tomporowski 2010, McMorris and Hale 2012, Larson *et al.* 2015). The factors which are postulated to potentially influence cognitive functions include level of dual task implications, energy expenditure (and subsequent physiological responses), and the impact of discomfort. The potential mechanisms (Section 7.6) and impact of discomfort (Section 7.7) will be discussed in light of the findings for Study 1 and Study 2 for sustained attention and creative problem solving. Further, the effect on mental state will also be addressed in Section 7.8.

7.6 Potential mechanisms for cognitive functions in various work positions

7.6.1 Dual task

In Study 1, it was anticipated that under-desk cycling may impact cognitive functions due to the dual task demands. The postural sway mentioned by other authors (Elmer and Martin 2014, Koren *et al.* 2016) had potential to impact task performance. Further, the motor cortex activity associated with rhythmic movement was also expected to result in additional demand on information processing. Brisswalter *et al.* (2002) states that depending on the physical task complexity the impact of dual task on performance will vary. The potential for impact on performance thus appears to be based on the level of attentional resources, physical interference and coordination required from the physical task (Brisswalter *et al.* 2002).

Attentional resources

Under-desk cycling required constant rhythmic movement while performing office based work. Cycling was not a familiar work position for the participants of Study 1. It was postulated that there was potential for attention to be diverted from the cognitive functions assessment tasks to coordination of the cycling movement. Results for under-desk cycling from Study 1 did not show a clear decrement across all cognitive functions which, based on capacity sharing theory, suggests that the attentional resource demands did not exceed capacity (Brisswalter *et al.* 2002). Indeed, the only cognitive function which differed between conditions was sustained attention reaction time. For under-desk cycling, participants' reaction time was slower than just-sitting. No-go success (inhibition) was also more accurate in under-desk cycling. Thus there was a speed-error trade off, with slower but more accurate responses (no-go success) with under-desk cycling. Potentially, the requirement to cycle meant participants slowed their reactions but in doing so this allowed more accurate responses. In contrast, the more familiar work position of just-sitting may have resulted in more automated responses, which were quicker but less accurate. Further investigation of sustained attention for under-desk cycling over longer durations (such as a full work day) would be beneficial to see if this accuracy is able to be maintained. The lack of difference in creative problem solving results, between under-desk cycling and just-sitting, suggest this domain of cognitive function may not be impacted by the alternate work position. Further research which supports this finding would be helpful to industry, who may have concerns about effects of under-desk cycling on more complex task completion.

The requirement to stand and work in Study 2 may have been a less familiar work position than the seated work position of Study 1. Interestingly, participants' sustained attention no-go success scores were considerably lower in Study 2 compared to Study 1. It is postulated that the diversion of attentional resources to maintaining an upright posture when standing, may have contributed to the difference in scores. When standing, reaction times were faster at baseline compared to the sitting conditions (noting the participants were different). Both of the standing conditions got slower with time but accuracy improved. This finding may have been the result of a speed-error trade-off, as occurred with under-desk cycling in Study 1. For problem solving just-standing had a greater number of errors at commencement which reduced over time while standing-with-movement started with a lower number of errors but errors increased over time(interaction effect). Thus, in comparing the overall results of Study 1 and Study 2, the standing positions appeared to have a slightly higher impact on the cognitive functions than the sitting conditions although no large decrement was found. Other studies have found lower cognitive functions performance for standing compared to sitting, such as the laboratory study by Schraefel *et al.* (2012), however the majority of the evidence does not support any clear decrement (MacEwen *et al.* 2015, Bantoft *et al.* 2016, Russell *et al.* 2016). In order to reduce potential impact on cognitive functions from participants being unfamiliar with the work position allowing time to become familiar with a standing work position prior to assessment of cognitive functions outcomes would be beneficial. Whilst it is not known if unfamiliarity affected Study 1 and Study 2 results, or affected the cognitive functions differently, addressing this would strengthen wider application any findings. For creative problem solving while working in a standing position, further research is required to understand potential influence over longer durations. If standing-with-movement errors continued to increase with time, this would be of concern to industry that relevant tasks and subsequent work performance may be effected.

Hypofrontality theory suggests that with increased activity level and subsequently increased arousal, performance of well learned tasks may improve (McMorris and Hale 2012). The results of Study 1 suggest that there was no considerable decrement to cognitive functions during under-desk cycling. Therefore, the rhythmic movement of cycling, which on its own is a well learned task for many, did not appear to impact attentional resources when undertaken while also working. For the standing work positions though there were differences in cognitive functions, compared to just-sitting. For sustained attention reaction time slowed for the standing conditions over time while for just-sitting reaction time sped up. While standing is a habitual task, the additional attention diverted to maintain an upright posture may have reached a level where capacity limitations became evident. Mullane *et al.* (2017) suggested that chronic exposure to standing may be required, allowing participants to become conditioned to the work position. Upon becoming conditioned and standing to work being more 'habitual', the need for additional attentional resources would theoretically reduce over time. Based on hypofrontality theory, the competition for cortex resources would then be less and there is potential for a less, or no, impact on cognitive functions.

While under-desk cycling in Study 1 did not result in clear decrement another type of under-desk cycle, such as an elliptical under-desk cycle, may not be familiar, to the standard circular cycling motion, and may have a greater dual-task impact. During under-desk cycling some participants were observed to slow their cadence or briefly pause cycling when undertaking some self-directed office tasks. It is postulated that for some participants certain tasks may have been impeded by the concurrent cycling. Further investigation of whether participants are comfortable to undertake all office tasks equally when cycling or if there is a preference to cease cycling for tasks requiring high dexterity is required.

Physical interference

A number of studies have reported on the physical 'interference' created by the alternate work position such as the sway of the upper torso when cycling (Straker *et al.* 2009). The extraneous movement has been found to impact proficiency of keyboard and/or mouse use (Beers *et al.* 2008, Straker *et al.* 2009, Commissaris *et al.* 2014). Whilst Study 1 did not investigate this specifically, correlation analysis between torso movement and cognitive functions during just-sitting together with user feedback may provide interesting information.

Cycling while working to date has been investigated while using a range of different cycles. These include upright cycles, which are inherently more unstable due to the smaller seat (Straker *et al.* 2009), recumbent which typically have a full backrest and seat (Elmer and Martin 2014) and under-desk cycles whereby a participant can use a standard office chair. It is postulated that from a stability perspective an upright cycle would be expected to have more of an impact on fine motor dexterity than using an under-desk cycle. In Study 1 participants sat on a standard office chair when using the under-desk cycle. This seated position is more familiar to users, than other cycle positions, and results from Study 1 suggest there may not have been any considerable physical interference, given the lack of decrement in cognitive functions. The difference in postural stability across the different cycle designs able to be used when working needs to be explored with any future research.

The physical interference of working while standing was postulated to be less than cycling. Other studies have found standing had little impact on mouse and keyboard use (Tudor-Locke *et al.* 2014, Kar and Hedge 2016) or impact only on precision mouse tasks (Commissaris *et al.* 2014). For standing-with-movement though, the asymmetrical posture and reduction in stability may have had an impact on fine motor dexterity. However this was not measured during Study 2. If there is a requirement for additional postural control this may also have an effect on attentional resources (Schwartz *et al.* 2018). Other studies have found participants have a preference for the type of tasks performed in a given work position (Grunseit *et al.* 2013). It is unclear if this preference, for example to avoid typing while standing, is due to dual task or physical interference mechanisms. As outlined above there was no clear decrement of cognitive functions during either of the standing conditions, however further investigation particularly of standing-with-movement and fine motor dexterity may be useful. In addition, greater understanding of subjective user experience over longer durations may assist in understanding and separating dual task and physical interference implications.

7.6.2 Energy Expenditure

The current literature suggests that with additional acute energy expenditure, and habitual increases in expenditure through exercise, there may be benefits to cognitive functions (Chang *et al.* 2012, Voss *et al.* 2014). However, where there is high intensity physical activity motor movement may impact cortical networks (Lambourne and Tomporowski 2010) resulting in a negative effect on cognition. For more moderate intensity activity though, the increased energy expenditure is postulated to result in acute improvements to cognitive functions due at least in part to changes in arousal (Mullane *et al.* 2017). The work positions explored in Study 1 and Study 2 were postulated to be of light rather than moderate intensity activity. Energy expenditure was not measured though and therefore a sufficient level of activity may not have been reached for acute cognitive functions improvement. Further, neither Study 1 nor Study 2 had moderate level activity conditions to allow comparison. When undertaking repetitive or mundane work in a static prolonged position the effect of both task and postural monotony can impact cognitive functions (Meuter *et al.* 2006, Thomson *et al.* 2015, Marandi *et al.* 2018). Use of an alternate work position with movement has potential to interrupt this monotony through constant rhythmic movement or transitions. Possible explanations for cognitive functions changes with increased energy expenditure include arousal, postural transitions and higher intensity activity bouts.

Arousal

Under-desk cycling was suggested to have the highest energy expenditure of the three alternative work positions (Tudor-Locke *et al.* 2014). The under-desk cycle was used without added resistance, and thus ‘free-wheeled’. This was hypothesised to represent light rather than moderate level activity. The cognitive functions results for under-desk cycling did not show better short term performance compared to just-sitting or either of the standing conditions. Participants were found to cycle at different cadences, resulting in considerable differences in distance cycled at conclusion of the two hours, which may have influenced the results. In Study 2, the standing conditions were expected to result in slightly higher energy expenditure than just-sitting (Barone Gibbs *et al.* 2016). The cognitive functions results did not show any significant improvement for standing conditions though, and as mentioned in Section 7.6.1, actually showed more errors for sustained attention that the seated conditions. Thus, Study 1 and Study 2 do not suggest improved cognitive functions from the energy expenditure increase during the light activity alternatives to just sitting trialled.

It is questionable whether the increase in energy expenditure for under-desk cycling, just-standing and standing-with-movement were sufficient to meet the required threshold for a beneficial effect (Brisswalter *et al.* 2002). In considering the inverted U hypothesis, the activity level of the alternative work positions were conceptually at the bottom left side of the U. In line with this theory, further increase in activity level, closer to a moderate level, is required for positive impact on cognitive performance (trending toward or approximating the top of the U) (Brisswalter *et al.* 2002). Considering then the hypofrontality theory, which suggests moderate exercise can increase arousal and improve well learned or habitual tasks (McMorris and Hale 2012), again the only very light level of activity of the conditions may be the reason for the lack of improvement in cognitive performance. Alternatively, as neither under-desk cycling, standing nor standing-with-movement are familiar or habitual ways to perform work tasks (given none of the participants had used for this purpose previously) this may have also contributed to the lack of improvement in cognitive functions. The lack of difference in cognitive functions was in line with other studies comparing alternative work positions, which have broadly found no considerable difference (Commissaris *et al.* 2014, Koren *et al.* 2016). It has also been suggested in other research, as was proposed above, that the light level of activity which results from use of some alternate work positions may not be sufficient to improve cognitive functions (Larson *et al.* 2015).

A study by Mullane *et al.* (2017) however did find improvement in using an alternative work position. Work positions investigated were sit, stand, cycle (20W, 25-30rpm) and walk (1.6km/h) with nine overweight adults. Cycling was controlled to match the energy expenditure of walking. Interestingly cycling had the best cognitive performance score (domains of working memory attention and executive functions), while walking and standing both had higher overall cognitive performance scores than sitting. This study suggests that despite similar energy expenditure, cognitive functions differed for cycling and walking. Cycling and walking had better executive functions while standing did not, compared to sitting. For working memory and attention, stand, cycle and walk all had better performance than sit. In explaining these findings, it was postulated that there may be different effects of work position on the various domains of cognitive functions (Mullane *et al.* 2017). A separate study which found cognitive functions improvement explored the impact on cognitive functions when walking compared to sitting (Oppezzo and Schwartz 2014). Reasoning and problem solving were evaluated using divergent (generating alternate uses for common objects) and convergent (identifying a common category for three words) tests. The majority of participants (81%) increased their scores on the divergent thinking test for walking but only 23% of participants scores improved for convergent thinking. When walking was compared to sitting, the average increase in divergent thinking was 60%. The results of this study suggest there was some improvement for walking, however as participants self-selected the walking speed, which was not measured, the extent of energy increase was not known. Further the conditions were only undertaken for a short duration (less than 10 minutes) and thus it is not known what effect there may be over a longer duration such as a work day.

Finding a balance between an increase in energy expenditure which may provide a physiological benefit e.g. via brain oxygenation (Rooks *et al.* 2010) without overloading cortical networks, and while still being able to undertake office work, is challenging. Even in studies with higher intensity work positions, results have lacked conclusive evidence of better cognitive functions. For example Commissaris *et al.* (2014) compared cycling (upright) at lower (25% heart rate reserve) and higher (40%) intensity (in addition to sitting, standing, walking, and using an elliptical trainer). The study assessed attention, reaction time, accuracy, perceptual performance and memory. Memory accuracy declined with the higher intensity cycling while all other measures were not significantly different. The results of that study suggest there is may not be a linear association between cognitive functions and activity level and rather specific domains may be affected differently. As outlined in the literature review (Section 2.4.1.3) other factors which can affect results include duration of the increased energy expenditure and scheduling of the testing (during or after).

Given the wide range of study designs (across work positions, protocols, domains of cognitive function and tests selected) it is difficult to compare the current cognitive functions findings with previous research. Mullane *et al.* (2017) and Oppezzo and Schwartz (2014) found some areas of improvement, while other authors have not (Bantoft *et al.* 2016, Russell *et al.* 2016). However, changes in energy expenditure may be only one of the mechanisms. Further research of work positions with varying intensity activity combined with specific cognitive domains may aid understanding of the influence of the work position and/or activity level for that cognitive domain.

Postural Transitions

Transitions are anticipated to play a role in increasing energy expenditure (depending on frequency) (Beers *et al.* 2008) and arousal (Hasegawa *et al.* 2001) through interruption to postural monotony. Conversely though, transition can result in acute interruption to concentration and depending on frequency, result in lost productivity. For Study 1 and Study 2, transitions were most evident in the standing-with-movement condition via alternation of feet on the footrest, and to a lesser extent during just-stand via weight shift. Transitions during standing-with-movement would have considerably less impact on energy expenditure than a sit to stand transition (which is the usual transition identified in most of the literature). While transitioning from sit to stand has potential to disrupt concentration (Thorp *et al.* 2014), alternating feet on a footrest may have less impact. Transitions during just-standing were expected to be less but would have included weight shift and smaller movement such as fidgets in varying degrees and frequency between participants. The increase in energy expenditure of either standing position compared to just-sitting was not measured but may not have resulted in a substantial difference (Tudor-Locke *et al.* 2014). The impact of transitions was not measured in the current studies. For standing-with-movement, cognitive functions testing occurred while participants remained in one position. During the just-standing condition identification of transitions (such as full weight shift) was also not conducted. Thus, the theory of postural transitions impacting cognitive functions was not able to be tested in the current studies.

From a postural monotony perspective, cognitive performance has been found to deteriorate with increasing time on task (Meuter *et al.* 2006, Thomson *et al.* 2015) and uninterrupted work positions (Langner and Eickhoff 2013, Marandi *et al.* 2018). Under-desk cycling with constant movement provides a work position with high potential for breaking up postural monotony if used intermittently through a work day. Working while standing is arguably also better able than just-sitting to allow a less monotonous work position due to the ability to move with less constraint. The results of Study 1 and Study 2 did not show clear improvement in the cognitive functions studied when compared to sitting. It could be postulated that the positions did impact monotony however other factors contributed to the overall result. A study by Hasegawa *et al.* (2001) investigated performance (multiplication of single digits) of a repetitive task, subsidiary behaviours (including stretching, yawning, closing eyes) and subjective fatigue with varying ratios of sitting and standing. Where there was no change in work position, performance reduced and perception of drowsiness was also higher. The study also found that over longer durations the effect of changes of work position reduced. Therefore, while transitions appear to have a positive impact on performance and subjective arousal level, the benefit may diminish over longer work durations suggesting other strategies may be required.

Bouts

A limitation of the current studies is that the energy expenditure may not have been sufficient to result in positive impact on cognitive functions. Therefore, alternative work positions with higher energy expenditure may be worth exploring. As previously outlined, moderate intensity activity has potential to move the functioning level toward the top of the U in the inverted U hypothesis (Brisswalter *et al.* 2002) resulting in a positive impact on cognitive performance (Chang *et al.* 2012). If intensity of energy expenditure while working is increased, it is likely that many workers would only be able to maintain the intensity over short durations, and not for prolonged periods. Results from studies where bouts of moderate intensity activity have been used are mixed. The evidence does not conclusively support moderate intensity bouts as being a solution to improving cognitive functions, while also addressing prolonged sitting in the workplace. Wollseiffen *et al.* (2016) trialled bouts of activity using a recumbent cycle and exercise (boxing). Participants worked for two hours performing office work without a break (although it is not described how much of this time was spent only sitting) then undertook the bout of cycling or boxing. There was a significant effect of increase in heart rate for both interventions. Cognitive functions results for decision making and memory were mixed despite significant differences in alpha-2 brainwave activity levels after each intervention. It was postulated that the bout of exercise resulted in changes in the cardiovascular system and increases in arousal which impacted some but not all domains of cognitive function.

Some studies have reported benefits from bouts (varying in duration 10-30 minutes) of light intensity. Mullane *et al.* (2017) had conditions of cycling, walking and sitting (for 10 minute bouts). Results indicated executive functions when sitting to be lower than cycling and walking. The bouts were of very low intensity with slow walking (1.6k/hr) and cycling cadence (25-30rpm), which is expected to be less than Study 1's under-desk cycling. Study 1 had continuous cycling at a potentially higher intensity, yet results showed no improvement compared to sitting, while bouts at a lower intensity in Mullane et al's (2017) study did show improvement. As previously suggested, this may be a result of the different cognitive domains evaluated and tests used. The cognitive functions tested by Mullane *et al.* (2017) were working memory and attention, psychomotor and executive functions using a commercially available test battery. In the current study, the tests used for sustained attention and problem solving were different and this may have contributed to different results. Alternatively, the use of bouts which assist with breaking up monotony may have been a factor rather than the level of activity. In the study by Mullane *et al.* (2017) participants had to move from a sitting workstation to the cycle (positioned under a separate height adjustable desk), similarly for they had to move to access the treadmill workstation. Therefore, the participant movement in the Mullane *et al.* (2017) study included the transition (between work stations) in addition to the bout. There may have been benefit from the combination of the transition and activity bout, breaking up positional monotony and increasing energy expenditure.

Wennberg *et al.* (2016) compared bouts of light intensity walking (3.2k/hr), for three minutes every 30 minutes over five hours, to uninterrupted sitting for central executive functions including memory and inhibition. There were no statistically significant differences for cognitive functions although there was a trend for improvement with the walking bouts. The authors also measured subjective fatigue and found the bouts of walking did attenuate this at both the four and seven hour assessments. In this study, participants were required to transition from sitting to standing and then access the treadmill. Again participants may have benefitted from the interruption to positional monotony in addition to the energy expenditure from the transition and the bout of activity.

In another study, although of moderate intensity bouts of walking, Bergouignan *et al.* (2016) trialled varying protocols including one 30 minute bout and another protocol with six shorter-bouts (each of five minutes) spread throughout a day. Neither condition had an effect on the cognitive functions of attention and flexibility. The study did find an improvement in mood and decreased levels of fatigue for the more frequent micro-bouts condition. Interestingly the effects on mood and fatigue did not improve for those who undertook only one bout of increased activity at the commencement of the day. Frequent bouts of shorter duration were found to be more beneficial for participants' mood and fatigue.

The nuances of alternate work position and impact on cognitive functions are complex with movement type, intensity, duration (continuous or length of bouts) and frequency (number of bouts) all potentially playing a role. It is also known from research on exercise and cognitive performance that time of testing (during or after the activity) can affect results (Chang *et al.* 2012). In Study 1 under-desk cycling was continuous and thus testing was completed while performing the rhythmic movement. For standing-with-movement testing was completed while one foot was raised, an unfamiliar work position. For further research it is recommended that testing occur without concurrent activity to allow greater comparison between studies. It is not known how different domains of cognitive function are affected by different work positions given the varying results across studies, which have used different tasks across a range of protocols. From an implementation perspective, creating the opportunity for sufficiently increased activity levels during a work day whilst still allowing workers to be productive may be challenging. The activity threshold required to provide benefit for cognitive functions in a work context requires further investigation. Further, identifying what level of cognitive function improvement would be required to be make a meaningful difference in work performance also requires further research (Mullane *et al.* 2017).

7.7 Discomfort and the association with cognitive functions

Correlation analysis for just-sitting and just-standing did not show a clear association between discomfort and cognitive functions. For Study 1, considering only the just-sitting condition, there was a positive association between problem solving errors and total body discomfort (rho = 0.480, p=0.032) (increasing errors and increasing discomfort). The analyses of potential associations between total body discomfort and the remaining variables (sustained attention no-go success, reaction time or problem solving unique designs) were not significant. For Study 2 and the condition of just-standing there was a trend (rho -0.403, p=0.087) toward a negative association for problem solving unique designs and total body discomfort (reduction in number of designs with increasing discomfort). No other variables had any trend toward or significant association findings. Therefore, there did not appear to be clear evidence of association for cognitive functions.

It is difficult to compare potential correlation results from Study 1 and Study 2 of cognitive functions and discomfort with other studies as typically productivity, rather than cognitive functions, has been evaluated. The studies which have investigated productivity and discomfort have had mixed results. One of the postulated reasons for the mixed evidence is that productivity, which is a more holistic construct of which cognitive performance is one component, may also be effected by other factors. Hagberg et al's (2007) cohort study (n=1,283) used self-report productivity measures rather than specific cognitive functions evaluation. Reduced productivity due to musculoskeletal symptoms was reported by 8.0% of the females and 8.4% of the males with a magnitude of reduction of 15% for females and 13% for males. However, other factors were also found to be associated with reduced productivity including work demands, computer issues and psychosocial factors (relationship status). The ability to clarify the effect of discomfort on productivity in a field based design is therefore challenging. Pronk *et al.* (2012) found after a four week field based intervention (ability to use sit-stand work positions) there was reduced upper back and neck pain and improved ratings of productivity (66% feeling more productive), however, no objective measures were taken to confirm the improvement in productivity. Pronk *et al.* (2012) also reported participants felt more energised (87%), healthier (71%), happier (62%) and less stressed (33%). The recruitment of health promotion department employees suggests that there may have been a level of bias in workers expecting better productivity with a 'better' workstation. Data collection with a sample group not associated with health, and over a longer period to allow any novelty effect to diminish, would be valuable. Further, measurement of other factors which may be confounding results, including psychosocial factors, should also be undertaken.

Husemann *et al.* (2009) found with a sit-stand protocol (for four hours repeated over five days) participants reported reduced musculoskeletal symptoms, however there was no effect on data entry efficacy. Arguably, discomfort may have a greater effect on higher order cognitive functions compared to data entry and thus data entry efficacy may not be a sensitive measure of a potential association. Discomfort may have selective effects depending on the cognitive task and load (Moore *et al.* 2017). In the two previous studies mentioned (Husemann *et al.* 2009, Pronk *et al.* 2012), discomfort was found to reduce with use of the alternate work position rather than increase as occurred in Study 1 and Study 2. The studies by Pronk *et al.* (2012) and Husemann *et al.* (2009) were both undertaken over longer duration and with discomfort measured less frequently (at end of work day or survey after a number of weeks). Further, participants were able to alternate between work positions in an unconstrained manner and thus had greater autonomy, allowing highly individualised strategies to manage discomfort to be used. Each of these aspects may have influenced perceptions of productivity, however they were not measured.

In understanding why there is a lack of clear association between discomfort and cognitive functions, consideration of individual factors and workplace issues may be important. Psychosocial aspects including job demands, social support and perceived psychological workload, in particular fatigue, have been suggested as having an association with musculoskeletal symptoms (Bystrom *et al.* 2004). Further expanding on this point, it has also been hypothesised that increased muscular tension can be linked to organisational and psychosocial factors as well as physical load and individual factors (Wahlström *et al.* 2004). In exploring impact on performance, Wahlström *et al.* (2004) suggested it was not known if the factors associated with musculoskeletal symptoms were the same as those associated with reduced productivity.

In Study 1 and Study 2 participants were able to undertake self-directed computer and clerical tasks. Thus, participants were not required to meet any deadlines and were not under any ‘work stress’ as a result of the study, although participants may still have had underlying stress. Psychosocial factors were not measured in the current study and it is unknown if this may have affected results. Being part of a laboratory study may have had its own bias noting participants had volunteered to participate. Further, the convenience sample group was based on a disproportionate number of participants working or studying in a health related field. Thus, the influence of motivation to participate and potential novelty effects on results should not be ignored. It is therefore suggested that future research of the impact of discomfort on cognitive functions should involve investigation of psychosocial factors.

7.8 Mental state

Mental state deteriorated for each condition over time. These findings were not expected as it had been hoped that alternation of work position would have aided mental state compared to sitting. As such, the hypothesis that an alternate work positon would result in improved (or less deterioration in) mental state was not supported. Correlation analysis for just-sitting and just-standing found there was a moderate positive correlation between total body discomfort and mental state (increased discomfort and deterioration in mental state). The extent to which discomfort, which increased over time, contributed to this finding compared to other potential mechanisms for mental state deterioration, such as monotony of task or work position, is not known.

Arousal level has previously been positively impacted where there is interrupted sitting and use of alternate work positions, compared to uninterrupted sitting (Ebara *et al.* 2008). This was not the case for Study 1with under-desk cycling given the deterioration of participants' mental state over time which was not significantly better than just-sitting. It had been hypothesised that the increased movement through under-desk cycling may have aided mental state through influence on arousal level. Instead, overall mental state was not significantly different in under-desk cycling compared to just-sitting. This finding was not in line with a mixed method field study where participants had access to a cycle during work hours (Torbeyns *et al.* 2017). The study was undertaken over a five month period however only one measurement was taken, at the study conclusion. This non-acute measure found an effect on attention and work performance and participants reported feeling more energetic (Torbeyns *et al.* 2017). In Study 1 mental state was measured during the condition and thus was less prone to recall bias. The amount and level of autonomy on use of the alternative work position may also be a factor which influences mental state. It is not reported how frequently the participants cycled in the study by Torbeyns *et al.* (2017) nor the duration of each cycling bout to make up the total cycling time. There was however a considerable reduction in amount of cycling from initial baseline measurement to conclusion of the study. It is postulated that those who did not like the cycling were likely to have undertaken considerably less cycling and thus self-selected the level which was perceived to be beneficial for work performance or at least non-detrimental. From Study 1 it is not known how a longer duration for under-desk cycling, and thus conditioning, may have influenced results. Further if participants had autonomy to self-select their use of the alternate work position, to use in bouts, according to their level of alertness or fatigue while also managing discomfort the results from Study 1 may have been different.

In comparing Study 2 to other studies of standing, conditioning through previous or longer habitual use of a standing work position may have been a factor which influenced results. Dutta *et al.* (2014) found participant reports of fatigue reduced after one week, as amounts of standing increased (with participants aiming to stand 50% of time). Further, there was an increase in reported sense of overall increased energy and decreased fatigue at four weeks. In another study, also of longer duration was a study, participants reported feeling more efficient and alert after 3 months (Grunseit *et al.* 2013). Of interest though was the finding that some found standing to be a distraction. Some participants also developed a preference for the type of task undertaken while standing. Assessments such as these, made after a period of familiarisation to the alternate work position, would give better insight to how longer term use may affect mental state. Where feasible objective measurement of the work position being used (frequency and duration) and acute mental state at times of position change would help to address gaps in the literature. This would also provide guidance of what protocol provides benefit at an individual level.

The current studies involved prolonged and consistent level of activity rather than bouts and this may also have influenced mental state results. It is postulated that bursts of activity may break up monotony and also provide a greater arousal response as outlined in Section 7.6.2. Wennberg *et al.* (2016) trialled the use of bouts of activity and found mental fatigue levels were lower in a movement condition (walking) over a seven hour day, of which five hours included the intervention, compared to only sitting. A further study which investigated the effect of bouts (of intensive exercise cycling for 20 minutes or boxing three minutes) on perceived mental state after participants had undertaken two hours of office work found boxing resulted in a positive although non-significant effect which was objectively correlated with an increase in brain frontal lobe activity (Wollseiffen *et al.* 2016). The measures included perceived physical state (e.g. lethargy, tiredness), psychological state (e.g. drowsiness, positive mood) and motivational state (e.g. energetic and self confidence). Wollseiffen *et al.* (2016) found cycling had less of an impact than boxing on mental state, however still showed an increase in prefrontal cortex activity. Finally, Bergouignan *et al.* (2016) found five minute bouts (repeated six times throughout the day) had more effect on mood and fatigue than one bout of 30 minutes. Therefore, the continuous cycling in Study 1 and continuous standing in Study 2 may have been a factor which negatively impacted the overall benefit of an alternate work position for mental state.

Measurement of mental state is impacted by participant perception. In some studies measurement was delayed (by weeks) and may have been effected by recall bias. In other studies acute measurement did not occur, which is in contrast to Study 1 and Study 2. Whilst it was hoped the alternative work positions would have assisted acute mental state (attenuated deterioration) future studies could investigate bouts rather than continuous use for potentially greater net benefit.

7.9 Participant perceptions on implementation of alternative work positions

Implementation of alternatives to sitting through alternate work positions has had long term efficacy and feasibility issues as outlined in Section 2.5.2. In the previous Sections, discomfort was identified as a factor which may impact user acceptance, however organisational factors such as education, wide scale adoption and management support may also influence feasibility. The need to collect qualitative information to assist with interpretation of findings was identified from Study 1. It was anticipated this additional data, would provide a greater richness in interpretation of the quantitative results, both subjective ratings and objective measures. Feedback from participants was thus obtained for Study 2 relating to just-standing and standing-with-movement. Participants were asked to complete a questionnaire after each session. Suggestions for implementation, likes and dislikes were sought. For their second session (counterbalanced) a final question was included requesting participants identify a preference of just-standing, standing-with-movement or neither. There were a number of shared themes identified by participants for implementation including social influences, equipment and individual elements, while for positive and negative aspects, common themes were around discomfort and posture. In comparing the conditions, six participants preferred just-standing while 13 preferred standing-with-movement and one had no preference.

Implementation

Participants suggested if implementing any standing option in a workplace, the workplace as a whole, including co-workers and supervisors, should be involved rather than just an individual. It was suggested participants would be encouraged to use a standing option if "*other colleagues around me [were] using it*". From a behavioural perspective, social settings have an influence of what is considered acceptable, and thus understanding the culture and what would encourage a behaviour is important (Owen *et al.* 2011). Previous studies which have included environmental, individual and organisational elements when introducing alternate work positions, have been successful in reducing sitting time at work (Healy *et al.* 2013, Chau *et al.* 2015b). Key components of successful implementation approaches include management support, education and electronic reminders to break from posture (Healy *et al.* 2013, Chau *et al.* 2015b).

From an equipment perspective, participants suggested having either a height adjustable desk (not stand-only as was provided during Study 2) or a high stool to allow the option to sit. Given prolonged standing has been found to result in increased discomfort over time

(Karakolis *et al.* 2016) this feedback was not unexpected. Further, a number of studies have found alternating between sitting and standing has been perceived as preferable to sitting only or standing only (Roelofs and Straker 2002, Wilks *et al.* 2006, Alkhajah *et al.* 2012). The field study by Pronk *et al.* (2012) resulted in participants feeling more comfortable with use of a sit-stand device. It was not clear in the study by Pronk *et al.* (2012) what duration participants used the standing only position for, without alternating with sitting or walking.

At an individual level, some participants from Study 2 suggested comfortable shoes should be recommended. There has been a number of studies which have explored footwear and impact on discomfort when standing (Hansen *et al.* 1998, Alkhajah *et al.* 2012). Softer footwear has previously been found to reduce foot oedema, however not necessarily have a statistically significant effect on discomfort (Hansen *et al.* 1998). Other studies, investigating different types of footwear and floor surfaces (e.g. mats), have demonstrated this can assist to reduce lower limb discomfort (Cham and Redfern 2001, Lin *et al.* 2012a, Karimi *et al.* 2016). While evidence suggests there is potential for these interventions to be effective, improved studies with more rigorous study protocols are required to give guidance to industry (Waters and Dick 2015). As ankle/foot discomfort reached a clinically meaningful level, it is not surprising participants raised lower limb discomfort as a concern.

Another suggestion from participants to assist individuals to adapt to use of a standing workstation was to implement a conditioning program. It was suggested that workplace support of a graded program increasing time-spent-standing, and thus improved tolerance, may aid uptake. For those at risk of clinically relevant symptoms particularly in the low back, this graduated approach may assist in improved tolerances of standing to reduce time-spent-sitting concurrent to education about health risks (Callaghan *et al.* 2015). Even if the total time spent standing is not high, there are likely to be metabolic benefits from regular breaks in sitting (Healy *et al.* 2008) and musculoskeletal benefits from the muscle use to switch between positions and unload static tissues (Callaghan *et al.* 2015).

Positive and negative feedback

Participants provided positive feedback around mental state for both standing conditions. Participants reported feeling more aroused compared to sitting. Comments included: “[Standing] *helps me focus more*”, “*More awake compared to sitting*”, “*Increased level of concentration*” and “*Feel more awake / alert*”. This is in line with Kar and Hedge (2016) who found accuracy improved while participants undertook typing in standing compared to sitting. It was suggested that the higher accuracy may be a result of increased physiological arousal levels in standing. Interestingly despite the comments above, mental state still deteriorated over time for both standing conditions (see Table 6.4). As there were different participants in Study 2 to those from Study 1, direct comparison of mental state rating between the standing conditions and just-sitting was not valid. Therefore while some participants suggested the standing conditions impacted mental state the quantitative results did not support this. Future research should consider which method is better, for mental state assessment. Further, qualitative feedback should be undertaken concurrently with mental state assessment in future studies as it is expected to provide greater insight.

There was a perception of having a 'better' posture when using a standing working position. These perceived benefits were reported across both standing conditions. For just-standing one participant indicated "*It prevents me from slouching my back*" while for standing-with-movement a participant suggested *"[it was] more comfortable on my lower back. I felt my posture was better in standing than in sitting position. Can move around more, legs and weight shifting between left and right*". Another suggested "*the footrest allowed me to rest and alternate my foot when one is tired/sore*". Of note though, was a comment made by one participant of "*good alignment (but only for short periods – otherwise posture seems worse)*" suggesting this may only be a short term benefit. As outlined in Section 7.4 the postural changes during prolonged standing over time requires further investigation. Individual factors including initial standing posture and use of movement may be important (Gregory and Callaghan 2008).

Not all participants found working in a standing position to be positive though. With time, fatigue was reported to impact negatively on cognitive functions. A participant's comment relating to the sustained attention test is an example of this impact: "…*after standing for a long period of time I feel that the fatigue caused me to have less concentration and feel very edgy. An example would be the number test where I was slightly agitated that kept hitting the space bar when the number 3 popped up.*"

Discomfort featured strongly as negative feedback for both conditions. In particular, feet soreness and low back ache were reported. From a participant who did not complete the two hours "*Thinking about my discomfort most of the time; distracting*". These comments were expected given the ratings of discomfort as outlined in Table 6.2. The ability to move more was also raised with comments such as disliking "*the five minutes of not moving much*" during standing-with-movement. This comment is in line with the protocol used by earlier studies which found participants switched more frequently (on average every 90 seconds) when unconstrained (Satzler *et al.* 1993). A protocol with shorter duration of foot alternation in using a footrest would appear to be indicated for some participants. Other researchers have found participants react differently to alternate work positions with participants becoming pain developers or non-pain developers (Gallagher *et al.* 2011). Being able to identify pain developers, provide education and support implementation are expected to play a role in determining whether an individual adopts the new work position readily.

Another aspect disliked by participants was the inability to use their elbows for support on the desk surface. The protocol used required participants to avoid leaning on the desk to ensure consistency (Nelson-Wong *et al.* 2010). In the real world, participants may lean their abdomen against the desk and also rest their forearms on desk surface, however this could potentially also lead to less ideal postures as a means of accommodating discomfort when sitting or movement may be a preferred strategy.

Overall, participants had divided opinion on the use of standing and standing-with-movement as a work position suggesting either position would only be viable for some. Given the levels of discomfort identified in Section 7.1, ways to reduce discomfort would be required before recommendations of wide scale implementation. Participants suggested that for implementation with optimal adoption organisational culture should encourage use of the alternative work position and education should be provided especially to those with existing conditions including footwear recommendations to reduce likelihood of discomfort.

7.10 Strengths, contributions and limitations

7.10.1 Strengths and contributions

Study 1 and Study 2 assessed prolonged sitting and three commonly promoted alternative work positions. Each of these work positions, including prolonged sitting, had gaps in knowledge as outlined in Chapter 2 particularly relating to discomfort and when and why it occurs. Further each alternate work position had gaps around the impact on domains of cognitive function if undertaking for prolonged periods. Study 1 and Study 2 have provided evidence around whole body discomfort and when clinically meaningful levels were reached for each work position, for each body area and at what point in time. For the low back these studies were the first to investigate changes in low back angle while using an under-desk cycle during prolonged sitting. The studies added to evidence about low back angle and movement for the other work positions, noting very limited evidence was previously available for standing-with-movement. Muscle fatigue was also collected for under-desk cycling and standing-with-movement for the first time. For the lower limb previous research of standing while using a footrest had not explored lower limb swelling and Study 2 has provided results to address this gap. Measurement of cognitive functions while using an under-desk cycle and standing-with-movement workstation were also novel. Very limited research has included the cognitive function of creative problem solving for any of the work positions. The measurement of mental state particularly for prolonged use of under-desk cycling and standing-with-movement has also addressed a prior literature gap. A further strength is that each of the alternate work positions chosen for further study (under-desk cycling, just-standing and standing-with-movement) would require minimal workplace disruption and cost for implementation. It is acknowledged that height adjustable desks would be required however redesign of workplaces (to fit larger equipment) would not.

The design chosen for the thesis included a number of variables being measured concurrently to allow a detailed understanding of the impact of each of the work positions on discomfort and cognitive functions. The variables of low back angle, movement and muscle fatigue allowed detailed examination of potential mechanisms for the low back. Measurement of discomfort together with cognitive functions also allowed investigation of associations, to add to limited existing literature applying to use of alternate work positions. The within subject design also strengthened findings by reducing the likelihood of findings being due to between participant variation. The use of repeated measures every 30 minutes allowed understanding of how variables changed over time and rather than only a pre-post comparison. This was important for both discomfort and cognitive functions, noting the majority of other studies of alternative work positions have not used this design. Importantly the same variables were assessed for prolonged sitting to allow comparison to the other work positions. In many studies of alternate work positions there is no comparison to sitting, that is, acknowledgement that sitting also has discomfort over prolonged periods and potential to have decrement in cognitive functions.

The duration of assessment for each condition (two hours) addressed a gap in the research of prolonged postures when using alternate work positions. The duration was chosen to simulate the typical time before a break (e.g. meal, bathroom) for office based work. This extends on a number of the studies of alternate work positions which have been of short duration (one hour or less). The use of a laboratory based design allowed for a high level of control, to reduce the number of confounders evident in field and epidemiological studies. These included variations in usage of the alternative work position and objective data of usage, access to required equipment (not shared) and objective measures for cognitive domains rather than self-reported productivity. Participants' use of the work position was also able to be undertaken to a protocol (e.g. standing-with-movement) which would not be viable in a real world setting. Finally, the ability to collect acute discomfort and mental state data throughout the study to correlate with changes was also a strength compared to longer duration studies where recall bias (for ratings) can occur.

7.10.2 Limitations

Study 1 provided valuable learnings which enhanced the design of Study 2. Therefore, by default, Study 1 had some limitations which Study 2 did not. For instance, calf swelling was not measured in Study 1 but was added to Study 2. Thus for Study 1 it is not known if calf swelling occurred in just-siting and/or whether under-desk cycling may have impacted this. Qualitative feedback was also added to Study 2 to provide greater insight to the findings which was not available for Study 1. In addition, EMG and kinematic sampling periods were lengthened in Study 2 to ensure analysis of movement had more likelihood of capturing a representative sample of participant activity. A further enhancement would have been to collect EMG and kinematic data continuously to allow even greater capture of movement. Continuous data collection would have allowed assessment of total movement including the movement to switch feet on the footrest during standing-with-movement. Prior to analysis of EMG data visual inspection of EMG traces were undertaken. There were no appreciable variations in muscle activity and therefore characterisation of variability was not undertaken. Should continuous data collection yield different results this could be explored. Another consideration would be use of alternate EMG equipment allowing measurement at different locations within the same muscle and also additional back muscles' activity, including deeper muscles such as multifidus. Study 2 also used different equipment for muscle activity measurement. Due to equipment availability, only four muscles were able to be measured concurrently. Trapezius muscle activity was therefore not measured in Study 2, although this would have been desirable.

Study 1 and Study 2 were undertaken with two separate groups of participants, thus direct comparison across all conditions was weaker than if the same participants had been used across both studies. Whilst using the same participants was considered, the burden on participants would have been greater (requiring approximately 12 hours spread over four sessions for all conditions). In comparing the descriptive statistics across the two Studies though, it is noted that age, height and weight were relatively similar and thus may not have greatly impacted results (see Tables 4.1 and 6.1).

Participant ratings were used for discomfort and mental state which are subjective, and therefore subject to bias. Two participants who withdrew before the end of the study duration (two hours) in Study 2 did not rate discomfort at maximum level at the point of withdrawal. Provision of additional guidance material for ratings could assist to address this (for example advising participants that a mark at the high discomfort end of the scale suggests inability to continue).

A study protocol was used to ensure consistent positioning for Study 1 and Study 2. It seemed however that, based on qualitative feedback from Study 2, participants had individualised approaches in how they preferred to interact with equipment. It is therefore postulated that the use of a strict protocol was a limitation in understanding this better. For instance the ability to undertake intermittent cycling rather than continuously cycling, and use the footrest as desired rather than a set schedule, may have resulted in considerably different findings especially for discomfort. Participants also only undertook a short familiarisation period and a longer conditioning period before cognitive assessment would appear to be worthwhile.

During both Study 1 and Study 2, participants were able to undertake self-directed computer/clerical activities between cognitive assessments. This aspect of the study design aimed to reduce the participant burden and mimic realistic office work. Allowing choice of activity may have affected cognitive functions results depending on the activity chosen by the individual. Passive activities such as streaming material from the internet compared to problem solving or more cognitively demanding tasks may have affected subsequent cognitive function assessments. Further, the interruption to participants' self-directed activity to undertake the computer based assessments may have influenced motivation. For cognitive functions, a potential learning effect for the tests used to measure cognitive function can not be ruled out. A counterbalanced design was used and testing for effect of order was also undertaken to address this.

Applicability of these results to a real world setting were high given the simulated office set up and tasks chosen however there are aspects which were not representative. An example of this was use of the upper limb. In a workplace, activities such as reaching for a telephone, accessing hard copy data from files or shelves would also be expected to occur. In Study 1 and Study 2 participants used the mouse and keyboard only. In addition, it is possible some people may not perform prolonged positions continuously for two hours in the field and may have work related tasks which require transitions such as walking to a meeting room.

Data was not collected for swelling for Study 1. For Study 2, volumetric measures would have been preferred to circumferential however liquid measurement was not viable due use of the sensors for EMG. In addition, interrupting participants to measure volume (using the liquid volume displacement approach) would have also impacted other variables (such as posture and muscle activity) and impacted self-directed activity thus increasing the participant burden.

The type of under-desk cycle selected is postulated to have negatively impacted results. The strap over the foot may have increased discomfort. Further research of other under-desk cycling equipment would be valuable. Further a more elliptical pedal device which did not require adjustments to desk height (thus could be at a standard height) may also yield different results for low back and buttock/hip/thigh discomfort with expected differences in pelvis-hip position. For standing-with-movement the footrest chosen may not have been optimal in size, height, angle and placement and research of alternatives would aid recommendations in this area. In addition, research of different alternatives such as a swinging bar instead of a footrest, and thus increased movement, when standing may assist with reducing discomfort and may be beneficial.

7.11 Policy and practice implications

The results of Study 1 and Study 2 suggest use of alternate work positions in the workplace needs to be undertaken with caution due to discomfort implications. Study 1 and Study 2 measured acute effects across discomfort and cognitive functions.

The discomfort results indicate change of work position should occur by 120 minutes and as early as 60 minutes for healthy individuals, for each of the positions examined based on the protocols used. Use of alternative work positions instead of sitting appears to have merit, though for shorter durations of less than two hours. Participants had delayed onset of body clinically meaningful levels of discomfort in some body locations when under-desk cycling, compared to sitting. The use of standing alternatives however resulted in earlier onset of discomfort and at higher levels. Therefore prolonged standing is a concern for both musculoskeletal discomfort and cardiovascular risks. Participant feedback suggested that the option to use a standing work position, in combination with a non-weight bearing position such as sitting, would be feasible. Therefore each of the positions trialled, if used for the optimal duration, appears to provide opportunity to increase movement while working, without being detrimental to health. Each work positions is expected to require specific recommendations around appropriate patterns of use.

For just-sitting, Study 1 discomfort results suggest a change in position before 90 minutes should be recommended if using a standard 'ergonomic' office chair. For under-desk cycling Section 7.4.2 outlined the increases in lower limb discomfort with time with four body areas reaching clinically meaningful levels by 120 minutes. The under-desk cycle equipment used in Study 1 had a strap to hold the foot in position and this may have contributed to the levels of discomfort. If using an under-desk cycle an alternate design without an uncomfortable foot strap would be recommended. The under-desk cycle design aimed to reduce the knee clearance requirements, however it still resulted in a higher desk surface than would typically be recommended and may have longer term implications for the upper limb. Use of an elliptical cycle may be a viable alternative which addresses this issue. Bouts of cycling may be more viable than continuous cycling and the ability to cycle at a self-determined intensity, pace and bout pattern may be advisable.

For standing a recent systematic review of laboratory studies by Coenen *et al.* (2017b) recommended refraining from standing for more than 40 minutes in a single bout. As Study 2 only collected discomfort rating every 30 minutes it is not known how long before 60 minutes clinically meaningful levels were reached but the current findings are in alignment with the systematic review recommendation. Given the number of studies examined by Coenen *et al.* (2017b), the more conservative recommendation of a maximum of 40 minutes standing in a singular bout would therefore be suggested. For standing-with-movement, despite the objective discomfort findings, the use of a footrest was preferred by some participants. An alternate protocol, or potentially unconstrained use, would appear to warrant trialling.

From a cognitive functions perspective, the alternate work positions did not result in clear acute deterioration in sustained attention or creative problem solving. While further research is required, there is promise that introduction of alternate work positions within the workplace may not be deleterious to office workers cognitive functions.

The current studies only had acute measurements over two hours. It is not known if conditioning to the use of an alternative work position would occur and how this may vary between individuals. Further, research and guidance is also required to inform how a full work day should be managed, and over longer durations (such as consecutive days or a work week) to understand cumulative effects. Therefore, guidance on when a change of work position should occur, and the length of repetitive bouts of use of an alternative work positions, is also needed. Adoption of alternate work positions may be determined to be relatively low risk compared to other workplace hazards, however as outlined in Section 2.6.2 there are potential long term musculoskeletal effects in addition to acute discomfort.

With long term use, alternate work positions can have broader health risks, such as circulatory issues with prolonged standing, therefore do not appear to be the sole solution to addressing sedentary behaviour in workplaces. Further, some work positions such as standing and standing-with-movement do not greatly increase movement and thus may not result in substantially better health outcomes compared to sitting. Given this, broader ergonomics consideration of how to address workplace sedentary behaviour appears warranted. Greater use of combined approaches which focus on individual, environment and organisational changes are warranted (Straker *et al.* 2014). This could include work redesign to reduce periods of prolonged sitting and increase movement aiming to get the 'just right' amount of physical activity (Straker *et al.* 2018). Currently regulators are attempting to provide guidance, however there is a lack of national legislation, regulations and codes of practice related to managing sitting in the workplace (Coenen *et al.* 2017a). In the meantime, employers remain responsible for managing risks in the workplace and require guidance.

For workers who already have pre-existing musculoskeletal issues (particularly low back pain) use of alternate work positions (such as standing) are often recommended. There is a lack of research and therefore guidance available to industry on managing these workers to avoid additional musculoskeletal risks to individuals. Guidance outlining contraindications of specific alternate work positions for relevant musculoskeletal conditions and health concerns is needed. All participants in Study 1 and Study 2 were healthy, having confirmed they did not have known pain in response to maintaining a prolonged position. As such, recommendations based on Studies 1 and Study 2 can not be made for those with pre-existing conditions. It is recognised however that in the standing positions, healthy individuals experienced clinically meaningful increases in discomfort in weight bearing joints within 60 minutes. Therefore standing for those with conditions of low back and lower limb may well need to be of less duration than this and depending on the level of symptoms and disability may not be recommended at all. In contrast, under-desk cycling may be beneficial for some lower limb conditions where weight bearing is to be avoided. Careful consideration of the length and frequency of use of an under-desk cycle in addition to equipment type, to avoid additional discomfort, would need to occur. Therefore, a prescriptive individualised approach to work designs involving alternate work positions should be taken considering the worker's condition and symptoms. Graded introduction and monitoring of symptoms should be also be standard practice.

If introducing alternative work positions within a workplace, a plan to provide education to users regarding musculoskeletal risks should be included. However, a range of other factors also have potential to influence feasibility. These include organisational factors such as management support and workplace culture, and individual psychosocial factors including job demands, perceived workload and social support. Planning the implementation approach needs to consider the broader context to maximise likelihood of success.

7.12 Future research

Extensive evidence supports a link between sedentary behaviour and negative health outcomes however evidence linking excessive *occupational* sitting and negative health implications is inconclusive (van Uffelen *et al.* 2010). Previous studies which have attempted to separate the various domains of sedentary behaviour have primarily been via self-report.

Further studies which investigate sedentary behaviour need to objectively capture how this was accumulated, across work and leisure domains.

7.12.1.1 Research implications for sitting and standing based work and discomfort

Evidence causally linking occupational sitting and musculoskeletal discomfort is inconclusive (Marshall and Gyi 2010, Straker *et al.* 2016). Field studies which extend upon laboratory findings, including acute discomfort measures, are required. Such field studies, undertaken over longer durations, will provide data of user conditioning and whether this has an effect on discomfort and potential cumulative effects. An example where a longer duration study would provide valuable insights is under-desk cycling. There was a trend toward attenuation of discomfort for the low back when under-desk cycling. If over longer durations cycling assisted with managing low back discomfort, this would influence recommendations of use.

From an acute perspective, Study 1 found discomfort increased over the two hours for both of the seated conditions and importantly, discomfort reached clinically meaningful levels for some body areas. Thus a change of work position before two hours was recommended. In the current study though, the grouping of body areas for discomfort limited inferences for some of the findings. For instance due to the grouping of buttock, hip and thigh, it was unclear if increases differed by body area (for instance thigh versus buttock) for just-sitting compared to under-desk cycling. In the lower limb discomfort was measured with ankle and foot combined. It is not known if it was just ankle, just foot, or both which led to the increased level of discomfort. It was hypothesised that the design of the under-desk cycle (use of foot strap) used in Study 1 may have contributed to the increased discomfort rating for the ankle/foot. Alternatively use of bouts rather than continuous cycling may have yielded different results. Further studies which separate these body parts would allow investigation of potential cause/s of increased discomfort, and subsequently exploration of alternate equipment design or recommendations for use.

One of the limitations of the current studies' was the measurement of cumulative movement over the entire condition including transitions. Movement is postulated as a mechanism to alleviate low back and buttock/hip/thigh discomfort. Further, movement which unloads passive tissues appears to be a key differentiator for pain and non-pain developers. Future research with capability to measure cumulative movement over the duration of the prolonged position, in addition to distinguishing types of movement (shifts, drifts, fidgets and transitions) throughout, together with discomfort measurement would aid understanding of how movement impacts discomfort. For prolonged sitting exploration of dynamic chairs, which allow sufficient variation in movement, while also ensuring adequate knee clearance to allow optimal positioning, would appear worthwhile. For the lower limb, discomfort was postulated to also be linked to swelling evident in the upper calf for just-stand and standing-with-movement. The amount of movement during standing-with-movement to raise a foot may not have been sufficient to activate the muscle pump to attenuate swelling. If more standing in workplaces occurs, there is potential for impact on lower limb venous conditions for some people. Therefore, investigation of how much movement is required to manage swelling is clinically important. Future research involving work positions should include lower limb swelling measurement as part of the study design.

Study 2 also found discomfort increased with time in both standing conditions, and reached clinically meaningful levels for the back and lower limb body areas. The results also suggested that when assuming a prolonged standing work positions, a break before 60 minutes was recommended. The use of a footrest when standing did not sufficiently change discomfort such that this would be recommended as a viable alternative for prolonged standing based on the protocol used. An alternate protocol with a different ratio of alternation of raising a foot may have had different results and should be explored further. For the low back, discomfort was lower when undertaking standing-with-movement compared to just-standing which shows promise. Another factor for further investigation is the impact of the asymmetrical pelvis position which is postulated to occur when using a footrest while standing. This asymmetrical positioning may have implications for low back discomfort with loading of zygapophyseal joints. Investigating the degree and variation of lateral pelvis asymmetrical positioning over time, when using a footrest while standing, together with discomfort would address this. In addition, use of a standing-with-movement work position in combination with a sitting work position, as would be expected for office workers in industry, would also ecologically valid.

Based on epidemiological studies to date evidence of a link between occupational sitting and upper limb discomfort is inconsistent. Further research which examines this relationship should quantify use of technology to objectively measure amount of time spent using a keyboard or mouse, compared to other office tasks such using the telephone, attending to customers or meetings. Greater understanding of the implications of movement with alternative work positions on discomfort and muscle fatigue (to maintain postural control for fine motor performance) would also be valuable. Standardised objective data capture across such studies, not just self-report, would allow for pooling of data and robust analysis.

7.12.1.2 Research implications for sitting and standing based work and cognitive functions

Cognitive functions during prolonged occupational sitting have not been extensively researched. There are gaps in the evidence of how prolonged sitting affects varying cognitive domains and how use of alternate work positions, which increase movement, may impact this. To date, the broad range of testing available and protocols used to measure cognitive functions means a large number of gaps continue to exist. A challenge in interpreting results from cognitive functions testing is the lack of an agreed threshold from which results would be considered clinically meaningful. In Study 1, under-desk cycling was suggested to have some dual task cost for sustained attention. For creative problem solving while there were differences between the conditions the clinical significance is not known given the lack of studies to determine what is clinically meaningful. Future research to define a clinically meaningful threshold would assist in application of findings. Wherever possible future studies should use of a standard testing protocol when considering alternative work positions to allow results to be compared more broadly. This standardised protocol should include the test battery and timing of the testing (during use of work positions, afterward, length of time afterward).

Cognitive functions did not show any significant differences between the standing conditions. There appeared to be some differences between the standing and the seated conditions, although as the participants were different results were not directly comparable. One of the mechanisms proposed to influence cognitive functions was increased energy expenditure. The current studies did not measure energy expenditure however it is postulated that aside from under-desk cycling, the increase may not have been sufficient to induce any observable change based on the measures used. Future research should measure energy expenditure of alternative work positions, including those used in Study 1 and Study 2, compared to sitting, to determine the level of activity and allow comparison between alternative work positions. Further, research needs to continue to investigate the impact of alternate work positions on specific domains of cognitive function domains. Field based repeated objective measurement of work performance when using alternative work positions also needs to occur to provide broader data. With research of both cognitive functions and work performance, there will be greater understanding of potential implications when implementing use of alternate work positions.

Based on self-report mental state for all conditions deteriorated over time. The movement interventions did not attenuate deterioration as had been hoped. A limitation of the current studies was finding a measure which was sensitive to, and accurate in, capturing mental state changes. Future studies should use technology to measure mental state more objectively (such as wearable technology for dry contact electroencephalogram or eye-blink timing). Such data would provide evidence to quantify whether mental state changed, and when. This evidence could provide recommendations for beneficial use of alternate work positions in occupations where a high degree of vigilance is required (such as air traffic controllers). Mental state ratings may also have been influenced by personality factors of the individual. Emerging research has investigated autonomy and behavioural motivation in influencing sedentary behaviour (Hermans *et al*, 2018). Further research should consider personality traits, concurrent to interventions to reduce prolonged sitting, to provide greater understanding in this area.

Chapter 8 Conclusion

This thesis has investigated prolonged sitting and three alternative work positions potentially suitable for office workers. The two laboratory studies undertaken assessed prolonged sitting, under-desk cycling, standing and standing-with-movement (each for two hours). The primary aim was to investigate the impact of the work positions on musculoskeletal discomfort and cognitive functions for healthy adults. The secondary aims were to assess the impact of prolonged sitting and each alternative work positions on muscle fatigue, posture, pelvis movement and mental state. In addition, correlations between discomfort and cognitive functions were also explored. Participant perceptions of feasibility of standing alternatives to prolonged sitting were also evaluated.

The number of variables measured concurrently when assessing alternative work positions in the current studies was novel and allowed a rich analysis of the data. The main findings from Study 1 and Study 2 suggest a change of work position before two hours and as early as 60 minutes is recommended to avoid reaching clinically meaningful levels of discomfort. Use of alternative work positions for shorter durations of less than two hours though may be beneficial. During under-desk cycling participants' experienced an onset of clinically meaningful levels of body discomfort later compared to sitting. This suggests there is merit in exploring under-desk cycling further to address equipment design issues which appeared to contribute to discomfort experienced in the current study. The use of standing alternatives should only occur in combination with seated options, given the considerably higher and earlier onset of discomfort compared to sitting and other known health risks from excessive standing. Participant feedback suggested that the option to use either of the standing work positions, in combination with sitting, would be feasible. Use of the alternative work positions did not result in a clear detriment to cognitive functions (problem solving and sustained attention). There was no consistent association between discomfort and cognitive functions for just-sitting and just-standing conditions. The findings of Study 1 and Study 2 have provided information about aspects which had not been researched previously (particularly relating to under-desk cycling and standing-with-movement) and extend on research for other areas (just-sitting and just-standing).

Addressing sedentary behaviour is an important health issue. For workers who undertake higher levels of sitting as a result of their work, interventions which are workplace-based are appealing. Recommendations to guide industry in the use of alternate work positions are emerging however a number of unanswered questions remain. The results of the current studies suggest there are risks of clinically meaningful acute musculoskeletal discomfort when alternate work positions are used over prolonged periods, even with healthy individuals. Users with underlying musculoskeletal conditions are likely to be at higher risk. This thesis has provided evidence which can be used to educate industry about the risks for healthy workers, and how to reduce these through timing of changes of position. The thesis also showed that the cognitive functions evaluated did not have any clear short term decrement thus supporting use in the workplace. In conclusion, use of alternate work positions in the workplace, while allowing workers to be productive, are not without issues suggesting they are likely to form only part of the solution to addressing workplace based sedentary behaviour.

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APPENDICES

Appendix A Study 1 Participant information and consent

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PARTICIPANT INFORMATION SHEET

Project title: Musculoskeletal discomfort and cognitive performance using an active cycling workstation

Principal Investigator: Ms Richelle Baker
Supervisors: Prof. Leon Straker, Dr Darren Beales, Dr Erin Howie, Prof Ann Williamson

Purpose of Research

Sedentary behaviour and activity can have effects on cognitive performance and musculoskeletal discomfort. In most cases sedentary behaviour involves prolonged sitting. As occupational sitting occupies a significant amount of time for many people, this study will replicate use of an office workstation.

The majority of studies which have previously looked at addressing sedentary behaviour in the workplace have attempted to increase the level of activity through use of sit/stand desks and treadmills. Less research has considered cycling particularly under desk options. One of the benefits of an under desk cycle is that it would allow a worker to stay at their existing workstation.

A number of the studies to date have been for short duration only thus not replicating sitting for prolonged periods as would be typical for an office based worker. This study is aimed at trying to get a better understanding of using an under desk cycle and potential effect on concentration, problem solving and musculoskeletal discomfort over a longer period.

Your role

Participation would require initially attending the laboratory in the School of Physiotherapy and Exercise Science for a familiarisation session (approximately 15 mins) during which time you will undertake a brief assessment (10 mins) and we will explain the procedure.

The testing will then occur across two sessions, approximately 1 week apart. The difference between those sessions will be using an under desk cycle on one occasion and sitting on a standard office chair for the other. During the cycling session you will undertake near to continuous cycling (at a light level). During the office chair session you will just sit throughout.

You will complete a baseline test then approximately 8 mins of assessments each 30 mins. The assessments are:

- Brief questionnaire regarding discomfort and alertness
- Creative problem solving activity

- Computer based attention test

Further musculoskeletal testing throughout will include:

- Muscular and postural sensors (which we will tape to your neck, trunk, abdomen and leg to record muscle activity and posture)
- Heart rate monitor (chest strap)

You will need to wear shorts and sleeveless t-shirt (ie tank top) for placement of sensors and wear flat shoes (ie trainers).

Overall each session will involve two hours of testing (plus set up time therefore 2.5 – 3 hours overall). During this time we ask you bring your own reading material (ie on USB or ability to access on the internet) and you will then need to type summaries of your reading between testing activities.

Risks and Discomforts

If you have known pain / discomfort symptoms with activity (ie pre-existing injury and with activity pain increases) we would need to exclude you from the study. You may experience slight discomfort from the prolonged position however this is not anticipated to be any greater than normal activity where prolonged sitting is required (ie travel). Cycling will not be against any resistance and therefore considered light activity only. If you have had any significant vascular medical condition (i.e. heart attack, deep vein thrombosis, peripheral arterial disease) please advise us as it may not be appropriate for you to participate in the study.

You will be requested to avoid use of any pain relieving medication and drinking caffeine for up to 1 hour prior to attendance for the session. If you have allergy (or possible) to tape we will provide you with a small sample to trial before participating.

Benefits

Benefits to you will include opportunity to trial an underdesk cycle, performing light activity, while completing computer based tasks. Benefits to the broader community will include potential countermeasure to sedentarism in the workplace. The findings will be presented at international conferences and published in international scientific journals.

Confidentiality

All information will be coded such that only the researcher and supervisors will be able to reidentify participants. Any data presented as part of thesis/publication will not identify participants. You will be allocated an identification number so that your name will remain confidential to the researcher and supervisors. All the data will be recorded using this identification number. The master data linking names and codes, will be stored in a locked room at the School of Physiotherapy. Photographs will be taken of postures throughout however will also be altered to protect identity. Aside from when you have given consent for public use of the images, it will not be possible to identify any individual in any report on this research.

Refusal or Withdrawal

You may refuse to participate in the study, and if you do agree to participate then you will be free to withdraw from the study at any time. If you do decide to withdraw from the study then please contact the researcher at the earliest opportunity. If you withdraw, all your data will be destroyed.

Curtin University

Further Information

This study has been approved under Curtin University's process for lower-risk Studies (Approval Number PT018/2014). This process complies with the National Statement on Ethical Conduct in Human Research (Chapter 5.1.7 and Chapters 5.1.18-5.1.21). For further information on this study contact the researchers named above or the Curtin University Human Research Ethics Committee. c/- Office of Research and Development, Curtin University, GPO Box U1987, Perth 6845 or by telephoning 9266 9223 or by emailing hrec@curtin.edu.au.

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CONSENT SHEET

Project title: Musculoskeletal discomfort and cognitive performance using an active cycling workstation

Principal Investigator: Ms Richelle Baker
Supervisors: Prof. Leon Straker, Dr Darren Beales, Dr Erin Howie, Prof Ann Williamson

This study has been approved by the Curtin University Human Research Ethics Committee (Approval Number PT018/2014).

- I understand the purpose and procedures of the study.
- I have been provided with the participant information sheet.
- I understand that the procedure itself may not benefit me.
- I understand that my involvement is voluntary and I can withdraw at any time without problem.
- I understand that no personal identifying information like my name and address will be used and that all information will be securely stored for 7 years before being destroyed.
- I have been given the opportunity to ask questions.
- I agree to participate in the study outlined to me.

Signature Date

Witness Signature Date

Descriptive Data Form

Age:

Height (cm):

Weight (kg):

Select one of the following statements best describes the work that you do in your current job?

1. Sedentary occupation (eg secretary- where you spend most of your time sitting)
2. Standing occupation (eg shop assistant, security guard spend most of your time standing/walking but not intense physical effort)
3. Physical work (eg plumber, nurse - a job that requires some physical effort including handling of heavy objects and use of tools)
4. Heavy manual work (eg bricklayer - a job that involves very vigorous physical activity including handling very heavy objects)

Appendix B Study 1 Data collection protocol

Checklist

Date		Time	
Participant ID		Consent signed	
Medication in past 24 hours	Caffeine in past 1 hour	Toilet	Current MS Sx
Condition	Cycling / Non cycling	If second condition issues from 1st condition	
Ergonomic set up: 100 hip angle, 90 elbow Divide articles into 2 folders ☐			
Chair height	*Ground to underneath rear seat*		
Chair position	Wheel in front or behind cycle		
Desk height	Ground to underneath of desk surface (front edge bottom of corner edging) Set for cycling at first session		
Cycle resistance set at level 1, distance 0 ☐			
Heart rate monitor			
EMG shave, emery, alcohol, 20mm centre to centre, not touching Parallel to muscle fibres	Submax ref contractions 3 seconds x 3 repeats	Notes	
Upper Trapezius 2cm lat midpoint acromium & C7 ☐ Acromium – earth ☐	Lift 1kg weights bilaterally in scapular plane ☐	***Dominant side (Start menu/type 'mouse'/change settings)*	
Erector Spinae L1 sp process midway to lat body ☐	ES and Hamstrings: Knees bent 90 degrees lift both knees off plinth 5cm** ☐		
Ext Oblique RIGHT just below rib cage along line connecting most inferior point of the costal margin and the contra-lateral pubic tubercle ☐	Hips 45 degrees, knees 90, raise legs 1cm off plinth ☐		

24/9/14

<table>
<tr><td>Hamstrings BF RIGHT

ischial tuberosity (gluteal crease) and knee crease halfway
Distance of distal electrode to knee crease
__________ cm ☐</td><td>ES and Hamstrings:
Knees bent 90 degrees lift both knees off plinth 5cm**
☐</td><td></td></tr>
<tr><td>Quad RF RIGHT

ASIS and sup border of patella
Distance of distal electrode to patella
__________cm ☐</td><td>Ankle weight 2kg hold knee in extension with knee slightly bent</td><td></td></tr>
<tr><td colspan="3">Fastrak, double sided tape, fixomull tape with hole cut out. For postural 'sensors'</td></tr>
<tr><td>1. S2 PSIS (dimples) ☐
2. L3 (iliac crest – L4) ☐
3. T12 equal with lowest rib ☐
4. C7 (C6 disappears with neck flexion) ☐

Check fastrak tail toward door ☐</td><td colspan="2"></td></tr>
<tr><td colspan="3">Sitting normalisation</td></tr>
<tr><td>Usual Sitting
Fully slump post tilt as far as possible
Fully ant tilt as much as possible
Select normal</td><td colspan="2"></td></tr>
</table>

<table>
<tr><td>Time</td><td>Baseline tests
(cycle or not according to condition)</td><td colspan="2">EMG</td></tr>
<tr><td>0 start timer when commencing tests</td><td>• START HR monitor

• SART ☐
- mod Nordic Questionnaire ☐
- VAS ☐
• RUFF ☐

> Create Word document ☐</td><td>30 SART:
20☐ Typing/not
17☐ Typing/not
14☐ Typing/not
11☐ Typing/not
8 ☐ Typing/not
5 ☐ Typing/not
2 ☐ Typing/not</td><td>Notes:</td></tr>
<tr><td rowspan="2">30 mins</td><td>Record cycling distance ☐
Reset timer 30 mins ☐
Save Word doc ☐</td><td colspan="2"></td></tr>
<tr><td>• SART ☐
- mod Nordic Questionnaire ☐
- VAS ☐
• RUFF ☐</td><td>30 SART:
20☐ Typing/not
17☐ Typing/not
14☐ Typing/not
11☐ Typing/not
8 ☐ Typing/not
5 ☐ Typing/not
2 ☐ Typing/not</td><td>Notes:</td></tr>
<tr><td>60 mins</td><td>Record cycling distance ☐
Reset timer 30 mins ☐
Save Word doc ☐</td><td colspan="2"></td></tr>
</table>

24/9/14

	• SART ☐ - mod Nordic Questionnaire ☐ - VAS ☐ • RUFF ☐	30 SART: 20☐ Typing/not 17☐ Typing/not 14☐ Typing/not 11☐ Typing/not 8 ☐ Typing/not 5 ☐ Typing/not 2 ☐ Typing/not	Notes:
90 mins	Record cycling distance ☐ Reset timer 30 mins ☐ Save Word doc ☐		
	• SART ☐ - mod Nordic Questionnaire ☐ - VAS ☐ • RUFF ☐	30 SART: 20☐ Typing/not 17☐ Typing/not 14☐ Typing/not 11☐ Typing/not 8 ☐ Typing/not 5 ☐ Typing/not 2 ☐ Typing/not	Notes:
120 mins	Record cycling distance ☐ Save Word doc ☐		
	• SART ☐ - mod Nordic Questionnaire ☐ - VAS ☐ • RUFF ☐	30 SART: 20☐ Typing/not 17☐ Typing/not 14☐ Typing/not 11☐ Typing/not 8 ☐ Typing/not 5 ☐ Typing/not 2 ☐ Typing/not	Notes:

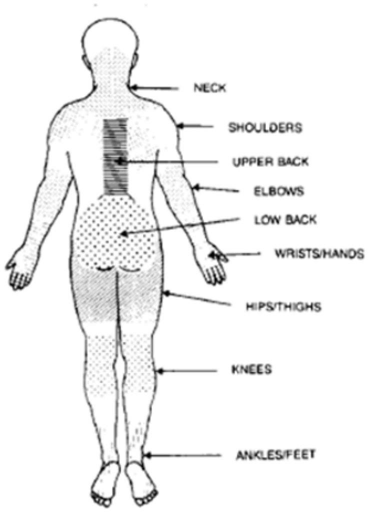
24/9/14

Appendix C Discomfort measure

Thinking about **NOW** do you have discomfort (ache, pain, soreness)?

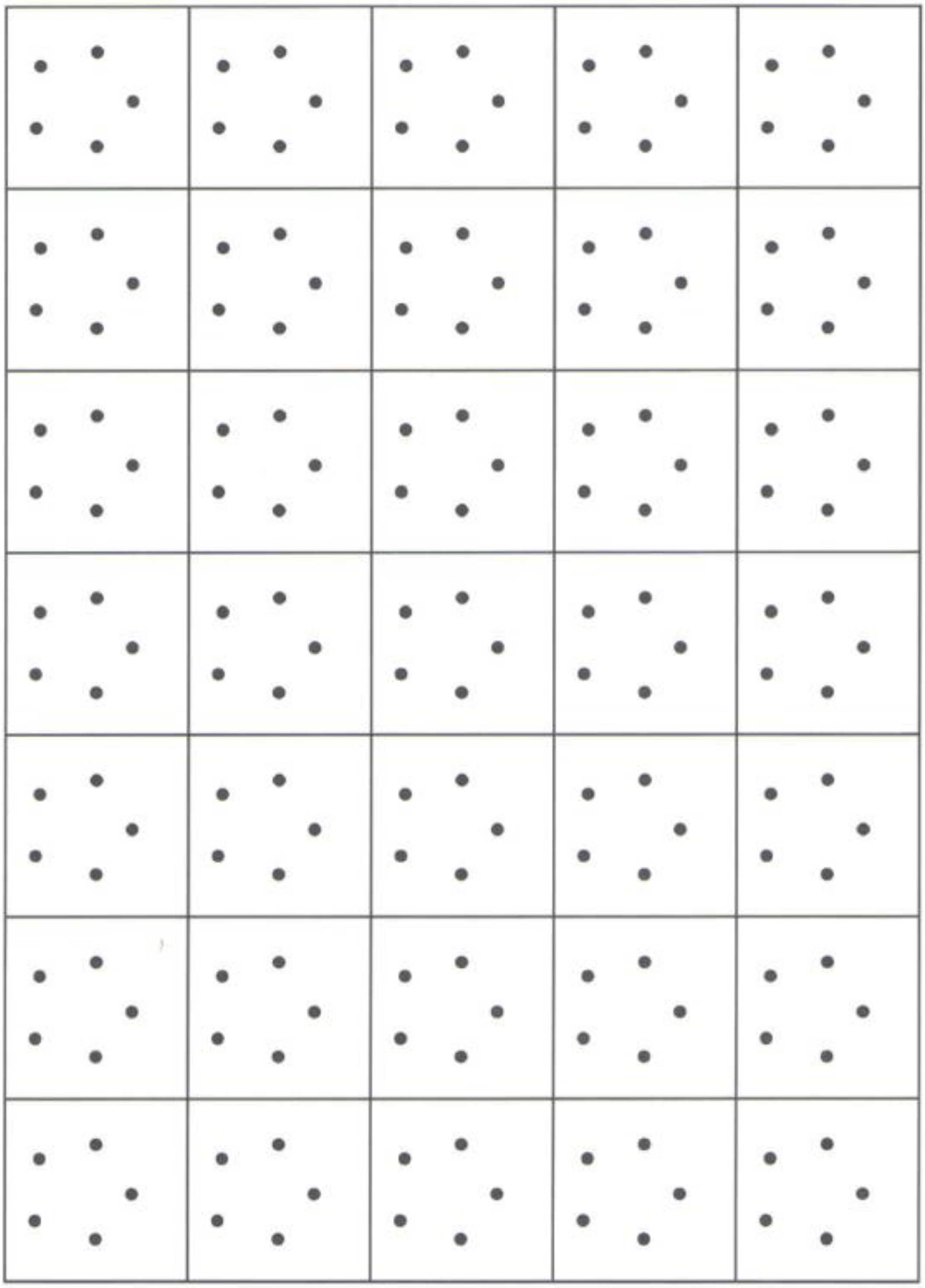
If yes, how intense is your discomfort on a scale of 0-10 *(where 0 = no discomfort, 10 = discomfort as bad as it could be)*

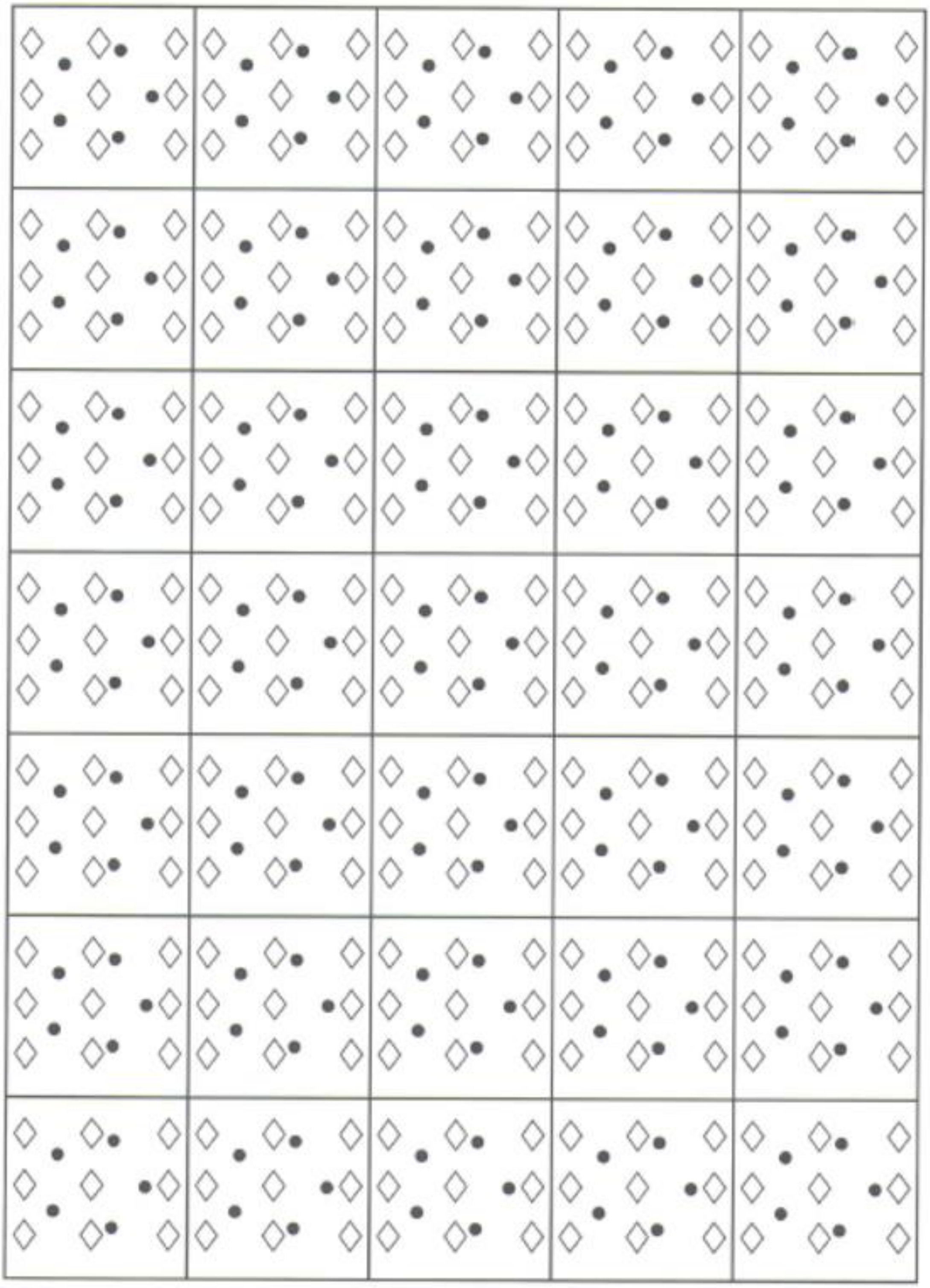
Neck	0	10
Shoulders	0	10
Elbows	0	10
Wrists/ hand	0	10
Upper back	0	10
Low back	0	10
Hips/thighs (buttocks)	0	10
Knees	0	10
Ankles/feet	0	10

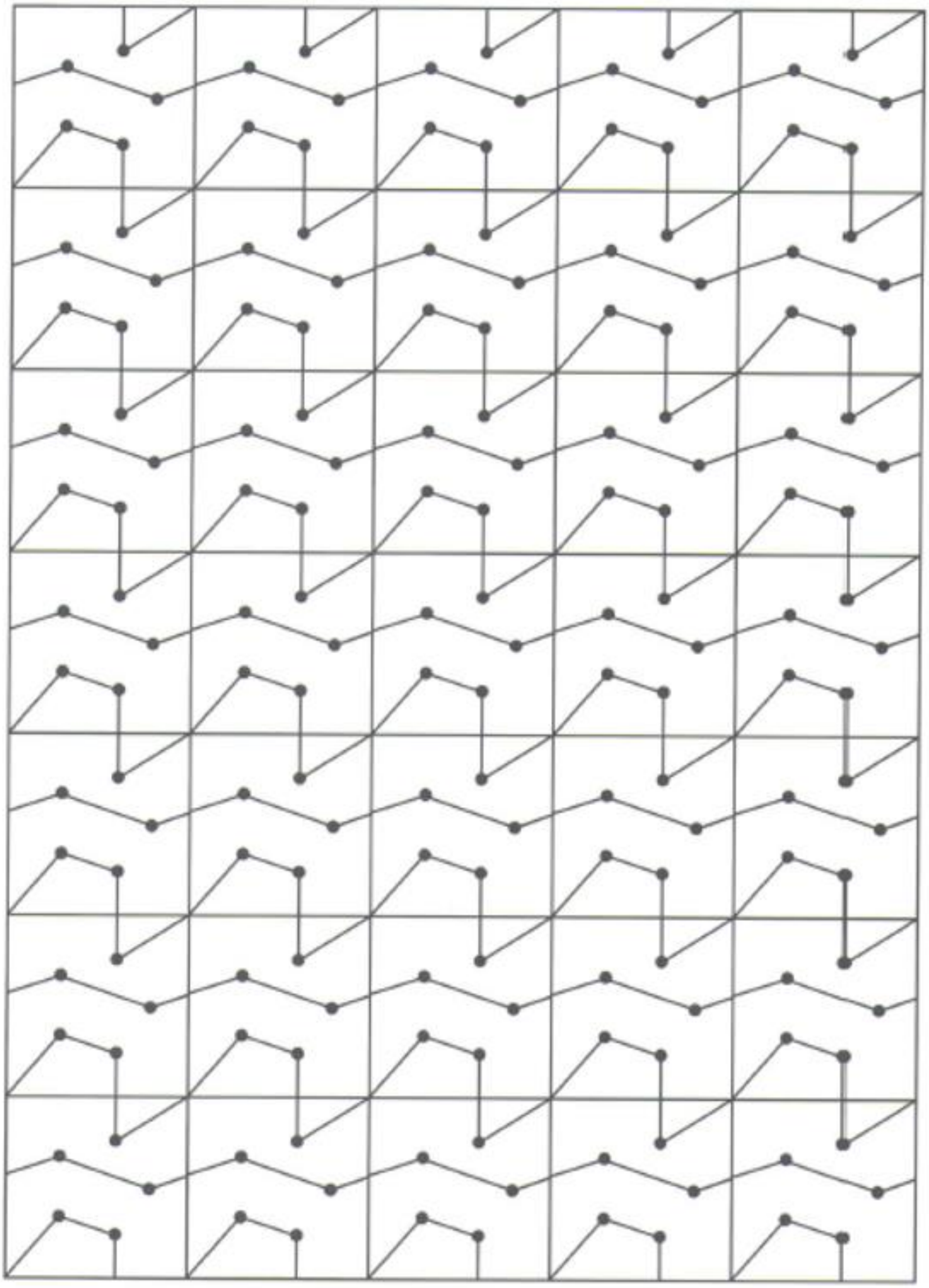


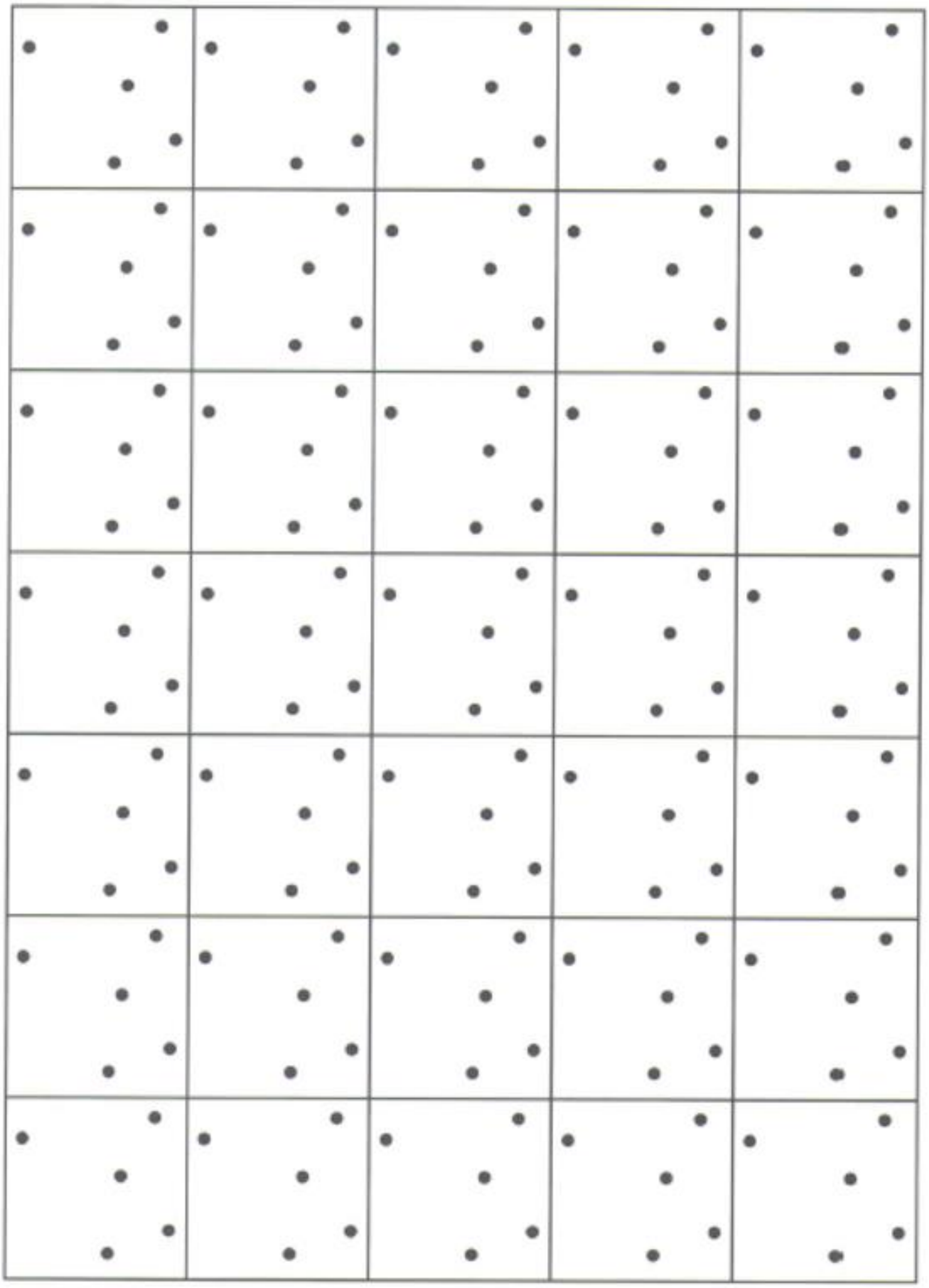
Appendix D Cognitive function measures

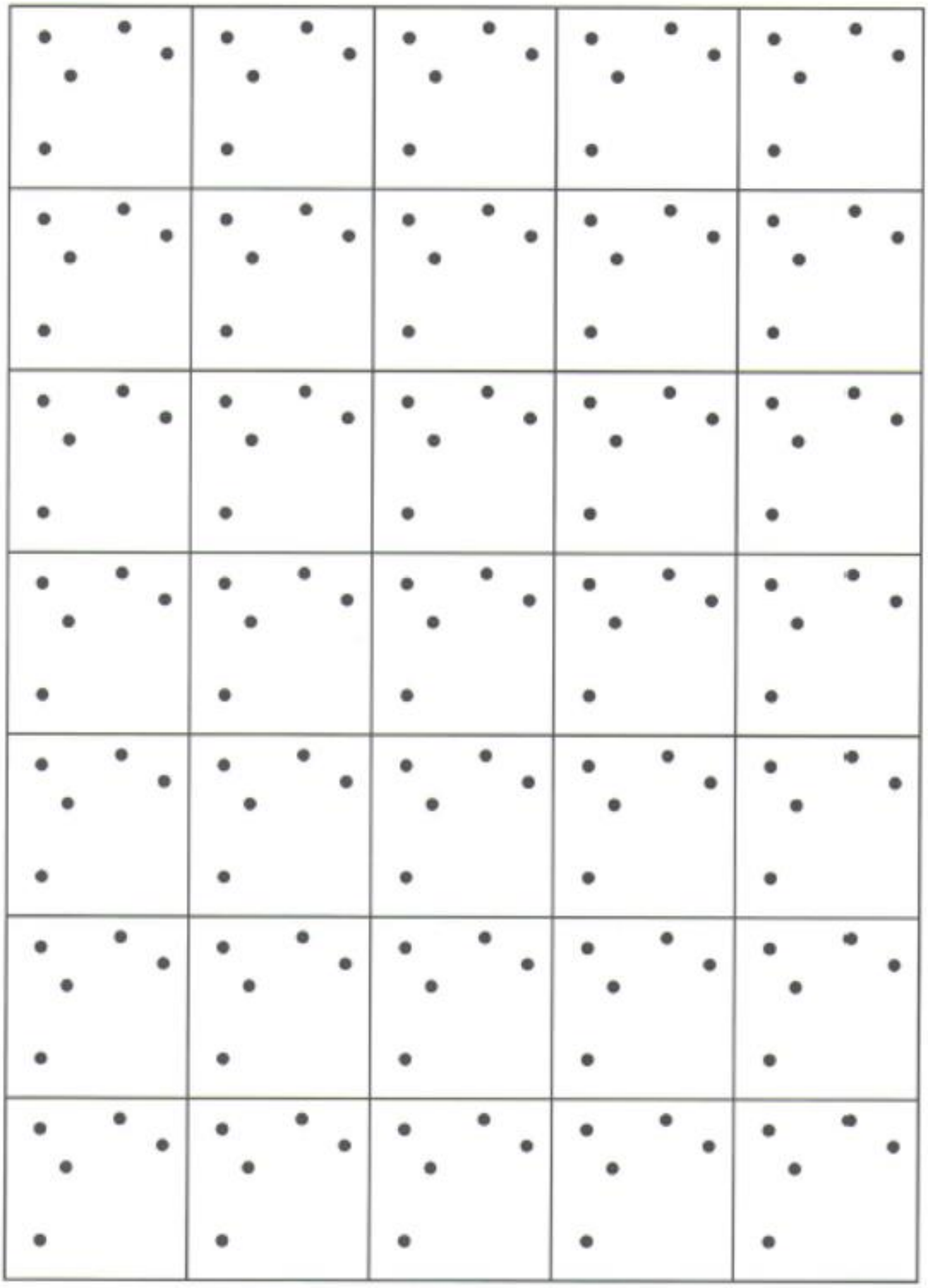
Creative Problem solving (Ruff Figural Fluency Test)



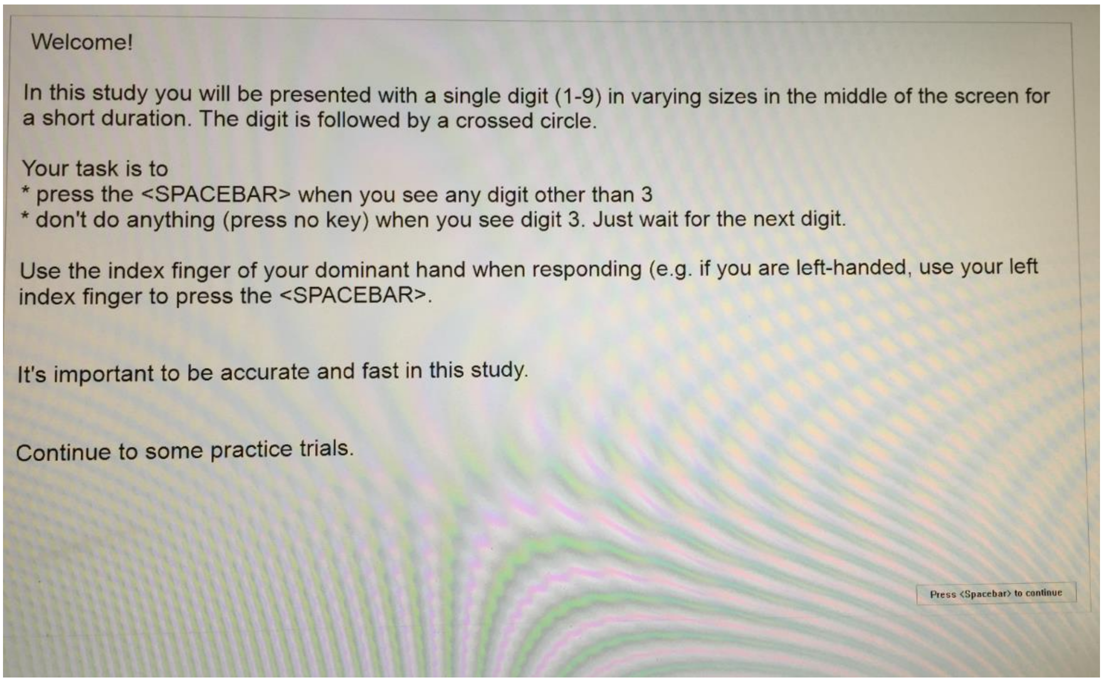








Sustained Attention (Sustained Attention Response Test)




3

Appendix E Mental state measures

Thinking about **NOW**, rate how you are feeling on the scales below

(where 0 indicates you completely agree with statement on left, 10 indicates you completely agree with statement on right)

Not at all alert	0	10	Extremely alert
Not at all tired	0	10	Extremely tired
Not at all drowsy	0	10	Extremely drowsy
Not at all fatigued	0	10	Extremely fatigued
Concentrating is no effort at all	0	10	Concentrating is a tremendous chore

Appendix F Study 1 Ethics approval

Curtin University

Memorandum

To	Professor Leon Straker
From	Dr Penny Moss
Subject	Protocol Approval PT018/2014
Date	30 October 2014
Copy	Richelle Baker (Co-investigator)

Office of Research and Development

Human Research Ethics Committee

Telephone 9266 2784
Facsimile 9266 3793
Email hrec@curtin.edu.au

Thank you for your amended Application for Approval of Research with Low Risk (Ethical Requirements) for the project titled *"Reducing musculoskeletal discomfort and cognitive performance decrement using an active cycling workstation"*.

On behalf of the Human Research Ethics Committee, I am authorised to inform you that this project is approved.

Your approval has the following conditions:

(i) An annual progress report/completion report (attached) on the project must be submitted to the School of Physiotherapy, Ethics Coordinator.

(ii) It is your responsibility, as the researcher, to meet the conditions outlined above and to retain the necessary records demonstrating that these have been completed.

Approval of this project is for a period of four years from the 30 October 2014 to 30 October 2018.

The approval number for your project is PT018/2014. Please quote this number in any future correspondence. If at any time during the approval term changes/amendments occur, or if a serious or unexpected adverse event occurs, please advise me immediately.

Penny Moss.

Dr Penny Moss
Coordinator, Ethics Committee
School of Physiotherapy and Exercise Science
Curtin University

Please Note: The following standard statement must be included in the information sheet to participants:
This study has been approved under Curtin University's process for lower-risk Studies (Approval Number PT018/2014). This process complies with the National Statement on Ethical Conduct in Human Research (Chapter 5.1.7 and Chapters 5.1.18-5.1.21).
For further information on this study contact the researchers named above or the Curtin University Human Research Ethics Committee. c/- Office of Research and Development, Curtin University, GPO Box U1987, Perth 6845 or by telephoning 9266 9223 or by emailing hrec@curtin.edu.au.

Standard conditions of ethics approval

These standard conditions apply to all research approved by the Curtin University Human Research Ethics Committee. It is the responsibility of each researcher named on the application to ensure these conditions are met.

1. **Compliance.** Conduct your research in accordance with the application as it has been approved and keep appropriate records.
    a. **Monitoring** - Assist the Committee to monitor the conduct of the approved research by completing promptly and returning all project review forms that are sent to you.
    b. **Annual report** - Submit an annual report on or before the anniversary of the approval.
    c. **Extensions** - If you are likely to need more time to conduct your research than is already approved, complete a new application six weeks before the current approval expires.
    d. **Changes to protocol** - Any changes to the protocol are to be approved by the Committee before being implemented.
    e. **Changes to researcher details** - Advise the Committee of any changes in the contact details of the researchers involved in the approved study.
    f. **Discontinuation** - You must inform the Committee, giving reasons, if the research is not conducted or is discontinued before the expected completion date.
    g. **Closure** - Submit a final report when the research is completed. Include details of when data will be destroyed, and how, or if any future use is planned for the data.
    h. **Candidacy** - If you are a Higher Degree by Research student, data collection must not begin before your Application for Candidacy is approved by your Faculty Graduate Studies Committee.
2. **Adverse events.** Consider what might constitute an adverse event and what actions may be needed if an adverse event occurs. Follow the procedures for reporting and addressing adverse events (http://research.curtin.edu.au/guides/adverse.cfm). Where appropriate, provide an adverse events protocol. The following are examples of adverse events:
    a. Complaints
    b. Harm to participants. This includes physical, emotional, psychological, economic, legal, social and cultural harm (NS Section 2)
    c. Loss of data or breaches of data security
    d. Legal challenges to the research
3. **Data management plan.** Have a Data Management Plan consistent with the University's recordkeeping policy. This will include such things as how the data are to be stored, for how long, and who has authorised access.
4. **Publication.** Where practicable, ensure the results of the research are made available to participants in a way that is timely and clear (NS 1.5). Unless prohibited from doing so by contractual obligations, ensure the results of the research are published in a manner that will allow public scrutiny (NS 1.3, d). Inform the Committee of any constraints on publication.
5. **Police checks and other clearances.** All necessary clearances, such as Working with Children Checks, first aid certificates and vaccination certificates, must be obtained before entering a site to conduct research.
6. **Participant information.** All information for participants must be approved by the HREC before being given to the participants or made available to the public.
    a. **University logo.** All participant information and consent forms must contain the Curtin University logo and University contact details for the researchers. Private contact details should not be used.
    b. **Standard statement.** All participant information forms must contain the HREC standard statement.
    This study has been approved under Curtin University's process for lower-risk Studies (Approval Number PT018/2014). This process complies with the National Statement on Ethical Conduct in Human Research (Chapter 5.1.7 and Chapters 5.1.18-5.1.21).
    For further information on this study contact the researchers named above or the Curtin University Human Research Ethics Committee. c/- Office of Research and Development, Curtin University, GPO Box U1987, Perth 6845 or by telephoning 9266 9223 or by emailing hrec@curtin.edu.au.
    c. **Plain language.** All participant information must be in plain language that will be easily understood by the participants.

Please direct all communication through your Form C Ethics Co-ordinator.

Appendix G Study 2 Participant information and consent

Curtin University

Faculty of Health Sciences
School of Physiotherapy

Telephone +61 8 9266 3618
Facsimile +61 8 9266 3699
Web www.physiotherapy.curtin.edu.au

PARTICIPANT INFORMATION SHEET

Project title: The impact of prolonged standing and use of a foot rest on musculoskeletal discomfort and cognitive performance

Principal Investigator:	Prof. Leon Straker
Investigators:	Ms Richelle Baker, Mr Jeremy Lee, Dr Darren Beales, Dr Pieter Coenen, Dr Erin Howie

Purpose of Research

Office workers can spend a large part of their work day sitting – and this may reduce their ability to think well and may increase the discomfort they feel in their muscles and joints. Standing to do computer work is currently being promoted as a way to reduce sitting at work. However standing for long periods may also impact on how well someone can think and discomfort they feel. One simple device which may help is a foot rest. Although this is commonly used in some situations, there is not good research evidence about what happens with prolonged standing and whether a foot rest can help. So, the focus of this study is to compare prolonged standing with standing using a foot rest.

Your role

Participation would require initially attending the laboratory in the School of Physiotherapy and Exercise Science for a familiarisation session (approximately 15 mins) during which time you will do a brief assessment (10 mins) and we will explain the study in detail.

The testing will then occur across two sessions, approximately 1 week apart. For both sessions you will stand for about 2 hours and do reading and note-taking work on a computer – one session will be just standing and the other will be standing using a foot rest. We ask you bring your own electronic material for reading (ie on USB or via the internet). You will be able to access email/internet etc using the desktop computer supplied.

Before each session we will set you up with sensors to monitor your muscle activity (neck, back, abdomen, upper thigh (front and back) and calf), posture (neck, middle and lower back, upper pelvis) and heart rate (chest strap). After the sensors are in place we will collect information from the sensors, measure the size of your calf and ask you to do 6-8mins of assessment every half hour including: a brief questionnaire regarding discomfort and alertness, a creative problem solving activity and an attention activity.

You will need to wear shorts and a sleeveless t-shirt (ie tank top) for easy placement of sensors and wear flat shoes (ie trainers, and to wear the same shoes both times).

Overall each session will involve two hours of testing (plus set up time therefore 2.5 – 3 hours overall).

Curtin University

Risks and Discomforts

If you have a pre-existing musculoskeletal condition for which you are actively seeking treatment, or which you believe may be aggravated by participating in the study, or requires medication, we would need to exclude you from the study. You may experience slight discomfort from the prolonged position however this is not anticipated to be any greater than normal activity where prolonged standing is required. If you have had any significant vascular medical condition (i.e. heart attack, deep vein thrombosis, peripheral arterial disease) please advise us as it may not be appropriate for you to participate in the study.

When undertaking the sessions you will be asked to tell us when you experience discomfort 'such that you would usually cease standing at that point'. You will be asked if you wish to continue standing. Should you elect to cease standing you will then be asked to sit for a recuperation period with the session concluding shortly after this. Alternatively if you are willing to continue standing you will continue with ongoing monitoring until the 2 hours are completed. You will be asked to avoid use of any pain relieving medication in the prior 24 hours and also to avoid drinking caffeine in the 1 hour prior to attendance for the session. If you have allergy (or possible) to sports tape we will provide you with a small sample to trial before participating. You will be able to drink water during the session however will not be able to drink other beverages or eat. We ask that you undertake the sessions without having done vigorous exercises in the 48 hours prior (ie avoiding commencing the session with muscle soreness or stiffness).

Benefits

Benefits to you will include the opportunity to trial working in standing, while completing computer based tasks. Benefits to the broader community will include understanding potential ways to reduce sitting at work which let office workers think better without discomfort. The findings will be presented at international conferences and published in international scientific journals.

Confidentiality

All information will be coded such that only the researchers will be able to re-identify participants. Any data presented as part of a thesis/publication will not identify participants. You will be allocated an identification number so that your name will remain confidential to the researchers. All the data will be recorded using this identification number. The master data linking names and codes, will be stored in a locked room at the School of Physiotherapy. Photographs will be taken of postures throughout however these will be altered to protect your identity. Aside from when you have given consent for public use of the images, it will not be possible to identify any individual in any report on this research.

Refusal or Withdrawal

You may refuse to participate in the study, and if you do agree to participate then you will be free to withdraw from the study at any time. If you do decide to withdraw from the study then please contact the researchers at the earliest opportunity. If you withdraw, all your data will be destroyed if you request this.

Further Information

This study has been approved under Curtin University's process for lower-risk Studies (Approval Number RDHS-266-15). This process complies with the National Statement on Ethical Conduct in Human Research (Chapter 5.1.7 and Chapters 5.1.18-5.1.21). For further information on this study contact the researchers named above or the Curtin University Human Research Ethics Committee. c/- Office of Research and Development, Curtin University, GPO Box U1987, Perth 6845 or by telephoning 9266 9223 or by emailing hrec@curtin.edu.au.

Curtin University

Faculty of Health Sciences
School of Physiotherapy

Telephone +61 8 9266 3618
Facsimile +61 8 9266 3699
Web www.physiotherapy.curtin.edu.au

CONSENT SHEET

Project title: The impact of prolonged standing and use of a foot rest on musculoskeletal discomfort and cognitive performance

Principal Investigator: Prof. Leon Straker
Investigators: Ms Richelle Baker, Mr Jeremy Lee, Dr Darren Beales, Dr Pieter Coenen, Dr Erin Howie

This study has been approved by the Curtin University Human Research Ethics Committee (RDHS-266-15).

- I understand the purpose and procedures of the study.
- I have been provided with the participant information sheet.
- I understand that the procedure itself may not benefit me.
- I understand that my involvement is voluntary and I can withdraw at any time without problem.
- I understand that no personal identifying information like my name and address will be used and that all information will be securely stored for 7 years before being destroyed.
- I have been given the opportunity to ask questions.
- I agree to participate in the study outlined to me.

Signature Date

Witness Signature Date

Appendix H Study 2 Data collection protocol

Checklist

Date		Time	
Participant ID		Consent signed	Toilet
Standing	Stand with Movement – footrest 10cm (flat)	If second condition any issues from 1st condition?	
Desk height : elbows at 90 degrees - 5cm : ______________________cm Top of monitor at eye level: How much paper ___________________cm ** Put on Heart rate monitor **			
Baseline tape on calf: Mark positions	• 10 cm below medial knee joint • Midpoint • 10cm above medial malleolus	________ cm __________cm ________cm __________ cm ________ cm __________cm	

EMG shave, emery, alcohol, Parallel to muscle fibres	Electrode #	Submax ref contractions 3 seconds x 3 repeats	Notes:
1. Erector Spinae L1 sp process on musc belly lat	No number	ES and Hamstrings: Knees bent 90 degrees lift both knees off plinth 5cm **	
2. Hamstrings BF RIGHT ischial tuberosity (gluteal crease) and knee crease halfway	2	ES and Hamstrings: Knees bent 90 degrees lift both knees off plinth 5cm **	Distance distal electrode to knee crease ______ cm
3. Quad RF RIGHT ASIS and sup border of patella	9	Ankle weight 2kg hold knee in extension with knee slightly bent	Distance of distal electrode to patella: _________cm
4. Tibialis Anterior Upper third ~ 15cm below inferior point of patella	16	Hold foot off ground and parallel to ground. Can hold desk for balance	

Fastrak, double sided tape, fixomull tape with hole cut out. For postural 'sensors' Check fastrack tail position (to door) ☐	Standing normalisation
1. C7 (C6 disappears with neck flexion) ☐ 2. T12 equal with lowest rib ☐ 3. L3 (*iliac crest – L4*) ☐ 4. S2 PSIS (*dimples*) ☐	Normal upright standing : Looking straight ahead at eye height. feet sh width apart ☐ Verbally instruct and demonstrate - Movement into full anterior pelvic tilt hold 5 seconds Move into full posterior pelvic tilt 5 seconds ☐
☐ Start HR monitor	

- stand in your usual manner as if you were standing for an extended period of time. You can not lean on the table surface with your upper extremities aside from *support for your wrists/forearms in conducting usual computer/clerical tasks*'. You may not lean against the desk.
- *We would like you to undertake standing for 2 hours if you can.*
- *We will be recording your discomfort as we go along. I would like you to tell me **if you were not participating a study** when you would choose to sit.*
- *We would like you to stand for 2 hours if possible and you are able to tolerate this. If however your discomfort reached intolerable levels please advise and we will stop before 2 hours.*

25/2/16

Start Time	____________ (2 mins data collection)		
0 start <u>timer</u> when comm tests 1.0	1. SART ☐ 2. VAS and RUFF ☐	1.0_____30 ☐ Typing/not 1.1_____ 25 ☐ Typing/not 1.2_____20☐ Typing/not 1.3 _____ 17 ☐ Typing/not 1.4_____14☐ Typing/not 1.5_____11☐ Typing/not 1.6 _____ 8 ☐ Typing/not 1.7 _____5☐ Typing/not _____ 2 mins☐ calf measurements	Notes:
30 mins	Reset timer 30 mins ☐ Measure Calf	Top ____________ Middle ____________ Bottom ____________ Top ____________ Middle ____________ Bottom ____________	
30	1. SART ☐ 2. VAS and RUFF ☐	2.0_____30 ☐ Typing/not 2.1_____ 25 ☐ Typing/not 2.2_____20☐ Typing/not 2.3 _____ 17 ☐ Typing/not 2.4_____14☐ Typing/not 2.5_____11☐ Typing/not 2.6 _____ 8 ☐ Typing/not 2.7 _____5☐ Typing/not _____ 2 mins☐ calf measurements	Notes:
60 mins	Reset timer 30 mins ☐ Measure Calf Tape	Top ____________ Middle ____________ Bottom ____________ Top ____________ Middle ____________ Bottom ____________	

Photos: Left foot up ☐ Right foot up ☐ Both feet down ☐

If discomfort goes above ***<u>4 on VAS prompt each 30 mins</u>*** – 'Remember to tell me if your discomfort reaches the point where if you were able to freely sit you would choose to do so and if your discomfort becomes intolerable'.

60	1. SART ☐ 2. VAS and RUFF ☐	3.0_____30 ☐ Typing/not 3.1_____ 25 ☐ Typing/not 3.2_____20☐ Typing/not	Notes:

25/2/16

		3.3 ____ 17 ☐ Typing/not 3.4_____14☐ Typing/not 3.5_____11☐ Typing/not 3.6 ____ 8 ☐ Typing/not 3.7 _____5☐ Typing/not ____ 2 mins☐ calf measurements	
90 mins	Reset timer 30 mins ☐ Measure Calf Tape	Top ___________ Middle __________Bottom _______________ Top ___________ Middle __________Bottom _______________	
90	1. SART ☐ 2. VAS and RUFF ☐	4.0_____30 ☐ Typing/not 4.1_____ 25 ☐ Typing/not 4.2_____20☐ Typing/not 4.3 ____ 17 ☐ Typing/not 4.4_____14☐ Typing/not 4.5_____11☐ Typing/not 4.6 ____ 8 ☐ Typing/not 4.7 _____5☐ Typing/not ____ 2 mins☐ calf measurements	Notes:
120	Reset timer 30 mins ☐ Measure Calf Tape	Top ___________ Middle __________Bottom _______________ Top ___________ Middle __________Bottom _______________	
120	1. SART ☐ 2. VAS and RUFF ☐	5.0_____30 ☐ Typing/not 5.1_____ 25 ☐ Typing/not 5.2_____20☐ Typing/not	Notes:

Time ceased standing: ______________ Complete cognitive tests in standing if participant is able/possible.

Exit Questionnaire ☐ Did discomfort reach > 7/10. If yes have participant remain until discomfort goes below 7/10. F/up with participant via phone 3 days post session.

HR information:

Time:____________________ Kcal:______________________

HR average:_____________________ HR max:______________________

25/2/16

Appendix I Study 2 Participant questionnaire

Exit Questionnaire : Standing or Standing with movement (please circle)

Participant Code:____________________

1. If offered by my employer I would use this positon at work:

strongly agree	agree	neutral	disagree	strongly disagree

2. During this work position, my work related productivity ...

decreased a lot	decreased	stayed the same	increased	increased a lot

3. The quality of my work while undertaking this work position ...

decreased a lot	decreased	stayed the same	increased	increased a lot

4. I could conduct clerical tasks while using this work position

strongly agree	agree	neutral	disagree	strongly disagree

5. If this work position was to be implemented in a workplace do you have any suggestions which would help to make this successful :

____

____

____

6. What would encourage you to continue to use this work position?

____

____

____

7. What did you like about this work position?

____

____

____

8. What did you dislike about this work position?

____

____

____

For end of second condition

9. Do you have a preference of standing or standing with movement

   a. YES Standing
   b. YES Standing with movement
   c. NO

If yes, why:____

____

____

Appendix J Study 2 Ethics approval

MEMORANDUM

Curtin University

To:	Leon Straker
	School of Physiotherapy and Exercise Science
CC:	Richelle Baker, Jeremy Lee
From	Dr Catherine Gangell, Manager Research Integrity
Subject	Ethics approval Approval number: RDHS-266-15
Date	24-Nov-15

Office of Research and Development
Human Research Ethics Office

TELEPHONE 9266 2784
FACSIMILE 9266 3793
EMAIL hrec@curtin.edu.au

Thank you for your application submitted to the Human Research Ethics Office for the project: 6507

The impact of standing work postures on musculoskeletal discomfort and cognitive performance

Your application has been approved through the low risk ethics approvals process at Curtin University.

Please note the following conditions of approval:

1. Approval is granted for a period of four years from **24-Nov-15** to **24-Nov-19**
2. Research must be conducted as stated in the approved protocol.
3. Any amendments to the approved protocol must be approved by the Ethics Office.
4. An annual progress report must be submitted to the Ethics Office annually, on the anniversary of approval.
5. All adverse events must be reported to the Ethics Office.
6. A completion report must be submitted to the Ethics Office on completion of the project.
7. Data must be stored in accordance with WAUSDA and Curtin University policy.
8. The Ethics Office may conduct a randomly identified audit of a proportion of research projects approved by the HREC.

Should you have any queries about the consideration of your project please contact the Ethics Support Officer for your faculty, or the Ethics Office at hrec@curtin.edu.au or on 9266 2784. All human research ethics forms and guidelines are available on the ethics website.

Yours sincerely,

Dr Catherine Gangell
Manager, Research Integrity

Appendix K Conference Abstract International Ergonomics Association (Melbourne, 2015)

Proceedings 19th Triennial Congress of the IEA, Melbourne 9-14 August 2015

Can light under-desk cycling enhance cognitive performance during prolonged sedentary work?

Richelle Baker[a], Darren Beales[a], Erin Howie[a], Pieter Coenen[a], Ann Williamson[b], Leon Straker[a]

[a] *School of Physiotherapy and Exercise Science, Curtin University, Perth, WA, AUSTRALIA*
[b] *School of Aviation, University of New South Wales, Sydney, NSW, AUSTRALIA*

1. Prolonged sedentary behaviour and negative health and performance consequences

It has been well established that there is substantial negative health risk from prolonged sedentary time, potentially even in individuals who otherwise meet health guidelines for moderate to vigorous activity[1]. Excessive occupational sitting[2] is a substantial component of a sedentary lifestyle for many which has been associated with increased risk of cardiovascular disease[3] and musculoskeletal discomfort[4], and may be related to reduced cognitive performance[5].

In the workplace, active workstations, such as sit/stand desks and treadmills, have been promoted as countermeasures to sedentary behaviour. However prolonged use of sit/stand workstations may not be sustainable due to musculoskeletal discomfort, in particular low back pain[6]. The use of treadmill workstations has had barriers to wide scale acceptance due to concerns with noise, safety and a larger workstation footprint. The potential negative performance impact of active workstations is also seen as a major barrier to implementation. Use of an under-desk cycle at a standard work station may allow easier implementation of a lower cost alternative, however little is known about the potential performance impact.

Light cycling activity promotes circulation and muscle activity through rhythmic contractions of the large muscles in the legs, and also potential for activation of trunk muscles for stabilising posture[7]. Light cycling may thus mitigate some of the health risks associated with prolonged sitting[8]. Cycling can increase cerebral blood flow[9] and may thus also be able to promote enhanced cognitive performance. However, active workstations require dual task performance, which can result in physical and/or cognitive performance decrement in one or both tasks. Cycling has been found to result in less performance decrement than walking during computer based work activities, with this being suggested to be related to lesser balance attentional requirements and greater torso stability[10].

Recent evidence indicates an indirect association between increasing sedentary time and reductions in cognitive performance[5] that might be alleviated by light physical activity. Past performance testing of cognition, whilst undertaking light activity, has included short term memory, attention reaction time[11] and transcription typing tests[12]. Assessments of *sustained* alertness and vigilance and higher order cognitive functions including problem solving, imperative in sedentary occupations such as radiographer, control room operator and air traffic controller, requires further research – as does the potential impact of light activity.

1.1 Study aim

Given the implications of sedentary behaviour on health and cognitive performance, this study aimed to compare the impact of performing a prolonged sedentary task with and without light activity (under-desk cycling) on cognitive performance.

2. Methods

2.1 Design and participants

The study was a within-subject experimental design laboratory study approved by Curtin University Human Research Ethics Committee. Participants completed two conditions; sustained sitting for 2 hours and sustained sitting with continuous light under-desk cycling for 2 hours. Condition order was randomised and balanced. Participants were adults recruited from the researchers' networks. Exclusion criteria included those for whom workstation set up was anthropometrically unsuited due to height or girth and who had known pain in response to activity (pre-existing condition). Participants required English and computer literacy. Participants brought their own computer based reading material/tasks to undertake throughout the two hour duration, except for completing the computerised assessments.

2.2 Dependent variables

Dependent variables included a subjective rating of mental alertness (visual analogue scale), vigilance (Sustained Attention to Response Test) and creative problem solving (Ruff Figural Fluency Test). Five serial measures were taken for each variable, at the start of the two hour period and every ~30 minutes.

3. Results

Preliminary analysis was conducted for the first 13 participants. Electromyography confirmed light activity was performed during the under-desk cycling condition compared with the non cycling condition (see example from one participant in Figure 1 a and b). End of condition group means (standard deviation) suggested no difference between non cycling and cycling for subjective alertness (non cycling 21 (8.6); cycling 20 (7.0)) and Ruff Figural Fluency unique designs (non cycling 37.5 (5.9); cycling 41.6 (11.1), however Sustained Attention to Response Test appeared better during cycling (non cycling 49.8 (25.5); cycling 63.0 (22.5) (see example from one participant in Figure 2 a and b).

a) b)

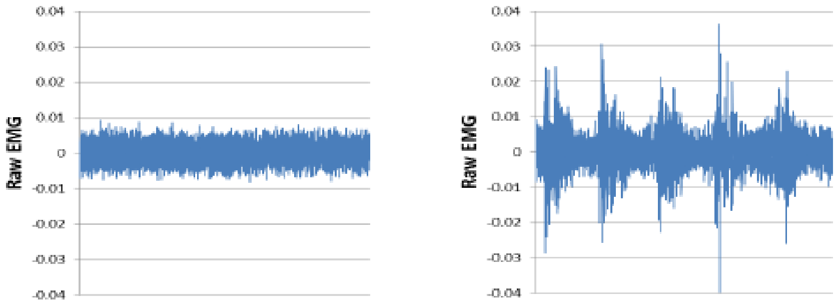


Figure 1. Raw quadriceps muscle electromyography over 4 seconds during not cycling (a) and cycling (b) for one participant

a) b)

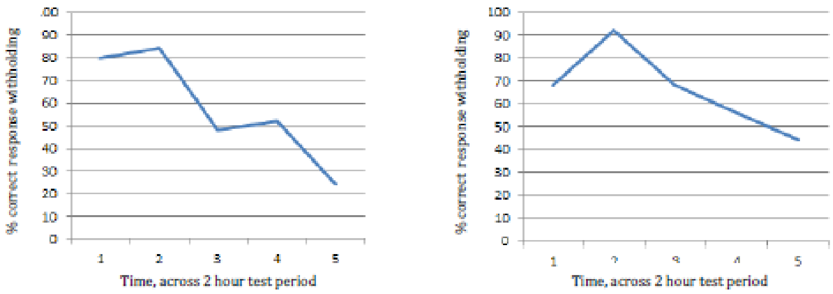


Figure 2. Sustained Attention to Response Test scores at 5 time points (1 at commencement, 2/3/4 during and 5 at end of 2 hour period) of non cycling (a) and cycling (b) for one participant showing less decrement for cycling condition.

4. Conclusion

Under-desk cycling provides light activity during prolonged sitting but appeared to have minimal impact on subjective alertness or objectively measured creative problem solving. Objectively measured sustained attention may have had less decrement over time and will be evaluated with further analysis of more participants.

Acknowledgements

We thank the School of Physiotherapy and Exercise Science, Curtin University for funding support and Paul Davey for technical support.

References

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Appendix L Conference Abstract International Ergonomics Association (Florence, 2018) – Discomfort

Don't just sit there: A comparison between discomfort in sitting to three alternate work positions (under-desk cycling, standing and standing-with-movement).

Richelle Baker[a], Pieter.Coenen[a, b], Erin Howie[a,c], Ann Williamson[d] and Leon Straker[a]*

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Abstract

Office workers have been shown to spend a large proportion (up to 82%) of their time sitting [1] and therefore are potentially at increased risk of all-cause mortality, cardiovascular disorders, diabetes although the impact on musculoskeletal disorders is unclear [2]. Work position alternatives to interrupt prolonged sitting have been trialled, with evidence of issues regarding feasibility [3], impact on productivity [4] and discomfort [5]. The current laboratory study aimed to compare discomfort across four work positions; sitting, sitting with under-desk cycling, standing and standing-with-movement (alternating footrest use by left and right foot while standing).

Participants (n=20 per condition) performed these four conditions while completing a visual analogue scale to measure musculoskeletal discomfort across nine body areas [6] every 30 mins over a 120 minute period.

Discomfort significantly increased over time for all conditions. For the low back, at 120 minutes, each of the conditions had clinically meaningful levels of discomfort (defined as >10/100 change in discomfort rating [7]). For the lower limb; standing, standing-with-movement and under-desk cycling all had clinically meaningful levels of discomfort across hip/thigh/buttock, knee and ankle/foot at 120 mins. None of the conditions had clinically meaningful levels of discomfort by 120 mins for any of the upper limb body areas.

At 120 minutes standing-with-movement had the greatest number of body areas (five) with clinically meaningful levels discomfort, compared to four, four and two body areas for the standing, under-desk cycling and sitting conditions respectively. Earliest onset of meaningful levels of discomfort was 60 mins for both standing and standing-with-movement conditions. This was evident in the following body areas: low back [standing group mean 21 (SD 19.3)] and standing-with-movement 17.6 (16.5)], hip/thigh/buttock [standing 15.3 (19.7), standing-with-movement 14.0 (16.0)], knee [(standing 19.5 (22.0), standing-with-movement 13.0 (15.3)] and ankle/foot [standing 23.1 (22.7), standing-with-movement 26.7 (15.9)]. For sitting the earliest onset reaching meaningful level of discomfort was hip/thigh/buttock at 90 minutes [11.5 (13.8)]. For under-desk cycling four body areas reached clinically meaningful levels at 120 minutes; low back [15.7 (15.6)], hip/thigh/buttock [18.6 (19.4)], knee [13.6 (19.6)] and ankle/foot [16.3 (18.2)]. The highest magnitude of discomfort was seen in the ankle/foot during standing-with-movement [36.6 (25.7)] followed by standing [33.1 (22.1)].

All four work positions resulted in clinically meaningful levels of discomfort by 120 minutes. The implications for workplaces are to encourage regular change between work positions, before 120 minutes and perhaps as early as 60 minutes, to help decrease musculoskeletal discomfort risk.

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Appendix M Conference Abstract International Ergonomics Association (Florence, 2018) – Cognitive functions

Where do we stand on sitting and cognitive function? Testing alternatives to sitting (cycling, standing and standing-with-movement).

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Abstract

Evidence of negative effects from sedentary behaviour is increasing with concerns about general health [1] and musculoskeletal discomfort [2], as well as cognitive function [3, 4]. As occupational sitting can be a considerable contributor to overall sedentary exposure [5] one of the ways to address this hazard is through alternative work positions. However, trials of these work positions have shown issues with feasibility [6] and impact on productivity [7]. This laboratory study aimed to compare cognitive function (creative problem solving and sustained attention) and mental state across four work positions; sitting, sitting with under-desk cycling, standing and standing-with-movement (participants used a footrest to alternately raise left and right foot while standing).

Participants completed assessments of creative problem solving (Ruff Figural Fluency Test, creating maximum number of unique designs without errors), sustained attention (Sustained Attention to Response Test, Go/No-go success and reaction time) and perceived mental state (five visual analogue scales combined to create one score) every 30 mins over a two hour period adopting one of the four conditions (n=20 per condition). Linear mixed models (with random intercepts for participants) was used to compare dependant variables between conditions using all five time points, with sitting as reference condition.

There were no differences between conditions for creative problem solving (unique designs or errors). Sustained attention no-go success (%) was lower in both standing conditions (standing β=-16.9, p=0.021, standing-with-movement β=-17.4, p=0.018). Sustained attention no-go success (%) was higher during cycling (β=-5.6, p=0.006), but reaction time was slower in (β=-30.13, p=<0.001). Condition had no effect on mental state.

It was postulated that the conditions with movement may impact cognitive function and mental state due to physiological responses including increased cerebral blood flow [8]. Whilst energy expenditure was not measured it was expected that under-desk cycling would have had the greatest [9], followed by standing-with-movement and standing with sitting having least. The cognitive function and mental state findings did not support any implication of better function in conditions with likely more energy expenditure. The lower no-go success in both standing conditions may have been due to the standing positions being less familiar and may have thus required more attentional resources. Under-desk cycling performance difference are likely to be due to a change in speed-error trade-off.

Based on cognitive performance and mental state data from this study there did not appear to be a benefit when using alternatives to a sitting work position (sitting with under-desk cycling, standing or standing-with-movement) compared to sitting. It is unclear if differences may appear during longer exposure, such as a full day in a workplace. Further research of cognitive performance is recommended before wide scale implementation of work position changes.

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Appendix N Sub-study (led by honours student)

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Use of a footrest to reduce low back discomfort development due to prolonged standing

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A B S T R A C T

Prolonged standing is common in many occupations and has been associated with low back discomfort (LBD). No recent studies have investigated a footrest as an intervention to reduce LBD associated with prolonged standing. This study investigated the effect of a footrest on LBD and sought to determine if LBD changes were accompanied by changes in muscle fatigue and low back end-range posture and movement. Twenty participants stood for two 2-h trials, one with and one without a footrest. LBD, lumbar erector spinae electromyography, upper lumbar (UL) and lower lumbar (LL) angles were measured. A significant increase in LBD occurred in both conditions but the footrest did not significantly decrease LBD. The only significant finding between conditions was that UL lordosis became more similar to usual standing over time with footrest use. These findings suggest that footrest use may not reduce LBD development and that development of LBD with prolonged standing is unlikely to be due to muscle fatigue or end-range posture mechanisms.

1. Introduction

Standing for prolonged periods of over 30 min to several hours is a common feature of many occupations (Kim et al., 1994). For example, a survey of 4500 Australian workers revealed that 62% were involved with tasks that required standing in one place for prolonged periods (Safe Work Australia, 2011). Similarly, a Canadian survey found that 58% of 9425 workers reported prolonged standing at work (Tissot et al., 2005). Furthermore, there has been a growing trend in office workplaces of changing from sitting workstations to standing desks due to the negative health consequences of sedentary postures (Straker et al., 2016).

However, epidemiological studies have found associations between prolonged standing and substantial adverse health related consequences (Waters and Dick, 2015; Andersen et al., 2007; Coenen et al., 2016) including chronic venous insufficiency, preterm complications, and musculoskeletal symptoms such as low back pain (LBP) (Waters and Dick, 2015; Andersen et al., 2007; McCulloch, 2002). For example, Andersen et al. (2007) found standing for more than 30 min at work to be a strong predictor for LBP development. LBP creates a major burden in many societies (Vos et al., 2015), therefore reducing the impact of occupational risk factors such as prolonged standing should be a priority.

Previous studies have found that 40–64% of individuals exposed to prolonged standing will develop LBP despite having no history of LBP (Nelson-Wong and Callaghan, 2010). Classifying individuals into pain developers and non-pain developers has enabled researchers to detect factors that may be associated with LBP (Nelson-Wong and Callaghan, 2010). Additionally, in order to examine the mechanisms underlying LBP development due to prolonged standing, low back discomfort (LBD) has commonly been assessed in laboratory studies (Waters and Dick, 2015). Based on these studies, several proposed theories have evolved to explain how prolonged standing may cause LBD. Three of the more prominent theories suggest that LBD arises due to muscle fatigue, sustained end-range posture, and/or a lack of postural movement (Tissot et al., 2009; Nelson-Wong et al., 2010; Rahim et al., 2010; Gregory and Callaghan, 2008).

Prolonged standing requires the back extensors to remain active over an extended period of time, potentially leading to muscle fatigue (Rahim et al., 2010). Fatigue may arise from the increased production and accumulation of metabolic wastes that occurs due to prolonged static contraction (Zander et al., 2004). This can result in the muscles becoming hypersensitive and prone to nociceptive activation, thus causing discomfort.

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Prolonged standing may also involve static end-range spinal posture such as excessive lordosis (lumbar extension) which could be another possible mechanism of LBD development (Gallagher et al., 2014). These postures can lead to increased loading of facet joints, stretch on tissues such as spinal facet joint capsules, and decreased intervertebral foramen space (Gallagher et al., 2014). This theory has received some tentative support from recent studies which together suggested that standing with less lordosis may reduce the development of LBD (Nelson-Wong and Callaghan, 2010; Gallagher et al., 2012).

The third possible mechanism is that a lack of postural movement causes LBD development. When an individual's posture is constrained during standing whereby movement is limited (Gallagher et al., 2014), passive connective tissue creep might occur due to the sustained force, causing tissue lengthening (Caruso and Pleva, 2006). These tissues are sensitive to changes in length and pressure (Cavanaugh, 1995). Over a prolonged period of time stress on these tissues may activate the nociceptive receptors causing LBD (Gregory and Callaghan, 2008). Recently Gallagher et al. (2012). suggested that moving between postures of lumbar flexion and extension during prolonged standing may be another mechanism which can reduce LBD development, lending support to this theory.

Many interventions such as floor mats and shoe insoles have been investigated to address LBD caused by prolonged standing (Nelson-Wong and Callaghan, 2010; Zander et al., 2004; Lin et al., 2012). Recently, Nelson-Wong and Callaghan (2010) found that standing on a sloped platform significantly reduced LBD development and attributed this reduction to decreased end-range lumbar lordosis and increased postural movement. A similar intervention that is able to change lumbar posture during standing is a footrest (Bridger, 2008). To date, few studies have investigated footrest usage as an intervention for prolonged standing (Rys and Konz, 1994; Whistance et al., 1995; Bridger and Orkin, 1992; Mohan et al., 2014). Two of these studies found that using a footrest increased posterior pelvic tilt and prevented end-range lumbar lordosis (Whistance et al., 1995; Bridger and Orkin, 1992). Mohan et al. (2014) also found that footrest usage increased postural sway. However, the studies by Mohan et al. (2014) and Whistance et al. (1995) did not measure prolonged standing, only measuring standing over a 30 s and 10 min duration respectively. Moreover, none of these studies used LBD as an outcome measure; a global comfort rating was utilised rather than specific regional discomfort (Rys and Konz, 1994; Whistance et al., 1995). Hence, the potential of using a footrest to reduce LBD in prolonged standing has not been comprehensively explored.

Given the common occupational exposure and substantial health consequences of prolonged standing, as well as the current gap in the literature regarding the effects of footrest usage, the primary aim of this study was to investigate whether utilising a footrest reduces LBD development during standing over a period of 2 h. Furthermore, given that the mechanisms for LBD development during prolonged standing are not well understood, the secondary aim of this study was to investigate these mechanisms by examining if LBD development is accompanied by changes in low back muscle fatigue, low back end-range posture and low back postural movement.

2. Materials and methods

2.1. Participants

A convenience sample of 20 adults was recruited through personal and professional networks. Participant age, anthropomorphic, and occupational data are presented in Table 1. Exclusion criteria consisted of self-reported ongoing musculoskeletal disorders (LBP, joint disorders), existing cardiovascular conditions, or a history of injury likely to influence LBD.

Table 1
Descriptive statistics of the study sample.

	Males (n = 7)	Females (n = 13)
Age (years)	26.1 ± 11.6	29.2 ± 9.4
Height (cm)	174.1 ± 7.7	164.0 ± 7.6
Weight (kg)	69.1 ± 7.2	64.5 ± 12.1
Occupation		
Sedentary	4	9
Standing	1	3
Physical Work	2	1

Insert about here Table 1. Descriptive statistics of the study sample.

This study was approved by the Human Research Ethics Review Committee, Curtin University (RHS-266-15).

2.2. Study design and procedure

This study used a within-subjects experimental design, assessing two independent variables: 1) standing both with and without a footrest ["Z rest Mk1" Ergolink, Perth, Australia] and 2) time, with repeated measures over a period of 2 h. In the condition with the footrest, participants followed a prescribed standing protocol, switching repeatedly between three postures: having the right foot raised on the footrest, having the left foot raised on the footrest, and having both feet down on the floor (i.e. standing normally) – each for 5 min. Participants were not allowed to lean on the desk and were instructed to use only their forearms and hands for support. For both trials, participants performed self-directed computer activities such as reading documents and internet browsing. The desk height was adjusted to 5 cm below the participant's standing elbow height and the top of the computer screen was adjusted to eye level. The alternate footrest condition 2-h trial was conducted one week after the first, using a randomised order of conditions with the trials occurring at the same time of day on each occasion.

2.3. Dependent variables

2.3.1. Low back discomfort

Low back discomfort was quantified using a computer-administered body map with a visual analogue scale (VAS) with the anchors "no discomfort" on the left and "extreme discomfort" on the right (Summers, 2001). Participants indicated their discomfort along the VAS by drawing a line with the mouse. The files were later printed and the distance between the left anchor and the participant's mark was measured using a ruler and normalised to a 100 mm full scale. LBD was measured 5 times at 0, 30, 60, 90, and 120 min.

Participants were considered 'discomfort developers' if they indicated that their LBD level increased by more than 10/100 with respect to their baseline level. This VAS value was chosen to match prior studies (Nelson-Wong and Callaghan, 2010; Nelson-Wong et al., 2010) and be in line with previous reports which have suggested a minimum clinically significant difference in VAS of 9 mm (Kelly, 1998).

2.3.2. Low back muscle fatigue

Muscle fatigue was quantified using the median frequency (MF) and amplitude of the right erector spinae muscle electromyography (EMG). These measures have demonstrated reliability and validity, in both our laboratory (Dankaerts et al., 2004) and previous studies (Kim et al., 1994; Rahim et al., 2010).

A Trigno® Wireless system (Delsys Inc, Boston, USA) was used to collect EMG data, sampling at a rate of 2000 Hz. After skin preparation a wireless electrode was placed over the right lumbar erector spinae, 3 cm laterally to the right of the L3 spinous process as per McGill (1991).

EMG were collected for 2 min at 32 different time-points (at 0, 5, 10, 13, 16, 18, 21, 24 min in each 30-min block between LBD measures). The 5 samples closest to the 5 LBD measures when participants were standing symmetrically with two feet on the ground were selected for analysis.

Prior to each 2-h trial, participants performed submaximal reference contractions to allow amplitude normalisation (Dankaerts et al., 2004). Participants were instructed to lie prone on a plinth with their knees bent to 90° (Dankaerts et al., 2004). They were then asked to lift their legs just off the plinth and hold for 3 s. In total, 3 reference contractions were recorded with a short rest between contractions and the average amplitude output across the 3 contractions was used for normalisation.

A customised LabView program (National Instruments, Austin, USA) was developed in which raw signals were de-meaned, rectified, and high-pass filtered at a 4 Hz cut-off frequency. MF and normalised mean amplitude were calculated and used for further statistical analyses.

2.3.3. Low back end-range posture and movement

Low back postural data was collected using a Fastrak (Polhemus, Colchestor, Vermont, USA) motion capturing system sampling at 25 Hz with markers placed on the T12, L3, and S2 spinous processes (Ng et al., 2013). The Fastrak system has been shown to be a reliable and valid measure in our laboratory (Ng et al., 2013), and previous studies have quantified spinal postures with a similar approach (Gallagher et al., 2012; Whistance et al., 1995; Bridger et al., 1989).

Postural data were collected at 32 time-points in 2 min samples simultaneously with EMG with 5 samples closest to the 5 discomfort measures selected for analysis.

Prior to each 2-h condition, reference posture measurements were taken in usual standing with the arms by the side and mean sagittal angles collected during the trials were then normalised as a deviation from normal standing.

A customized LabView program was used to calculate the low back end-range posture as the lower lumbar (LL) and upper lumbar (UL) sagittal mean angles (absolute angle as the angle between the two sensors and normalised angle as the difference between the absolute angle and the usual standing posture angle) and low back postural movement as the mean sagittal standard deviations for the LL and UL angles. Fig. 1 displays sensor placement and the UL and LL angles. An increase in lordosis angle was represented as a more negative number, with a smaller negative number and larger positive number indicating more kyphosis.

2.4. Statistical analyses

Multiple mixed models were conducted for each of the following dependent variables: LBD, muscle fatigue, low back end-range postures and low back postural movement. In each of these models, condition (the use or non-use of a footrest), time (five repeated measures across 2 h), and the interaction effect of condition and time (condition*time) were modelled as within-subject independent variables. In order to determine the type of mixed model used, data for each of the outcomes were checked for normality visually using histograms.

As the LBD data did not meet the normality assumptions for the model (showing an over-dispersed zero-inflated distribution) the data were analysed using a negative binomial model. For the other variables (ES median frequency, amplitude, LL and UL angles normalised to usual standing and standard deviations for LL and UL angles) linear mixed models were used, with log transformation when data were not normally distributed (this was done for ES median frequency, amplitude, and standard deviations for LL and UL angles). Incidence rate ratio (IRR; for the negative binomial mixed models) and betas (for the linear mixed models) with standard errors were estimated to describe the association of independent and dependent variables. Analyses were repeated for the subgroup of 'LBD developers' separately.

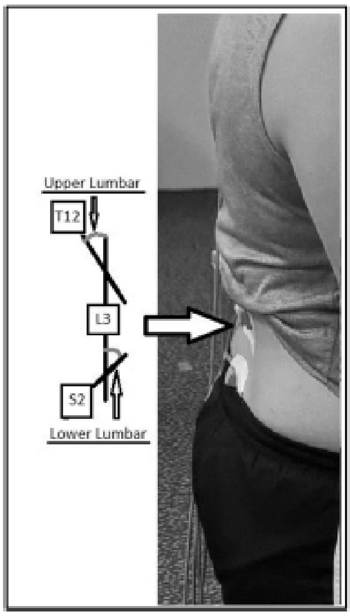

Fig. 1. Sensor placement and Upper Lumbar and Lower Lumbar sagittal angles.

Statistical analysis was performed using Stata (StataCorp. 2015. Stata Statistical Software: Release 14. College Station, TX: StataCorp LP) for Windows. P values of less than 0.05 were considered significant for the overall sample while more conservative p values of less than 0.01 were considered significant for the secondary analyses conducted on the subgroups to balance type 1 and type 2 errors.

18 participants completed both 2 h trials. One participant withdrew after ~90 min in the footrest condition and another participant withdrew after ~70 min in both conditions reporting that discomfort became intolerable. Available data of these participants were included in analysis.

3. Results

3.1. Low back discomfort

Baseline LBD ratings prior to prolonged standing exposures appeared similar at the start of both conditions (Fig. 2). For the overall sample there was a significant increase in LBD over time ($p < 0.001$) from 7.2 mm (±3.5 mm) at the start to 51.1 mm (±24.2 mm) without a footrest and from 5.9 mm (±2.8 mm) to 32.0 mm (±15.2 mm) with the footrest. Fig. 2 suggests a trend of a

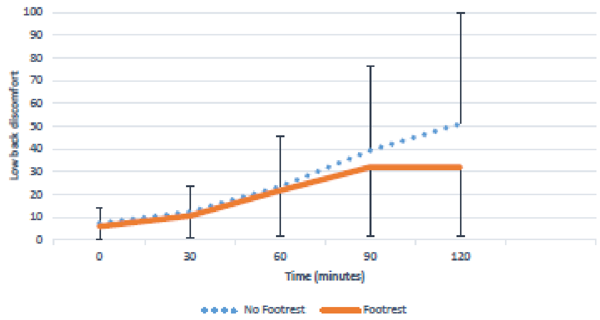

Fig. 2. Comparison of low back discomfort means and 95 percent confidence intervals over 120 min of prolonged standing without a footrest (dotted line) and with a footrest (solid line).

time * condition interaction, with discomfort appearing to increase more rapidly in the final 30 min in the no footrest condition compared with the footrest condition. However, neither the interaction effect ($p = 0.524$) nor the main effect of condition ($p = 0.987$) were statistically significant. Of the 20 participants, 14 developed LBD (increase greater than 10/100 mm) while 6 did not. Among LBD developers, there was the same pattern of results with a significant main effect of time ($p < 0.001$) with LBD increasing in both conditions after 2 h but there was no significant effect of condition ($p = 0.918$) nor was there a significant condition*time interaction ($p = 0.385$).

3.2. *Low back muscle fatigue*

Baseline MF measurements were similar for both conditions. In the condition without the footrest, the mean MF decreased from 52.1 Hz (±27.6 Hz) to 44.6 Hz (±6.2 Hz) and in the condition with the footrest the mean MF decreased from 49.6 Hz (±13.1 Hz) to 49.1 (±7.7 Hz). However, there was no significant main effect of condition ($p = 0.891$) or time ($p = 0.453$), nor was the interaction significant ($p = 0.585$) in the overall sample (Fig. 3). Amplitude results followed a similar pattern to MF, with no significant main or interaction effects. Results were similar in subgroup analysis for LBD developers, with no significant effects.

3.3. *Low back end-range and movement*

For UL end-range posture, there was a significant effect of condition, time, condition*time interaction in the overall sample and in LBD developers (Table 2). UL angle changed from −19° to −17° (i.e. slightly less lordotic) over time in the no footrest condition compared with a change from −18° to −20° (i.e. slightly more lordotic) in the footrest condition. In terms of a change in posture relative to usual standing posture, UL lordosis increased overtime bringing their posture approximately 1.6° (overall sample; 3.1° in LBD developers) back towards their usual standing posture, whilst UL posture moved away from usual standing posture without a footrest. There were no significant findings for LL end-range in the overall sample or in the LBD developer group.

In the overall sample and LBD developer group, there were no significant changes for both UL and LL postural movement.

4. Discussion

The primary aim of this study was to determine if using a footrest reduced LBD development over a 2-h period of standing. As

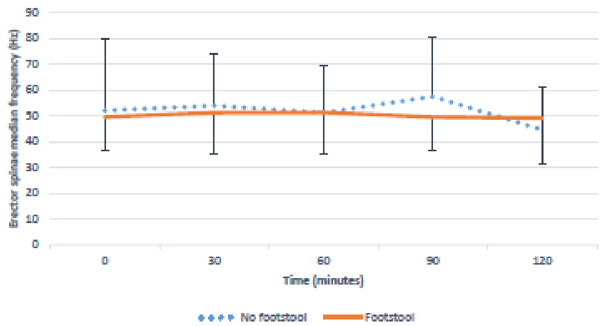

Fig. 3. Comparison of erector spinae median frequency means and 95 percent confidence intervals over 120 min of prolonged standing without a footrest (dotted line) and with a footrest (solid line).

Table 2
Means (95% confidence intervals) for upper lumbar (UL) end range normalised to usual standing and UL and lower lumbar (LL) absolute angles (angle between the two sensors) in the two footrest conditions and across the five measurement time points. Effects of condition, time and interaction of condition and time (expressed in beta, with standard error) are also shown.

	Time (Minutes)					Time Effect	Condition Effect	Time-Condition Interaction
	0	30	60	90	120			
Low back end-range UL (°) (usual standing) Overall sample								
No Footrest	−1.2 (−3.7–1.2)	−2.4 (−4.8 to −0.0)	−3.4 (−5.8 to −1.0)	−4.0 (−6.4 to −1.5)	−3.5 (−6.00 to −1.0)	p = 0.041	p = 0.016	p = 0.022
Footrest	−3.6 (−6.1–1.1)	−3.8 (−6.2 to −1.4)	−3.8 (−6.2 to −1.5)	−3.4 (−5.9 to −1.0)	−2.0 (−4.50–0.60)	β = −2.04 (0.30)	β = −2.40 (1.39)	β = 2.29 (0.42)
Low back end-range UL (°) (usual standing) Discomfort developers								
No Footrest	−0.5 (−3.6–2.7)	−1.8 (−4.8–1.3)	−3.1 (−6.1 to −0.1)	−3.8 (−6.9 to −0.7)	−3.8 (−7.0 to −0.6)	p = 0.008	p = 0.001	(p = 0.001)
Footrest	−3.9 (−7.0 to −0.7)	−3.6 (−6.6 to −0.6)	−3.4 (−6.4 to −0.4)	−2.5 (−5.6–0.6)	−0.9 (−4.2–2.3)	β = −2.65 (0.33)	β = −3.19 (1.56)	β = 3.28 (0.48)
Low back end-range UL (°) (absolute angle) Overall sample								
No Footrest	−19.4 (−23.5 to −15.3)	−18.3 (−22.3 to −14.3)	−17.3 (−21.2 to −13.3)	−17.0 (−21.0 to −13.0)	−17.5 (−21.6 to −13.4)	p = 0.174	p = 0.171	p = 0.060
Footrest	−18.0 (−22.1 to −13.9)	−17.9 (−21.9 to −13.9)	−17.9 (−21.8 to −14.0)	−18.7 (−22.7 to −14.6)	−20.1 (−24.3 to −16.0)	β = 1.36 (0.38)	β = 1.37 (1.78)	β = −1.88 (0.54)
Low back end-range UL (°) (absolute angle) Discomfort developers								
No Footrest	−20.8 (−27.2 to −15.3)	−19.6 (−24.9 to −14.2)	−18.2 (−23.5 to −12.9)	−18.0- (−23.4 to −12.6)	−17.9 (−23.5 to −12.4)	p = 0.121	p = 0.031	p = 0.018
Footrest	−17.6 (−23.1 to −12.1)	−18.0 (−23.4 to −12.7)	−18.3 (−23.6 to −13.0)	−19.7 (−25.1 to −14.2)	−21.2 (−26.8 to −15.6)	β = 1.55 (0.47)	β = 2.15 (2.23)	β = −2.37 (0.68)
Low back end-range LL (°) (absolute angle) Overall sample								
No Footrest	−9.2 (−13.2 to −5.3)	−9.1 (−13.0 to −5.3)	−9.0 (−12.9 to −5.2)	−8.7 (−12.5 to −4.8)	−9.5 (−13.5 to −5.5)	p = 0.997	p = 0.126	p = 0.979
Footrest	−11.9 (−15.9 to −7.9)	−11.7 (−15.6 to −7.9)	−11.6 (−15.4 to −7.8)	−11.2 (−15.1 to −7.3)	−12.1 (−16.1 to −8.1)	β = −0.00 (−0.36)	β = −1.53 (1.71)	β = 0.03 (0.52)
Low back end-range LL (°) (absolute angle) Discomfort developers								
No Footrest	−9.1 (−14.0 to −4.2)	−8.8 (−13.6 to −4.1)	−9.1 (−13.9 to −4.4)	−8.8 (−13.6 to −3.9)	−9.4 (−14.3 to −4.4)	p = 0.915	p = 0.062	p = 0.795
Footrest	−13.2 (−18.1 to −8.3)	−13.1 (−17.8 to −8.3)	−13.5 (−18.3 to −8.8)	−13.3 (−18.2 to −8.5)	−14.1 (−19.1 to −9.1)	β = −0.11 (0.44)	β = −1.87 (2.09)	β = −0.26 (0.64)

expected, there was a significant increase in LBD over the course of standing in both conditions, with the largest increase being in the LBD developer group. Unexpectedly however, in the overall sample and even among LBD developers there was no significant condition*time interaction.

Previous studies have had mixed findings regarding the effect of a footrest on subjective measures with one study finding no benefit of footrest usage on general body comfort (Whistance et al., 1995) while another study reported increased general body comfort levels (Rys and Konz, 1994). However, these prior studies had several method limitations that this study sought to address. Firstly, these previous studies measured general body comfort instead of localised LBD (Rys and Konz, 1994; Whistance et al., 1995). Secondly, the study by Rys and Konz (1994) had only 9 participants, of whom all were males. Lastly, Whistance et al. (1995) observed participants in a barefoot foot rail condition for only 10 min and Mohan et al. (2014) only examined participants for 30 s of standing.

Having addressed these issues, the findings in this study do not provide evidence to support the usage of a footrest to reduce LBD. However, LBD reported with and without a footrest appeared to be diverging at 2 h, suggesting differences may have become apparent with longer exposure. The current study also used a prescribed footrest protocol. The footrest may have been more effective in reducing LBD development if participants could use the footrest at their own choosing or using a different protocol. Indeed Rys and Konz (1994) found a significant increase in general body comfort with a different protocol of placing one foot forward for 1 min every 7 min.

The finding that LBD increased significantly over the 2 h in 14 LBD developing participants agrees with prior studies on standing (Nelson-Wong and Callaghan, 2010; Gregory and Callaghan, 2008) and highlights the impact of prolonged standing on LBD as these individuals had no history of LBP or injury. This also corresponds with previous epidemiological studies which found that occupations involving standing for durations of 4 h or longer on a daily basis (Tissot et al., 2009) lead to LBP development. This evidence reinforces the importance of developing effective strategies to reduce prolonged occupational standing.

The secondary aim of this study was to determine if LBD development was accompanied by changes in muscle fatigue, low back end-range posture, and low back postural movement to investigate three of the proposed theories for LBD development during prolonged standing. There were no statistically significant changes for both MF and amplitude of the right lumbar erector spinae EMG. Findings regarding erector spinae MF and amplitude from studies on standing are generally conflicting as some authors report noticeable muscle fatigue development (Kim et al., 1994) during prolonged standing while other authors suggest that EMG may not be sensitive to lumbar muscle fatigue that develops from standing (Rys and Konz, 1994). It is possible that either lumbar erector spinae muscle fatigue caused by prolonged standing cannot be detected by surface EMG or that low back muscle fatigue is not caused by prolonged standing and therefore is not a major contributor to LBD development. It is also probable that use of a footrest changes contralateral lumbar erector spinae activity, and that alternating left and right foot on a footrest and the ground (as done in the current study) will provide variation in erector spinae activity. However the lack of benefit to either muscle fatigue measures or low back discomfort suggest this variety is not sufficient to impact these outcomes.

In the footrest condition, UL lordosis increased slightly overtime to bring UL posture closer to usual standing posture, whilst UL lordosis decreased slightly over time without a footrest to take UL posture away from usual standing posture. Previous studies have reported a reduction in lumbar lordosis during use of a footrest

(Bridger, 2008). In the current study posture was assessed in the footrest protocol periods when both feet were on the ground, to provide evidence on changes to what participants used as their normal standing posture. The findings suggest that the periodic move into less lordosis (when a foot is on the footrest) may help reduce or prevent a creep in posture away from usual standing posture that was observed in the no footrest condition. This helped the posture to remain in a more neutral range. However, the observed changes were small in magnitude and change in UL lordosis towards usual standing posture was not accompanied by a significant reduction in LBD during the footrest condition. Authors of previous studies found that sloped surfaces were effective in reducing LBD development during prolonged standing and that it induced postural changes of a similar magnitude to that of footrest usage in this study (Nelson-Wong and Callaghan, 2010; Gallagher et al., 2012). They suggested that the effectiveness of the sloped surfaces in reducing LBD development was either due to these postural changes or the increased postural movement allowed by the sloped surface. However, the results from the current study indicate that inducing postural changes of this magnitude may be too small to significantly reduce LBD development.

The findings of the current study on UL and LL postural movement lend some support to the theory that postural movement may be important. The fact that the footrest did not increase postural movement may explain why it did not significantly reduce LBD development in the current study, as other authors posited that the effectiveness of the sloped surfaces in reducing LBD development was due to it allowing more postural movement (Nelson-Wong and Callaghan, 2010).

The current laboratory study had a number of limitations, including the limited duration and the footrest use protocol mentioned above, the limited number of older workers, lack of separate gender analysis, and that the tasks performed were computer-based and not similar to that of most prolonged standing occupations such as light industry tasks (Rahim et al., 2010). However, with the growing trend of replacing sitting with standing in office workplaces (Dennerlein et al., 2015) the results of this study point towards the potential issues that such a trend may create.

We believe this study makes an important contribution to knowledge and practice in this area by clearly articulating the previously proposed mechanisms for low back discomfort during prolonged standing and how the use of a footrest may mitigate this discomfort through these mechanisms. The study also provides the first detailed evidence on the impact of footrest use during prolonged standing and low back discomfort, low back muscle fatigue and regional (upper vs lower) lumbar posture. Additionally, the study contributes evidence on the association of changes in low back discomfort and changes in low back muscle fatigue, end-range posture and postural movement during footrest use to enhance understanding of potential mechanisms.

5. Conclusion

This study found a significant increase in LBD over 2 h of standing in 14 out of 20 participants, highlighting standing as a potentially important occupational risk factor for low back pain. However, using a footrest whilst standing did not significantly reduce LBD. Therefore, this study does not provide evidence to support the use of a footrest as an intervention for LBD development during prolonged standing. Additionally, the lack of change in muscle fatigue over time and the change in upper lumbar lordosis with footrest use were not in line with observed patterns of LBD development. However, the lack of change of postural movement with the footrest along with the lack of reduction of LBD development points toward a possible link between postural movement and LBD development. Future research should seek to explore potential mechanisms causing LBD from prolonged standing so that appropriate interventions can be developed to prevent or reduce low back pain in workers required to stand for prolonged periods.

Conflicts of interest

The authors have no conflicts of interest to declare.

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Appendix O Contribution

For papers of joint authorship the author attests to having completed the following aspects for each paper. I, Richelle Baker contributed to conceptualisation, methodology, data validation and analysis and, writing original draft and subsequent editing for the papers entitled:

- Baker, R., Coenen, P., Howie, E., Williamson, A., & Straker, L. (2018). The short term musculoskeletal and cognitive effects of prolonged sitting during office computer work. *International Journal of Environmental Research and Public Health*, 15(8), 1678.
- Baker, R., Coenen, P., Howie, E., Williamson, A., & Straker, L. (2019). The musculoskeletal and cognitive effects of under-desk cycling compared to sitting for office workers. *Applied Ergonomics*, 79, 76-85.
- Baker, R., Coenen, P., Howie, E., Lee, J., Williamson, A., & Straker, L. (2018). A detailed description of the short-term musculoskeletal and cognitive effects of prolonged standing for office computer work. *Ergonomics*, 61(7), 877-890.
- Baker, R., Coenen, P., Howie, E., Lee, J., Williamson, A., & Straker, L. (2018). Musculoskeletal and cognitive effects of a movement intervention during prolonged standing for office work. *Human Factors*, 60 (7), 947-961.

For the following article my contribution was assistance with conceptualisation, methodology, data validation and editing the paper:

- Lee, J.Y., Baker, R., Coenen, P. & Straker, L., 2018. Use of a footrest to reduce low back discomfort development due to prolonged standing. *Applied Ergonomics*, 67, 218-224

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Leon Straker		17/2/19

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- Baker, R., Coenen, P., Howie, E., Williamson, A., & Straker, L. (2018). The short term musculoskeletal and cognitive effects of prolonged sitting during office computer work. *International Journal of Environmental Research and Public Health*, 15(8), 1678.

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