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Title page

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

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Conflicts of interest

The authors have no conflicts of interest to declare.

Practitioner Summary

Standing is being used to replace sitting by office workers however there are health risks associated with prolonged standing. In a laboratory study involving 2 hours prolonged standing discomfort increased (all body areas), reaction time and mental state deteriorated while creative problem-solving improved. Prolonged standing should be undertaken with caution.

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

Abstract

Due to concerns about excessive sedentary exposure for office workers, alternate work positions such as standing are being trialled. However, prolonged standing may have health and productivity impacts, which this study assessed. Twenty adult participants undertook two hours of laboratory-based standing computer work to investigate changes in discomfort and cognitive function, along with muscle fatigue, movement, lower limb swelling and mental state. Over time, discomfort increased in all body areas (total body IRR[95% confidence interval]: 1.47[1.36-1.59]). Sustained attention reaction time (β=18.25[8.00–28.51]) deteriorated, while creative problem solving improved (β=0.89[0.29-1.49]). There was no change in erector spinae, rectus femoris, biceps femoris or tibialis anterior muscle fatigue; low back angle changed towards more lordosis, pelvis movement increased, lower limb swelling increased and mental state decreased. Body discomfort was positively correlated with mental state. The observed changes suggest replacing office work sitting with standing should be done with caution.

Key words

Human-computer interaction, musculoskeletal disorders, biomechanics, mental work capacity, office ergonomics

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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.* 2016) 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.* (2016) 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 function, 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.

Method

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.

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.

Dependent variables

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.

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.

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.* 2006a); 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.* 2006b, 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.

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.* 2006a).

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.

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.

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).

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.

Discomfort

Discomfort significantly increased over the 2 hours for all body areas (see Table 1). Figure 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, $p<0.001$).

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 2 and Figure 2). Pairwise comparisons showed that group sustained attention reaction times, compared to baseline, were also statistically significant from 60 minutes ($\beta=54.50$, $p=0.018$; 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).

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 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 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).

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 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). Total body discomfort was moderately positively correlated with perceived mental state rating (rho=0.670; p= 0.001; see Table 6), however had no significant correlation with creative problem solving (number of designs or errors), or sustained attention (accuracy or reaction time).

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.

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.

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.

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.

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.

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Figure 4. Mean (standard deviation) scores of sustained attention, No-go success and reaction time, over 2 hours of prolonged standing.

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

Confidence Interval is 95% confidence interval

*statistically significant pairwise comparisons of clinically meaningful increases from baseline

Table 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

Table 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)					Beta	Confidence Interval	p value
	0	30	60	90	120			
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	36.6*	36.6*	36.8*	36.8*	0.10	0.01 – 0.13	<0.001

	(2.9)	(2.8)	(2.8)	(2.7)	(2.8)			
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)								
perceived 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

Table 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 standing

	Low back discomfort	Usual stand (SD sagittal)	Usual stand (mean sagittal)	Pelvis movement	Erector Spinae (A)	Erector Spinae (MF)
Low back discomfort, r	1.000					
Usual stand (SD sagittal), r (p value)	-0.193 (0.429)	1.000				
Usual stand (mean sagittal), r (p value)	-0.156 (0.524)	0.679 (0.001)	1.000			
Pelvis movement, r (p value)	0.244 (0.330)	-0.129 (0.609)	-0.206 (0.413)	1.000		
Erector spinae (A), r (p value)	-0.213 (0.382)	0.351 (0.141)	0.118 (0.629)	-0.177 (0.483)	1.000	
Erector spinae (MF), r (p value)	-0.111 (0.651)	-0.042 (0.864)	0.144 (0.557)	-0.050 (0.844)	-0.088 (0.720)	1.000

Table 5: Change score correlations (r) between lower limb discomfort, calf swelling, muscle fatigue [amplitude (A) and median frequency (MF)] and pelvis movement over 2 hours prolonged standing

	Lower limb discomfort	Lower limb swelling	Rectus femoris (A)	Biceps femoris (A)	Tibialis Anterior (A)	Rectus femoris (MF)	Biceps femoris (MF)	Tibialis Anterior (MF)	Pelvis movement
Lower limb discomfort , r	1.000								
Lower limb swelling, r	0.336	1.000							

(p value)	(0.148)								
Rectus femoris (A), r	0.332	0.422	1.000						
(p value)	(0.194)	(0.092)							
Biceps femoris (A), r	0.323	0.354	0.061	1.000					
(p value)	(0.192)	(0.150)	(0.817)						
Tibialis Anterior (A), r	0.367	0.368	0.494	0.449	1.000				
(p value)	(0.162)	(0.161)	(0.073)	(0.094)					
Rectus femoris (MF), r	-0.311	-0.186	-0.577	-0.224	-0.080	1.000			
(p value)	(0.224)	(0.474)	(0.015)	(0.387)	(0.786)				
Biceps femoris (MF), r	0.440	0.118	0.008	0.011	0.409	0.059	1.000		
(p value)	(0.068)	(0.640)	(0.976)	(0.966)	(0.130)	(0.821)			
Tibialis Anterior (MF),r	-0.073	-0.101	-0.391	-0.034	-0.566	0.520	-0.212	1.000	
(p value)	(0.787)	(0.710)	(0.167)	(0.906)	(0.057)	(0.448)	(0.068)		
Pelvis movement, r	0.212	0.227	0.253	0.358	0.488	-0.069	-0.101	-0.012	1.000
(p value)	(0.398)	(0.365)	(0.344)	(0.158)	(0.065)	(0.801)	(0.701)	(0.966)	

Table 6: Change score correlations (rho) between body discomfort, creative problem solving, sustained attention and mental state over 2 hours prolonged standing

	Body discomfort	**Creative problem solving**		**Sustain attention**		**Mental state**
		Unique designs	**Errors**	**No-go success**	**Reaction time**	
Body discomfort, rho	1.000					
Unique designs, rho	-0.403	1.000				
(p value)	(0.087)					
Errors, rho	0.329	-0.641	1.000			
(p value)	(0.169)	(0.003)				
No-go success, rho	-0.370	0.020	-0.402	1.000		
(p value)	(0.118)	(0.936)	(0.088)			
Reaction time, rho	-0.174	0.038	-0.306	0.557	1.000	
(p value)	(0.477)	(0.876)	(0.204)	(0.013)		
Mental state, rho	0.670	0.045	0.113	-0.425	-0.133	1.000
(p value)	(0.001)	(0.855)	(0.646)	(0.070)	(0.586)	

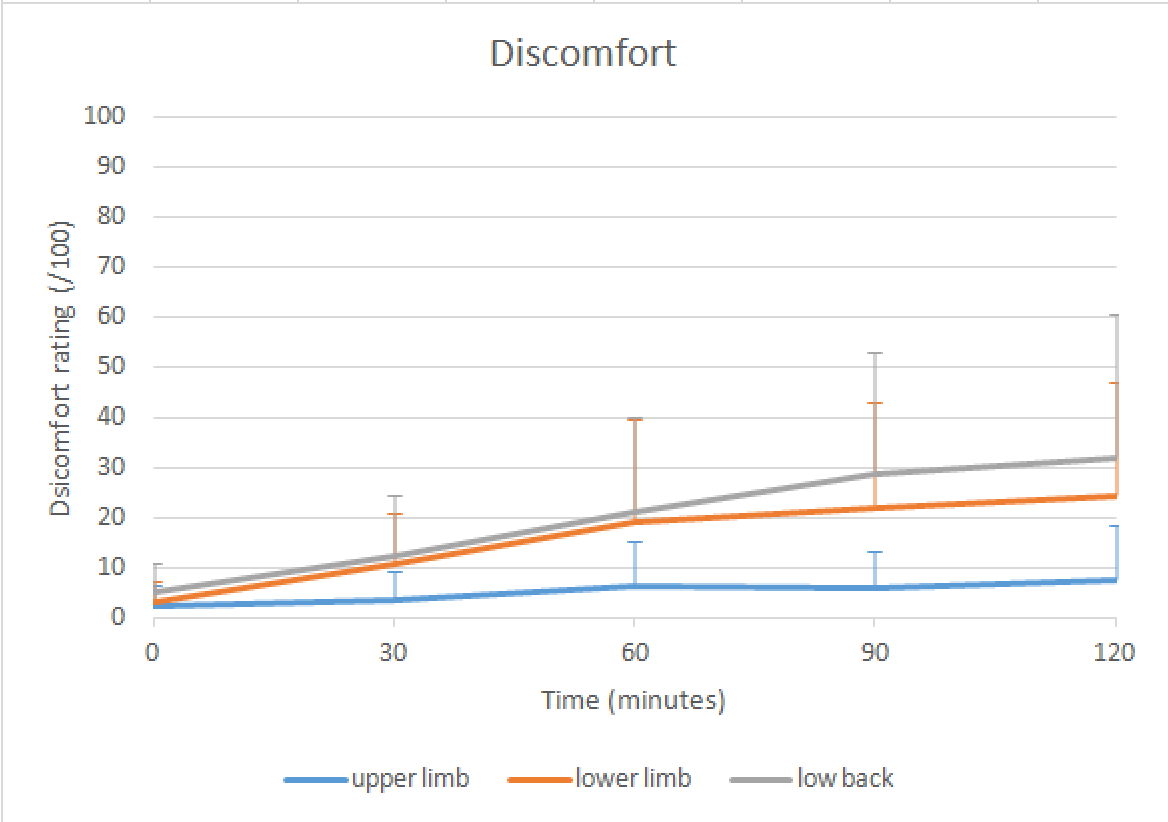
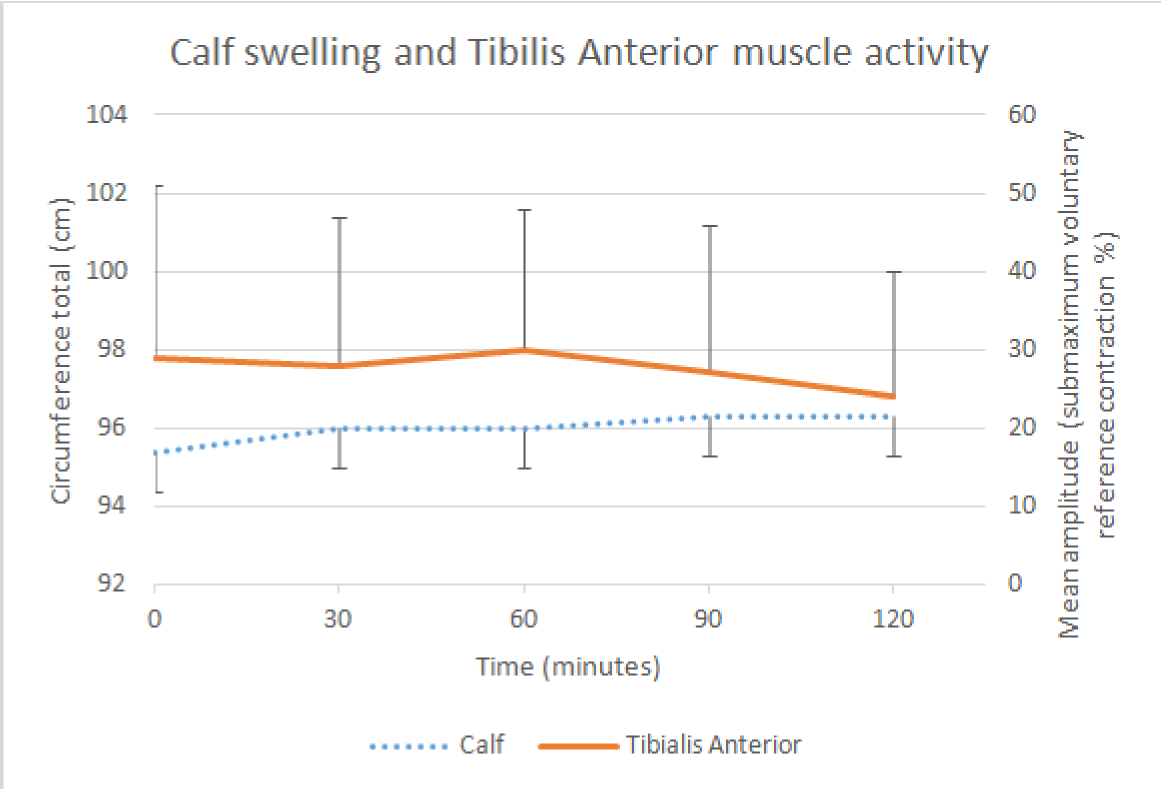

Discomfort
100
90
80
70
60
50
40
30
20
10
0
Dsicomfort rating (/100)
0
30
60
90
120
Time (minutes)
upper limb
lower limb
low back

Figure 1



Calf swelling and Tibilis Anterior muscle activity
104
102
100
98
96
94
92
Circumference total (cm)
60
50
40
30
20
10
0
Mean amplitude (submaximum voluntary reference contraction %)
0
30
60
90
120
Time (minutes)
Calf
Tibialis Anterior

Figure 2

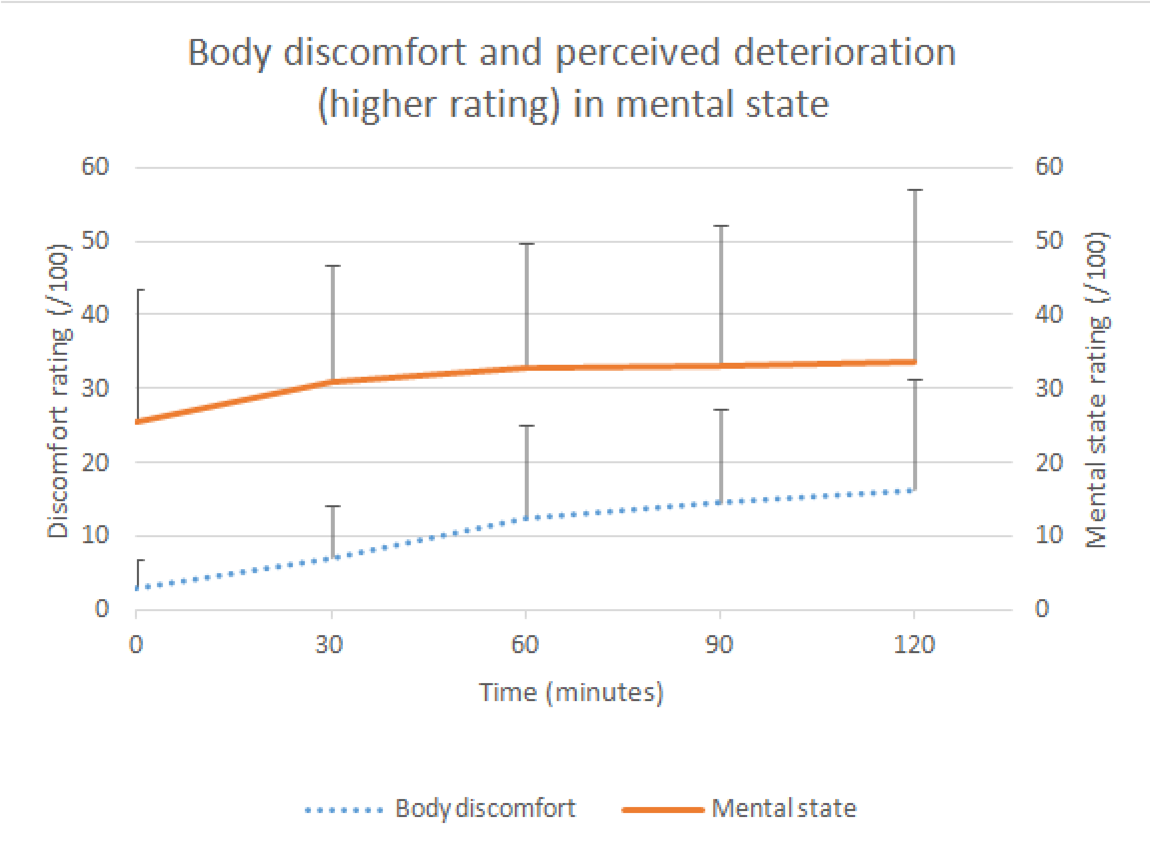

Body discomfort and perceived deterioration (higher rating) in mental state
Discomfort rating (/100)
Mental state rating (/100)
60
50
40
30
20
10
0
0
30
60
90
120
Time (minutes)
Body discomfort
Mental state

Figure 3

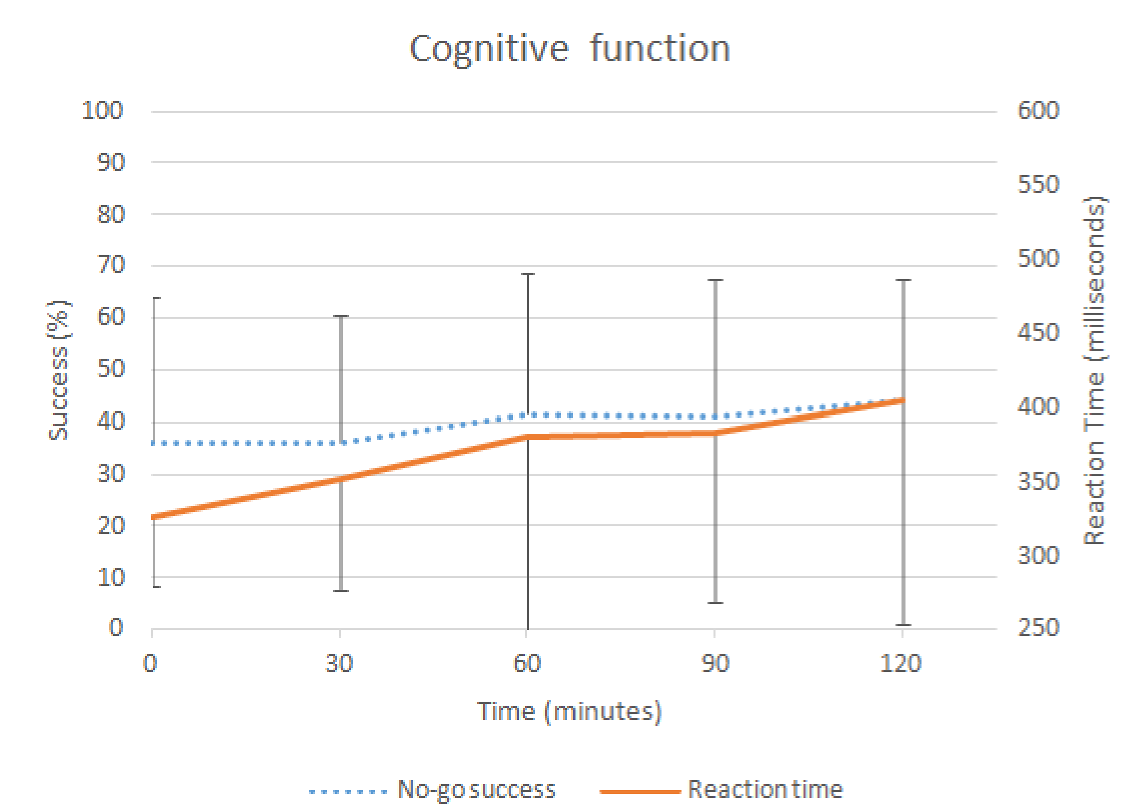

Cognitive function
100
90
80
70
60
50
40
30
20
10
0
Success (%)
600
550
500
450
400
350
300
250
Reaction Time (milliseconds)
0
30
60
90
120
Time (minutes)
No-go success
Reaction time

Figure 4