Does proactive cyclic usage of a footrest prevent the development of standing induced low back pain?

Kayla M. Fewster[a], Maureen F. Riddell[a], Kaitlin M. Gallagher[b], Jack P. Callaghan[a],[*]

[a] Department of Kinesiology, University of Waterloo, Waterloo, Ontario, Canada
[b] Health, Human Performance and Recreation, University of Arkansas, Fayetteville, AR, USA

ABSTRACT

Various interventions, such as standing intermittently with one leg on a footrest, have been suggested to prevent low back pain (LBP) development during prolonged standing. To assess this standing intervention twelve participants stood for 80 min while cycling through three minute periods of level-ground standing divided by one minute periods with either the right or left leg elevated onto a platform. All participants had previously participated in a prolonged level standing protocol and were classified as pain (PD) or non-pain developers (NPD). Out of the six known PDs, only one PD developed LBP by the end of the standing intervention. The intervals of elevated leg standing resulted in increased lumbar spine flexion in comparison to level standing. In addition, over time there was an increase in lumbar spine flexion during the level standing intervals. This change in lumbar spine posture in standing pain developers likely contributed to the reduced LBP development during this prolonged standing intervention

1. Introduction

Prolonged sitting has been highlighted as having a number of negative health outcomes. As a result, a shift in workplace design has occurred towards standing. However, prolonged standing has been shown to elicit low back pain (LBP) in 40–70% of asymptomatic population samples (Marshall, Patel, & Callaghan 2011; Nelson-Wong, Gregory, Winter, & Callaghan, 2008; Nelson-Wong & Callaghan, 2010b; Howarth, Gallagher, & Callaghan, 2013; Gallagher, Campbell, & Callaghan, 2014). In jobs that require standing for prolonged periods of time, numerous standing interventions have been suggested to help individuals tolerate prolonged periods of static standing. (Dolan, Adams, & Hutton, 1988; Gallagher and Callaghan 2016b; Nelson-Wong & Callaghan, 2010c; Gallagher, 2014; Fewster, Gallagher, & Callaghan, 2017). One such intervention includes standing with one foot on an elevated surface or footrest (Dolan et al., 1988). However, to date, limited evidence exists if standing with an elevated leg on a footrest is effective at reducing or eliminating LBP development during prolonged standing. Thus, the purpose of this study was to investigate if the cyclic movement of raising one leg on to an elevated platform in a 3:1 ratio, could decrease or delay the onset of prolonged standing induced LBP.

Prolonged standing has been linked to a number of negative health outcomes such as carotid atherosclerosis and venous pooling (Krause, Lynch, Kaplan, Cohen, Salonen, & Salonen, 2000; Smith, Ma, Glazier, Gilbert-Ouimet, & Mustard, 2017), as well as LBP (Nelson-Wong & Callaghan, 2010b; Howarth et al., 2013; Gallagher et al., 2014; Marshall et al., 2011; Nelson-Wong et al., 2008). Low back pain developed during a prolonged bout of standing manifests 30–45 min into prolonged standing and continues to rise throughout a 2 h period (Marshall et al., 2011). For jobs that already require prolonged standing, numerous standing aids or standing

interventions have been suggested to prevent LBP development. Carson (1995) previously recommended footrest heights between 10.0 cm and 12.7 cm above the floor, however there is no evidence in the literature that reports what footrest heights are successful at mitigating LBP development. In addition, there has been no "gold standard" ratio to govern the proportion of time spent with one foot elevated on the footrest versus flat level standing. Recent work by Lee, Baker, Coenen, and Straker (2018), implemented a 1:1 ratio of five-minutes level standing to five-minutes with each leg elevated on a footrest. This investigation found that the prescribed 1:1 footrest intervention was unsuccessful in mitigating LBP development in PDs throughout prolonged standing (Lee et al., 2018). Recommendations of a ratio of 3:1 have persisted as a recommendation to address a sitting and standing ratio when using height adjustable workstations (Paul & Helander, 1995; Paul, 1995a,b). However, whether this ratio will be transferable to an elevated leg standing intervention is unknown. Given the success of the 3:1 ratio previously in sit-stand work (Paul & Helander, 1995; Paul, 1995a,b), it was determined to be a good starting point in evaluating standing aid interventions.

Individuals who develop LBP during prolonged standing (Pain Developers (PDs)) have been shown to stand with greater lumbar lordosis (extension) than those who do not develop LBP (Non-Pain Developers (NPDs)), during prolonged standing (Sorensen, Norton, Callaghan, Hwang, & Van Dillen, 2015). A radiographic study imaging the lumbar spine found that PDs stood closer to the maximum extension angle of their lower lumbar arc (L3-S1) than NPDs (Gallagher, Sehl, & Callaghan, 2016). Movement of PDs during standing has also been shown to have fewer lumbar spine fidgets than their non-pain developing counterparts (Gallagher and Callaghan, 2016a). Static standing postures, in the absence fidgets, are hypothesized to be a potential pre-disposing factor of pain development. These kinematics responses exist in PDs at the start of a standing task prior to pain development. Based on these postural characteristics of PDs, inducing flexion in the lumbar spine and early movement may provide a means to mitigate the onset of LBP and mimic NPD kinematic profiles. Movement of the pelvis changes the posture of the lumbar spine and engaging in maximal posterior pelvic tilt can alter the lumbar spine angle by as much as nine degrees (Levine & Whittle, 1996). Previous work has demonstrated, in short term exposures, placing one foot on an elevated surface changes lumbar spine posture in comparison to flat standing, such that participants stood in a more flexed lumbar spine posture (Fewster et al., 2017). Thus, combining an elevated surface with early movement may be a successful intervention to prevent the onset of prolonged standing induced LBP.

Muscle activation patterns have also been demonstrated to differ between PDs and NPDs during periods of prolonged standing. In comparison to NPDs, PDs have demonstrated higher gluteus medius co-contraction indexes (Nelson-Wong et al., 2008) as well as higher and positive cross-correlation values indicating different motor control strategies between the two groups (Marshall et al., 2011). This response has been hypothesized to be another potential pre-disposing factor of pain development, since similar to static postures, it is evident at the start of a prolonged standing task prior to pain development (Nelson-Wong & Callaghan, 2010b). However, previous work has demonstrated that when using an elevated surface as a standing intervention, during short exposures, the standing aid was not successful in decreasing gluteus medius muscle co-activation in PDs (Fewster et al., 2017). In NPDs, the elevated standing intervention resulted in increased gluteus medius muscle co-activation patterns. This was hypothesized to be a potential concern because the NPD group exhibited a muscle activation pattern when using the standing intervention that could be indicative of identifying high-risk individuals for developing LBP in level standing (Fewster et al., 2017). Thus, it is important to not only assess if a standing intervention is successful in positively changing motor control and kinematic patterns for PDs, but to also ensure it does not negatively influence NPDs.

The purpose of this study was to investigate if the cyclic movement of raising a leg via a footrest, when applied in a 3:1 ratio at the start of prolonged standing, could decrease or delay the onset of LBP. We hypothesized that 1) the implementation of early movement would decrease the development of LBP and 2) that raising one leg onto an elevated platform would move participants into a more flexed lumbar spine posture in comparison to level ground standing with a subsequent increase in gluteus medius co-activation. Results from this investigation could contribute to an understanding if the use of a footrest can positively change lumbar spine postures, movement patterns and motor control strategies previously linked to LBP development.

2. Methods

2.1. Participants

Twelve participants (6 male and 6 female) volunteered for this study (average age = 23, average BMI = 24.6 kg/m^2). Participants were excluded if they had any previous history of low back, shoulder or arm pain (that required medical intervention or time off from work for longer than three days in the last three years), previous lumbar or hip surgery, an inability to stand or sit for two hours at one time, and any dizziness and/or fainting while standing. All participants had previously participated in either a 75 or 120 min prolonged standing laboratory study which was used to classify participants as either a PD or NPD. For both prolonged standing investigations participants wore running shoes. A participant was considered a PD if they reported pain greater than 10 mm on a visual analog scale score (VAS) from baseline during the prolonged standing protocol (Gallagher et al., 2014; Nelson-Wong & Callaghan, 2010b; Marshall et al., 2011). Half of the participants in the current study had been previously classified as a PD. All participants determined to be right leg dominant. Leg dominance was determined by asking participants to simulate the performance of four different tasks: kicking a ball, stomping out a simulated fire, tracing a shape, and picking up a marble (Schneiders et al., 2010). This study was reviewed and received ethics approval by the University of Waterloo Research Ethics Committee.

2.2. Instrumentation

An Optotrak Certus motion capture system (Northern Digital Inc, Waterloo ON, sampled at 32 Hz) was used to track kinematics of

Fig. 1. Example of a participant using the elevated surface (13 cm) during the leg raise condition.

the lumbar spine. Two rigid bodies were used to track movement, one rigid body containing four markers was placed at the level of L1/L2 (upper lumbar spine), the second rigid body containing five infrared markers was placed over the sacrum.

Two pairs of disposable surface EMG electrodes (Blue Sensor, Ambu A/S Denmark) were placed over the right and left gluteus medius muscles (GM, approximately 50% of the distance between the iliac crest and greater trochanter). A reference electrode was placed over the spinous process of the seventh cervical vertebrae. EMG signals were differentially amplified using a common mode rejection ratio of 115 dB, analog band-pass filtered from 10 to 500 Hz and gained by a factor of 500–5000 (AMT-8, Bortec Calgary AB, Canada). Maximum voluntary contractions (MVCs) were collected from the right and left GM for normalization purposes. MVCs were obtained through resisted hip abduction in a side laying position. MVCs were manually resisted by the experimenter, two sets of MVCs were completed for each leg, with a minimum of 30 s of rest between each exertion. Ten second rest trials were also taken with the participant lying in the supine and prone positions.

2.3. Experimental procedures and protocol

A maximum lumbar extension trial was recorded as a reference posture to normalize lumbar spine angle. Participants were instructed to lock their knees and bend backwards about their lumbar spine without shifting their hips. Following the normalization trials, participants started the standing intervention protocol. Each participant stood for 80-minutes while cycling through a 3-1-3-1 leg raise protocol. Participants stood on level ground for 3 min, then elevated their right leg for one minute, then stood on level ground for 3 min, then elevated their left leg for one minute. A 13 cm high elevated platform was used for participants to raise their left and right leg on to (Carson, 1995) (Fig. 1). During this time, participants completed a typing task designed to mimic a task completed at an office workstation. Perceived low back pain was collected on a 100 mm visual analog scale collected on an iPad every eight minutes (eVAS, Waterloo, ON).

2.4. Data analysis

2.4.1. Pain scores

Participants were categorized as an intervention-PD (I-PD) or intervention-NPD (I-NPD) based on VAS scores. A participant was considered an I-PD if they reported any change in VAS score greater than 10 mm from baseline during the 80-minute standing

intervention. In line with prior work, this is a conservative estimate based on the minimum clinically important difference for patients to feel their low back pain symptoms worsening (Hägg, Fritzell, and Nordwall 2003).

2.4.2. Kinematic data

Kinematic data were imported into Visual 3D (C-Motion, Kingston, ON) to calculate lumbar spine joint angles. Each marker's coordinate data were filtered using a 6 Hz, 4th order dual pass Butterworth filter. Lumbar spine angles were determined using a Flexion/Extension, Lateral Bend, Axial Twist rotation sequence and were expressed relative to maximum extension. For each of the level ground standing conditions the middle 30 s of the three-minutes were extracted and then averaged, giving one average lumbar spine angle for each level standing period. Similarly, for each of the right and left leg elevated conditions the middle 30 s of each one minute period were extracted and averaged, giving one average lumbar spine angle for each right leg elevated and left leg elevated condition.

2.4.3. Electromyography data

EMG signals were notch (bandstop) filtered using cutoff frequencies from 59 to 61 Hz, to remove any 60 Hz electrical contamination (Mello, Oliveira, & Nadal, 2007). EMG signals were then full wave rectified and dual pass filtered through a fourth order Butterworth filter with a cutoff frequency of 6 Hz (Nelson-Wong et al., 2008). Resting activation was subtracted from the EMG and the EMG signals were then normalized to MVC (Nelson-Wong & Callaghan, 2010b). The processed EMG signals were then down sampled to 32 Hz to align with the kinematic data.

Cross-correlation analysis was used to quantify the common signal between the right and left GM signals. Cross-correlation is a technique used to quantify the similarity in shape and the phase delay between two time-varying waveforms (Nelson-Wong, Howarth, Winter, & Callaghan, 2009). A highly positive correlation indicates that the two signals are acting together in phase, whereas a highly negative correlation indicates that one signal is at a maximum and the other is at a minimum (out of phase). Practically, this technique is often used to assess the degree of co-activation between two muscles. Positive cross-correlation values indicate muscles are activated together (co-activating), while negative cross-correlation values indicate that one muscle is being activated while the other is not, implying reciprocal firing of the muscles (Nelson-Wong et al., 2009). Eighty 1-minute blocks of the bilateral GM EMG were entered into a custom Matlab program (Version 8.5 Mathworks, Inc., Natick, MA, USA) to compute the cross-correlation coefficients, R_{xy} (Eq. (1))

$$R_{xy}(\tau) = \frac{1}{T} \int_0^T \frac{x(t)y(t+\tau)dt}{R_{xx}(0)R_{yy}(0)}$$

(1)

where $R_{xy}(\tau)$ is the normalized cross-correlation of two signals, $x(t)$ and $y(t)$ at a phase shift τ with a potential range of result values of $R_{xy}(\tau)$ between -1 and $+1$ and T is the length of the record. The maximum cross-correlation of each 1-minute block was computed across a phase shift (τ) of $+/-$ 500 ms. The average R_{xy} was calculated over each 3-minute level standing interval to provide an overall pattern of co-activation during each level, right leg elevated and left leg elevated interval (Nelson-Wong et al., 2009).

2.5. Statistical analysis

A three-way general linear model assessed the influence of level standing Pain Status, Gender and Time (20 separate 3-minute average intervals of level standing, 10 separate 1-minute average intervals of right leg standing and 10 separate 1-minute average intervals of left leg standing) (SPSS v20, IBM Corporation, Somers NY, USA) on lumbar spine angle and R_{xy}. No influence of gender was observed and thus data was collapsed across gender. Right leg elevated and left leg elevated were initially compared, there were no differences between the two legs (right vs. left leg elevated) observed for lumbar spine angle ($p = 0.109$) or R_{xy} ($p = 0.849$) and therefore for the elevated leg intervals only the right leg elevated was compared against level standing (for a total of 30 comparisons within the factor of time). Any significant effects or interaction effects were further evaluated using the Tukey post hoc test. An alpha level of 0.05 was set for significance.

3. Results

3.1. Participants

Out of all previously identified PDs, only one PD developed clinically significant levels of LBP during the intervention standing protocol (I-PD) (Hägg et al., 2003). None of the previously identified NPDs developed LBP (I-NPD). Thus, in total one participant was identified as an I-PD while eleven participants were identified as I-NPDs.

4. Kinematics

There was a main effect of Time for lumbar spine angle ($p = < 0.0001$). This was as a result of significantly greater lumbar spine flexion with the left or right leg elevated (right leg: 24.5 $\pm$ 0.5 degrees and left leg: 24.7 $\pm$ 0.4degrees) in comparison to level standing (18.7 $\pm$ 0.8 degrees) (Fig. 2) for both PD and NPD groups.
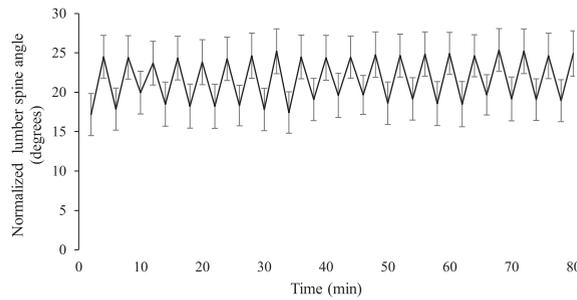
Fig. 2. Lumbar spine angle (degrees) with respect to maximum extension over time (note: maximum extension = 0 degrees, a greater value indicated greater lumbar spine flexion).

5. Cross-correlation differences

A main effect of time ($p = < 0.0001$) was found for GM cross-correlation. This was driven by a significant difference in Level Standing GM R_{xy} values (0.39 ± 0.061) versus Elevated Standing R_{xy} for both PDs and NPDs over time (right leg: 0.61 ± 0.047) (Fig. 3).

6. Discussion

Cyclically placing one foot onto a 13 cm footrest showed evidence, in a limited sized study sample, in mitigating low back pain development during an 80 min prolonged standing protocol. Of the previously classified six PDs, only one PD developed clinically significant levels of LBP when using the footrest. None of the previously defined NPDs developed LBP during this intervention. In addition, raising one foot onto the elevated platform resulted in a significant increase in lumbar spine flexion in comparison to level standing, with a subsequent increase in gluteus medius co-activation. Thus, results from this investigation suggest that cyclically elevating one leg onto a 13 cm elevated platform in a 3–1 min ratio may be effective at mitigating LBP development is susceptible individuals throughout prolonged standing.

This intervention showed success at diminishing LBP in a limited sample size (5 out of 6 known PDs) and did not induce LBP in any previously known NPDs. This result is in contrast to previously published work by Lee et al. (2018), whom found that implementing an elevated foot rest with a 1:1 ratio for 5 min each was unsuccessful at reducing LBP during prolonged standing in known PDs (Lee et al., 2018). One explanation for this difference in results could be the difference in time spent with one leg elevated during the intervention. It is possible that leaving one leg elevated for a five-minute duration might be too long and resulted in discomfort. Lee and colleagues did not track if the location of discomfort/pain changed over the course of the intervention (Lee et al., 2018). Secondly, Lee et al. (2018) did not report the height of their footrest used. Presumably, the higher the footrest, the more
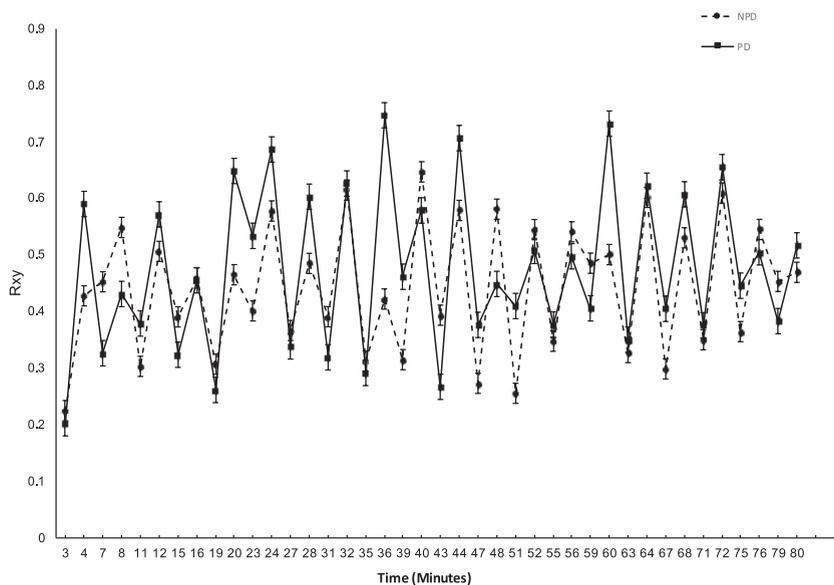

Fig. 3. The average Right-Left GM cross-correlation values for each interval of the 80 min standing intervention. An odd value in time represents an interval of level standing whereas an even value indicates an elevated leg interval. Standard error bars are displayed.

weight the standing leg would need to support. Thus, the possible difference in footrest heights used could have also influenced the successfulness of the standing intervention and be a possible explanation for the difference in results.

A possible explanation for the success of this intervention may be attributed to the decreased extension in the lumbar spine while one foot was raised onto the elevated platform. Sorensen et al. (2015) reported that those who exhibited greater amounts of LBP during level standing tended to stand with a greater lordosis than their counterparts. There was a difference of 4.37° between the lumbar curvatures of PDs and NPDs with the PDs demonstrating more lordosis (Sorensen et al., 2015). This increase in lumbar lordosis was directly related to higher amounts of LBP symptom reporting (Sorensen et al., 2015). In the current study, when participants were standing with one foot on the elevated platform their lumbar lordosis decreased by approximately 6° compared to level ground standing. These results agree with both Dolan and colleagues (1988) and Fewster and colleagues (2017). Dolan and colleagues (1988) reported differences in lumbar spine angle between level standing and standing with a foot on an elevated platform of 20 cm. They reported differences of 3° (± 5°) between level standing and standing with the left leg on an elevated platform (Dolan et al., 1988). Fewster and colleagues (2017) also reported that during short exposures, raising one leg onto an elevated platform resulted in increased lumbar spine flexion in comparison to level ground standing (Fewster et al., 2017). In the current study, there were no differences in lumbar posture when either the right or left leg was raised, allowing the participant to elicit the same amount of lumbar spine flexion when either leg was raised onto the elevated surface. In addition, the cyclic movement in this intervention may have promoted the offloading of structures throughout the 80-minutes protocol.

Trunk and hip muscle co-activation during level standing has been previously associated with the susceptibility to LBP development (Marshall, Patel, & Jack, 2011; Nelson-Wong & Callaghan, 2010a,b,c,d; Nelson-Wong et al., 2008). Unlike previous investigations, during the level standing portion of this intervention, PDs did not display significantly higher GM cross-correlation values when compared to NPDs. Both PDs and NPDs displayed a trend of significantly higher GM cross-correlation values when one leg was elevated in comparison to level standing. However, despite the increase in GM cross-correlation, during the elevated portion of the intervention, none of the previously classified NPDs developed LBP and only one previously classified PD continued to develop standing induced LBP. Trunk and hip muscle co-activation differences in response to clinical interventions is an area that remains understudied, the findings from this investigation support the idea that LBP pain generation is not simply a response of GM muscle activation patterns, but dependent on the duration and sequencing of recruitment when standing. Previous work by Nelson-Wong and Callaghan (2010a,b,c,d) found similar results when using a 4-week exercise intervention on PDs in attempt to decrease LBP development during prolonged standing (Nelson-Wong & Jack, 2010d). Post exercise intervention there was a significant decrease in LBP reports during prolonged standing for male and female PDs whom went through an exercise intervention (Nelson-Wong & Jack, 2010d). However, despite the decrease in LBP development in PDs, during prolonged level standing, female participants showed no change in GM co-activation during prolonged standing pre-post exercise intervention and both male and female PDs displayed minimal change in trunk flexor/extensor co-contraction (Nelson-Wong & Jack, 2010d). One possible hypothesis is that during level standing the increase in muscle co-activation may serve as a compensatory mechanism for poor postural control, leading to pain in areas of the low back.

The current study was limited to objectively capturing pain development in participants as a visual analog scale was used and a normalization of pain across participants was not possible. Classification of participants as either a PD or NPD was completed prior to the current study. Classification as PD or NPD has been shown to have excellent repeatability between days with intraclass correlation coefficients (ICCs) greater than 0.80 (Nelson-Wong & Callaghan, 2010a,b,c,d). Participants' level ground standing lumbar spine pain status was not re-evaluated as a part of the current study. The expanding of the current results to a field study in industry is needed to verify that the results are transferable to those working in an occupation that requires prolonged standing but have the ability to use a small stool. In addition, this investigation used a relatively small sample size and this may limit the generalizability of these findings to the general population. Given the lack of prior literature on the what footrest heights are successful at mitigating LBP development or if footrests reduce LBP, a single footrest height was employed for all participants. Future work should expand on the positive findings of this research by incorporating an adjustable footrest height to control for hip angle variability between participants.

7. Conclusions

This intervention was effective in reducing, and in some cases eliminating, low back discomfort in five of six previously known PDs. Clinically relevant levels of LBP in response to standing were only reported from one participant. This finding supports that a footrest intervention was effective in decreasing or prolonging the onset of LBP during prolonged standing. The use of the footrest altered the PDs' lumbar lordosis and provided a break in the co-activation profiles of the GM exhibited by PDs during level ground standing. All previously defined PDs behaved like NPDs with reference to lumbar spine posture. Success of this intervention may be attributed to early and consistent changes in lumbar spine posture and altering the chronic coactivation muscle patterns of PDs throughout a prolonged standing protocol.

Acknowledgements

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