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Relationships between lower limb and trunk discomfort and vascular, muscular and kinetic outcomes during stationary standing work

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ABSTRACT

Standing work is associated with discomfort and symptoms in the trunk and lower limb. However, mechanisms underlying these observations are poorly understood. Moreover, most research on standing-related symptoms has focused on only one region (lower limb or trunk), and has not considered the impact and interactions between vascular, muscular and balance outcomes. We measured foot and soleus blood flow, ankle mean arterial pressure, muscle activity of the plantar and dorsi flexors, gluteus medius and trunk flexors and extensors, center of pressure changes and leg and back discomfort in 18 healthy volunteers performing a repetitive box-folding task for 34 min. Results show significant decreases with time in lower limb muscle activity ($p < 0.00053$), and increases in foot blood flow and center-of-pressure mediolateral sway amplitude ($p = 0.00066$). There were significant time effects on back ($p = 0.017$) and lower limb ($p < 0.000001$) discomfort, the latter significantly correlated ($r = 0.35$) to time-related increases in foot blood volume. No changes were correlated to the increase in back discomfort. Results suggest that the origin of standing-related lower limb discomfort is likely vascular in origin, whereas back discomfort is likely multifactorial, involving muscular, vascular and postural control variables.

1. Introduction

Many occupations in industrial and service sectors are designed for employees to use relatively stationary standing posture [1]. However, stationary standing work is associated with lower limb discomfort [1–3] and vascular disorders [4–7], and trunk discomfort and musculoskeletal disorders [2,8–10].

Discomfort in the feet and lower limbs are suggested to have multiple pathways [11]. Previous research compared simulated work tasks in stationary standing versus dynamic walking and showed that lower limb discomfort and muscular fatigue in the gastrocnemius muscles were significantly higher in stationary standing conditions [12]. This suggests that muscular fatigue is a factor in the development of lower limb discomfort during stationary standing work. However, other research suggests that discomfort might be related to increases in lower limb blood pooling which places pressure on lower limb tissues [11], although this has not been thoroughly investigated experimentally. Findings from epidemiological studies do support work-related changes in vascular outcomes. For example, it has been hypothesized that prolonged standing reduces venous return and leads to increased hydrostatic venous pressure, which may explain the increased reports of discomfort, impairment of the venous valves and peripheral vascular disorders associated with standing work [6,13].

Standing-related back discomfort mechanisms are also poorly understood. Previous experiments show no change in trunk kinematics and fatigue-related EMG variables during prolonged standing [14]. However, recent work has shown that co-activation patterns in the hips and trunk be related to the development of standing-related back discomfort [14–16]. These studies showed that individuals who report back discomfort have initially elevated co-contraction of the right and left gluteus medius, as well as agonist–antagonist co-contraction between the lumbar erector spinae and external obliques, suggesting a cause and effect relationship between co-contraction patterns, postural control during standing and the development of symptoms [14–16]. In support of this hypothesis, it has been shown that individuals who present symptoms of low back discomfort performed fewer postural adjustments during a 30 min quiet standing task [17]. Thus, posturographical analyses can provide important information about postural control mechanisms related to low back discomfort.

Most experimental studies of prolonged standing work have only evaluated one region, either the lower limb or the back. To

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account for the complementary role of the trunk and legs in the control of prolonged standing posture, it is important to study the impact a working posture on multiple body regions in the same experiment [18]. In an earlier study, we found that during a 32 min standing work task, there were increases in lower limb blood flow and mean arterial blood pressure, with the time-based changes in blood flow correlating with time-based changes in reported discomfort [19]. However, there has yet to be a study combining assessments of cardiovascular, muscular and postural control outcomes during a prolonged standing task.

The present study investigated these objectives during a 34 min standing box-folding task, modeled from local industry. We evaluated changes in lower limb vascular outcomes and muscle activity, trunk and hip muscle activity and co-activation, and center of pressure shifting. We hypothesized that we would observe changes in all recorded vascular, muscular and postural control characteristics with time, and that these would correlate with the development of lower limb and trunk discomfort.

2. Methods

2.1. Participants

18 asymptomatic participants (10 men, 8 women) were recruited for this project. The exclusion criteria were any history of neurological, musculoskeletal or vascular disorders during the three previous years, and being currently pregnant. Participants signed an informed consent form, approved by the ethics committee of the Centre for Interdisciplinary Research in Rehabilitation (CRIR) of Greater Montreal. Mean age was 32.4 (SD = 8.2), mean weight was 75.8 kg (SD = 8.7), and mean height was 173.2 cm (SD = 10.6).

2.2. Apparatus and procedures:

The right tibialis anterior (TA), soleus (Sol) and gastrocnemius (Gast), as well as bilateral gluteus medius (GM), rectus abdominis (RA), external obliques (EO) and lumbar erector spinae (ES) muscles were fitted with bipolar silver–silver chloride surface electrodes (Ambu, King City, Ont.) for electromyographic (EMG) recordings (TeleMyo, Noraxon, USA, 10–350 Hz operating bandwidth) following EMG preparation guidelines. Participants removed their shoes and socks prior to the experiment and were outfitted with Laser Doppler Flowmetry (LDF) (floLAB Monitor, Moor Instruments, Devon, England) electrodes to measure skin blood flow; one electrode was placed on the distal third of the soleus, and another over the 4th metatarsal of the foot. Lower limb blood pressure was measured using a standard digital spygmometer at the left ankle region. Participants performed the experiment while standing on a dual force plate system (AMTI), covered with 2 mm thick rubber carpet. Participants gave assessments of discomfort for various body segments using a body map and scale (Fig. 1) [19,20].

Participants constructed one box every 9 s during 4, 8.5 min work bouts, totaling 34 min. While facing a table adjusted to knuckle height, they reached for individual pieces of cardboard placed 30 cm to their left, moved it in front of them, folded it into a box, and placed the completed box on a line 30 cm from the near edge of the work table. Participants could shift their weight at will, but could not move their feet during the task. EMG was recorded at 4 and 8 min of each work bout for 30 s at a frequency of 1080 Hz. After each 8.5-min work bout, LDF and ankle blood pressure measures were taken for 30 s; during this time, the participant was asked to stop working and avoid shifting their body weight to prevent movement artifacts in the LDF data; following the LDF data collection, blood pressure and discomfort ratings were taken. The time window for collection of the vascular and discomfort data was standardized to 1.5 min.

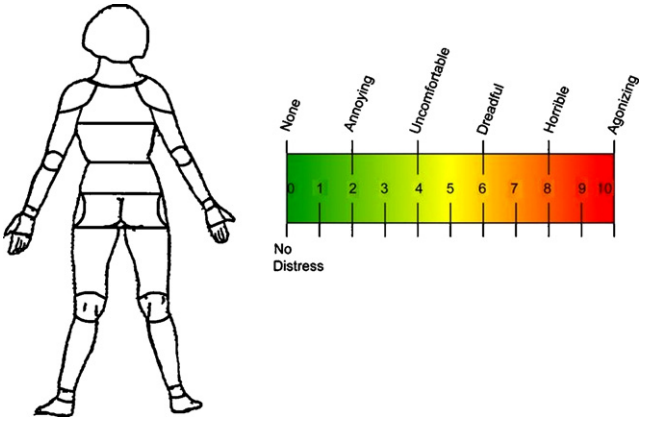

Fig. 1. Body map and discomfort rating scale.

2.3. Signal processing and data analysis

EMG data were filtered [band-pass, 20–500 Hz) and full-wave rectified. Root mean square (RMS) values were computed over 30×1 s non-overlapping windows for each collection period. The 30 RMS windows were averaged to obtain one value representing the mean amplitude of the signal over the interval. Levels of co-activation between trunk flexor–extensor pairs and between the bilateral gluteus medius were attained by calculating the linear envelop of each 30 s time series, applying a low pass filter set at 6 Hz, and calculating the cross-correlations using the following formula over non-overlapping 500 ms windows [16]:

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

$R_{xy}(\tau)$ is the normalized cross-correlation coefficient for two time series, x at time t, and y at time $t + \tau$, where τ is equal to the 500 ms phase shift. Following the method described by Nelson-Wong et al. [16], the 'max' and 'min' R_{xy} values calculated in each 500 ms window were extracted and the measure with the highest absolute value was selected to represent the R_{xy} during that window 500 ms period. The mean of the 60, 500 ms R_{xy} measures was calculated to represent the average level of co-activation during each collection period.

Data collected from the LDF was integrated over non-overlapping 3 s windows for the 30 s time series. The 10, 3 s windows were averaged to attain one value representing blood volume after each of the work bouts. Ankle blood pressure was reported as the mean arterial pressure (MAP).

Data attained from the two force plates were used to locate the net center of pressure (COP) under the feet in the anterior–posterior (AP) and medio-lateral (ML) directions according to the methods described by Winter [21]. RMS of the COP-ML and COP-AP were obtained from non-overlapping 1-s windows throughout the 30-s trials. The 30, 1-s windows were then averaged to attain a value representative of the COP shifting in each plane during that trial.

Time-related changes in EMG, blood flow, blood pressure, COP-AP and COP-ML, and reported discomfort were assessed using repeated measures ANOVA with one within-subject factor of time. Post hoc tests (Tukey) were used to identify the time(s) when various outcomes significantly changed from their baseline values and identify the order in which these changes occurred. Changes in measures during work bouts 2, 3 and 4 were reported as percentages of the corresponding work bout 1 values to allow simple comparisons of the relative changes across the experiment. Correlation coefficients were computed between parameters that showed significant change with time. Prior to this, each data point was demeaned based on each participant's mean value for each variable across the 4 work bouts, allowing comparison of the within-subjects effect without having between subjects effects confound the analysis [22].

3. Results

Table 1 summarizes the statistical analysis of changes in each of the measures.

3.1. Lower limb outcomes

Significant increases in lower limb blood pressure occurred from the 1st to the 2nd work bout (mean increase from first work bout: 8.59 mmHg, SE: 2.97 mmHg) (Tables 1 and 2). Significant changes in foot blood volume from the first work bout did not occur until the final work bout (mean percentage of first work bout measure: 124.25%, SE: 12.39%). There were significant decreases in EMG RMS values in the TA (mean percentage of first work bout measure: 87.30%, SE: 5.26%) and in the Gast (mean percentage of first work bout measure: 81.51%, SE: 4.96%).

3.2. Trunk and hip outcomes

No significant differences in EMG RMS activity in any of the trunk or hip muscles were found. There were also no significant effects of time on co-contraction indices between the bilateral GM muscles, or between any of the trunk flexor–extensor pairs.