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Muscle activation and energy expenditure of sedentary behavior alternatives in young and old adults

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Muscle activation and energy expenditure of sedentary behavior alternatives in young and old adults

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Abstract
The physiological mechanisms that underlie the metabolic benefits of breaking up sedentary behavior (SB) have yet to be determined. The purpose of this study is to compare energy expenditure (EE) and muscle activation (MA) responses to sitting and four SB alternatives in younger and older adults. Twenty-two adults, grouped by age (21–35 and 62–76 years), completed five randomly ordered 20 min tasks: (1) continuous sitting (Sit), (2) sitting on a stability ball (Ball), (3) continuous standing (Stand), (4) sitting interrupted by walking (S/W), and (5) sitting interrupted by standing (S/S). Muscle activation of two upper (trapezius and erector spinae) and two lower (rectus femoris and medial gastrocnemius) body muscles and total body EE were measured continuously. A linear mixed model using gender and age as a covariate with Bonferroni adjustment were used to determine significant differences between tasks. Collectively, S/W produced significantly higher MA and EE compared with Sit ($p < 0.001$). Stand and Ball provided significantly greater EE, but not MA, compared to Sit ($p < 0.05$), while S/S did not significantly change EE or MA compared to Sit. There were no net EE differences when comparing age groups across the tasks. Upper body MA was not consistent in both age groups across tasks. Specifically, during S/W the upper body MA of older adults ($9.7 \pm 1.5\% \text{ MVC}$) was double that of young adults ($4.8 \pm 0.7\% \text{ MVC}$, $p = 0.006$). Lower body MA responded similarly to all tasks in both age groups. Disrupting sitting with walking produced the largest increase in EE...
and MA compared to other SB alternatives in both age groups. These results are important considering the wide use of SB alternatives by researchers and public health practitioners.

Keywords: sedentary time, sedentary break, walking, inactivity, aging

(Some figures may appear in colour only in the online journal)

Introduction

Current population statistics suggest most American adults spend over half of their waking hours in a sedentary behavior (SB), with older adults (60+ years) at risk of accumulating greater than 70% of their waking hours spent sitting (Matthews et al 2008, Healy et al 2011). Recent investigations have identified associations between long, uninterrupted bouts of SB with chronic disease development and premature death independent of several confounding variables, including total time spent sedentary and in moderate-to-vigorous intensity physical activity (MVPA) (Healy et al 2008). This suggests that the physiological mechanisms to explain SB associated risks may be unique from the benefits of physical activity.

The causal link(s) between SB and health has not been fully established, but are suggestive that low daily energy expenditure (EE) and acute effects of skeletal muscle inactivity contribute to the ill effects of SB (Hamilton et al 2007, Tremblay et al 2010). Since 1950, a shift in occupational physical activity has led to an estimated EE deficit of 142 kcal d⁻¹ (Brownson et al 2005, Church et al 2011) possibly contributing to the paralleled and increased prevalence of obesity, and their comorbidities (Flegal et al 2002, Brownson et al 2005, Church et al 2011). Cross-sectional and experimental SB interruption studies have identified that periodic brief walking bouts to break up SB lasting 20–30 min provide acute benefits to glucose and insulin responses (Dunstan et al 2012) and improved post-prandial metabolic responses when compared to a caloric equivalent bolus of physical activity (Peddie et al 2013). Experimental models using bed rest studies in humans and hind limb unloading in mice have indicated immediate reductions of skeletal muscle activation (MA) leading to alterations in gene transcription, reduced skeletal muscle lipoprotein lipase (LPL) activity, and reduced myokine release (Bey and Hamilton 2003, Zderic and Hamilton 2006, Stephens et al 2011, Pratesi et al 2013). These recent findings are suggestive that acute MA driven metabolic responses, and not necessarily EE itself, may be the key culprit in the metabolic dysfunction and pro-inflammatory state observed in highly sedentary populations.

The current evidence between SB and health has led to an international expert consensus to urge seated occupations to progress towards 2–4 h d⁻¹ of standing or performing light activities for health benefits (Buckley et al 2015). Coincidentally, several SB alternative devices and strategies have been marketed in the past decade that propose the health benefits of altering SB. However, most of these devices are descendants from interventions designed to alleviate musculoskeletal pain and lacking evidence in effectively altering SB-associated health risks. These include sit-to-stand desks, walking or pedaling workstations, stability balls, seated stretches, frequent breaks of various sedentary durations, and sedentary break reminder devices. Also, while several of these SB alternatives have shown acute improvements in EE (Tudor-Locke et al 2014, Mansoubi et al 2015) or MA (Gregory et al 2006, McGill et al 2006, Ellegast et al 2012), none have measured EE and MA concurrently.

It remains unclear whether one SB alternative is more beneficial than the other without identifying how these SB alternatives comparatively affect both EE and MA. Without this clarification on the physiological mechanisms that underlie the metabolic benefits of breaking
up SB, public health officials may be misled in their efforts to combat SB. There are no prior investigations that combine the measurement of EE and MA to comparatively assess the effectiveness of popular SB alternatives. Also, there is a paucity of evidence that examines the effectiveness of SB interventions among older adult populations, whom may be at greatest risk to SB exposure. Therefore, the purpose of the study is to determine the acute effects of uninterrupted sitting on EE and MA, compared with sitting on a stability ball, standing, sitting interrupted by a brief bout of light-intensity walking, and sitting interrupted with a brief standing break in younger and older adults.

**Methods**

**Participants**

Twenty-two adults between the ages of 20–40 (younger adults) and 60–80 (older adults) years old were recruited to participate in the study. Recruitment strategies included posting flyers in the local community and university setting, the laboratory website, and contacted participants through a research participant registry. Participants were included in the study if they self-reported being healthy, did not meet 150 min/week MVPA, and capable of performing sitting or standing continuously for 20+ min at a time and were excluded if they had a diagnosed cardiovascular, metabolic or pulmonary disease, were pregnant or breastfeeding, or had a hip or knee replacement.

**Overview**

This experimental study included two visits to a laboratory separated by at least 7 d. Prior to both visits, participants were asked to abstain from any food or calorie containing beverages for 4 h and caffeine, stimulants, and exercise for 12 h prior to the lab visits. Upon arrival, all participants read and signed an informed consent that was approved by the University’s Institutional Review Board. After informed consent was completed, each participant filled out a health history and demographic questionnaire followed by having their height, weight, resting heart rate, and resting blood pressure measured.

Once all measurement devices were calibrated, the participant was fitted with the equipment and performed five randomly ordered, 23 min sitting or standing conditions with randomized bouts of arm support (arms resting on the table) and no arm support (arms holding smart-device or reading material) during each task. Arm support was randomized to ensure all participants were following similar body postures and activities, since prior studies have shown that the underlying office tasks may provide greater influence on muscle activity than the use of various dynamic chair devices (Ellegast et al 2012). The five tasks took place at a computer workstation and included: sitting on a computer office chair (Sit), sitting on a stability ball (Ball), continuous standing (Stand), sitting on an office chair interrupted by a 2 min of self-paced walking (S/W), and sitting on an office chair interrupted by 2 min of standing (S/S). The sedentary interruptions occurred at the 11 min mark of each condition to allow for capture of any residual EE post-task. Additionally, the initial 3 min of each of the five bouts were excluded from data analysis to provide 20 min of steady state data. During the walking bouts, the participants were asked to walk at a usual, self-selected pace through a university building hallway while being followed with a distance measuring wheel and a stopwatch to calculate the average walking speed.
Following a minimum 7 d monitoring period, participants returned to the laboratory for a second visit. During the second visit, body height and weight were re-measured and the participant performed a resting metabolic rate (RMR) using a metabolic measurement system, body composition testing a dual-energy x-ray absorptiometry (DXA), and a SB questionnaire. Both visits were completed within a 14 d period.

**Measures**

**Anthropometrics and body composition.** Body mass and height were measured using a physician’s balance beam scale and stadiometer (Continental Scale Corporation, Bridgeview, IL), respectively. Body mass was measured to the nearest 0.1 kg and height was measured to the nearest 0.1 cm and body mass index (BMI) was calculated (kg m$^{-2}$). Body composition was assessed using a three-compartment model with dual energy x-ray absorptiometry (DXA; GE Lunar Prodigy, Madison, WI). Whole-body percent fat (BF%) was measured to the nearest 0.1%. The DXA has previously been shown to be a valid and reliable measure of body composition compared to other multi-component models (Fields *et al* 2002).

**Resting metabolic rate.** A flow-through hood technique was used to collect a RMR and gas volumes were analyzed using a ParvoMedics TrueOne metabolic measurement system (ParvoMedics, Salt Lake City, UT). Each participant was asked to strictly avoid any food or beverage intake for 8 h prior to testing (excluding water) and no exercise for 12 h prior. Oxygen consumption, carbon dioxide production, and ventilation were collected and averaged minute by minute to determine a steady state period of 10+ min for assessment of RMR. The ParvoMedics TrueOne system was calibrated for gas and ventilation measurements according to the manufacturer’s specifications prior to each individual test. The ParvoMedics TrueOne system has been previously shown to be a valid and reliable measure of EE (Cooper *et al* 2009). Heart rate was assessed during the RMR testing with a heart rate monitor (Polar, Warminster, PA).

**Physical activity and SB.** Measures of physical activity and SB were objectively assessed with an Actigraph GT3X+ accelerometer (Pensacola, FL) and an *activPAL* accelerometer/inclinometer (Paltechnologies, Glasgow, UK) during a 7 d free-living monitoring period. The PA monitoring occurred between visits one and two. The Actigraph GT3X+ is a tri-axial accelerometer was developed to monitor physical activity using a dynamic range of 2 g and a bandpass filter of 0.25–2.5 Hz to exclude motion signals outside of human movement. The participants were instructed to wear the Actigraph GT3X+ accelerometer on their right hip during all waking hours of the 7 d monitoring period, except for when showering or submerged in water. Activity monitor non-wear time was determined by the use of written wear time logs and the use of a non-wear time classification algorithm (Choi *et al* 2011). A sampling frequency was set at 80 Hz and activity counts were collected and analyzed in 1 min epochs using suggested cut points for adult SB (<100 counts min$^{-1}$), light (100–759 counts min$^{-1}$), and moderate-to-vigorous (≥1952 counts min$^{-1}$) physical activity determination (Freedson *et al* 1998, Hagstromer *et al* 2007, Healy *et al* 2008, Matthews *et al* 2008). Accelerometry has been shown to be a valid and reliable measure of physical activity participation and physical inactivity across many populations and age groups (Matthew 2005, Staudenmayer *et al* 2009, Freedson *et al* 2011, Kozey-Keadle *et al* 2011).

The small, matchbox-sized *activPAL* device was included to supplement the hip-worn accelerometer in accurately identifying SB-related postures. The *activPAL* uses accelerometry to identify thigh angles to classify between sitting, standing, and walking activities which
are critical to the definition of a SB. All participants were instructed to wear the device on the mid-line of the right thigh for 24 h during the 7 d monitoring period, except for periods that included submersion in water. The device was held in place with hypoallergenic breathable adhesive tape. The *activPAL* has been shown to be a valid and reliable measure of steps (Grant *et al* 2006) and postural physical activity (Ryan *et al* 2008). After returning the activity monitors during visit two, all participants completed a SIT-Q to provide a context for their SBs. The SIT-Q has been shown to be valid and reliable measures of SB (Lynch *et al* 2014).

**EE during tasks.** Gross EE was collected continuously during the five 23 min tasks using a COSMED K4b² (Rome, Italy) portable metabolic measurement system which measured oxygen consumption, carbon dioxide production, and ventilation. Gas measurements were averaged to minute by minute values for analysis. Prior to testing, ventilation and gas calibrations were performed following the manufacturer’s instructions and participants confirmed a minimum of 4 h without food or caffeine and no vigorous exercise 24 h prior. The COSMED K4b² metabolic system has been previously shown to be a valid and reliable measure of EE at rest and during exercise (McLaughlin *et al* 2001, Welch *et al* 2015). Net EE for each activity was determined by subtracting measured RMR values from task related gross EE values for each individual.

**Muscle activity during tasks.** Muscle activity during the five conditions was collected using a portable surface electromyography system (ForEMG, OT Bioelectronica, Torino, Italy), similar to that validated during free-living situations (Walters *et al* 2013) with a bandpass filter of 20–399 Hz and a sample rate of 800 samples s⁻¹. Bipolar electrodes were placed on each of four muscle groups: *m. upper trapezius* (Tz), *m. medial gastrocnemius* (MG), *m. erector spinae* (ES), and *m. rectus femoris* (RF). These four muscle sites were then summarized into upper body (Tz and ES) and lower body (MG and RF) MA. The four muscle groups were selected based on previous studies investigating muscle activity during normal activities of daily living and those specific to seated occupations with and without a stability ball (Goulart and Vallis-Solé 1999, Ashford and De Souza 2000, Ellegast *et al* 2012, van Dieen *et al* 2003, Gregory *et al* 2006, McGill *et al* 2006, Tikkanen *et al* 2013). Being limited to four electrode channels did not allow for antagonist muscle group activity data collection. However, alternated- and co-activation patterns in agonist and antagonist muscle groups during these specific activities in the aforementioned studies suggest limited loss of information. Surface electrode placement was identified by a trained laboratory technician by visually locating and palpating each muscle with the participant providing muscle tension and according to the locations recommended by SENIAM (Hermens *et al* 2000). Specifically, all surface electrodes were applied to the dominant side of the body aligned with muscle fiber direction and located halfway between the most distal motor endplate zone and distal tendon. Once all surface electrodes were in place, baseline noise levels were examined at rest and maximal voluntary contractions (MVCs) were performed at all four muscle sites. The participants were familiarized with the MVC action before performing three MVC trials each lasting 3 s with verbal encouragement. Average full-wave rectified EMG amplitudes (MA) were normalized by maximal EMG during MVCs. MA was calculated during the five 20 min long data collection periods after removing the first and last minute of each condition to avoid contamination by adjacent tasks. All EMG analysis was performed using custom scripts written in MATLAB (Mathworks Inc., Natick, MA).
Table 1. Participant characteristics.

<table>
<thead>
<tr>
<th></th>
<th>Age: 20–40 years ($n = 11$)</th>
<th></th>
<th>Age: 60–80 years ($n = 11$)</th>
<th></th>
<th>$P$ for age differences</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Min</td>
<td>Max</td>
<td>Mean</td>
</tr>
<tr>
<td>Age</td>
<td>26.5</td>
<td>4.1</td>
<td>21</td>
<td>35</td>
<td>69.4</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>173.5</td>
<td>1.7</td>
<td>164.0</td>
<td>182.0</td>
<td>167.8</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>73.5</td>
<td>4.3</td>
<td>56.4</td>
<td>101.0</td>
<td>80.8</td>
</tr>
<tr>
<td>BMI (kg m$^{-2}$)</td>
<td>24.4</td>
<td>1.6</td>
<td>19.8</td>
<td>37.6</td>
<td>28.4</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>27.1</td>
<td>3.1</td>
<td>6.0</td>
<td>45.9</td>
<td>38.3</td>
</tr>
<tr>
<td>RMR (kcal d$^{-1}$)</td>
<td>1705</td>
<td>83.5</td>
<td>1311.0</td>
<td>2014.0</td>
<td>1540</td>
</tr>
<tr>
<td>Inactivity (± of day)</td>
<td>68.2</td>
<td>1.7</td>
<td>53.5</td>
<td>82.3</td>
<td>66.2</td>
</tr>
<tr>
<td>MVPA (min d$^{-1}$)</td>
<td>30.4</td>
<td>20.4</td>
<td>9.5</td>
<td>82.4</td>
<td>23.0</td>
</tr>
<tr>
<td>Sitting (h d$^{-1}$)</td>
<td>18.0</td>
<td>2.3</td>
<td>15.8</td>
<td>21.7</td>
<td>18.5</td>
</tr>
<tr>
<td>Standing (h d$^{-1}$)</td>
<td>4.2</td>
<td>1.6</td>
<td>1.4</td>
<td>5.9</td>
<td>4.0</td>
</tr>
<tr>
<td>Stepping (h d$^{-1}$)</td>
<td>1.7</td>
<td>0.8</td>
<td>0.78</td>
<td>3.1</td>
<td>1.6</td>
</tr>
<tr>
<td>Sleep (h d$^{-1}$)</td>
<td>7.6</td>
<td>1.7</td>
<td>5.5</td>
<td>12.0</td>
<td>7.3</td>
</tr>
<tr>
<td>TV time (h d$^{-1}$)</td>
<td>2.5</td>
<td>2.5</td>
<td>0.5</td>
<td>9.0</td>
<td>3.8</td>
</tr>
<tr>
<td>Computer time (h d$^{-1}$)</td>
<td>1.2</td>
<td>0.9</td>
<td>0.0</td>
<td>3.0</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Actigraph GT3X+: inactivity (% of day) and MVPA (min d$^{-1}$). Data based on waking hours wear-time minimum 5 d. Cut points based on current recommendations: sedentary/inactivity (<100 counts min$^{-1}$), light (100–1952 counts min$^{-1}$), and moderate-to-vigorous physical activity ($\geq$1952 counts min$^{-1}$). ($n = 21$).

ActivPal: Sitting, standing, and stepping (h d$^{-1}$). Data collected from 24 h wear-time minimum 5 d ($n = 17$).

SIT-Q (h d$^{-1}$): sleep, TV time, computer time.
Statistical analysis

Descriptive statistics were performed on demographic, anthropometric, physical activity, and SB variables. Two sample t-tests were used to determine if differences existed between the descriptive characteristics of the younger and older adults at baseline. Measurements for EE and MA were averaged across the 20 min data collection period prior to statistical analysis. As this study involved subjects who are repeatedly measured over the five different activities, linear mixed effects models were used to analyze the data which allowed for within-subject correlation. Specifically, mixed effects models with unstructured variance-covariance were used. Of particular interest for this study was to evaluate differences in the EE and MA across tasks and also to see whether the degree of difference in EE and MA across tasks was the same for younger and older adults. All model estimates for MA and EE were adjusted for gender and age as a covariate. All pairwise comparisons were done using the Bonferroni adjustment method to safeguard against increased Type I error. All descriptive statistics are listed as mean ± SD. All statistical analyses were performed using SPSS 22.0 (IBM, Chicago, IL) and all p-values were based on two-tailed tests with a criterion of 0.05 to determine significance.

Results

Participant characteristics

Twenty-two participants successfully completed the study, including eleven younger (21–35 years; five male/six female) and eleven older (62–76 years; five male/six female) adults and primarily consisted of a Caucasian sample (91%). Descriptive characteristics of the study

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Net EE (kcal min⁻¹)</th>
<th>Upper body MA (% normalized MVC)</th>
<th>Lower body MA (% normalized MVC)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EST</td>
<td>SE</td>
<td>P</td>
</tr>
<tr>
<td>Intercept</td>
<td>0.25</td>
<td>0.08</td>
<td>.019</td>
</tr>
<tr>
<td>Older adult (REF: young adult)</td>
<td>−0.06</td>
<td>0.12</td>
<td>.615</td>
</tr>
<tr>
<td>Female (REF: male)</td>
<td>−0.03</td>
<td>0.10</td>
<td>.732</td>
</tr>
<tr>
<td>Activity (REF: Sit)</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Ball</td>
<td>0.10</td>
<td>0.04</td>
<td>.23</td>
</tr>
<tr>
<td>Stand</td>
<td>0.25</td>
<td>0.06</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Sit-walk</td>
<td>0.35</td>
<td>0.03</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Sit-stand</td>
<td>0.07</td>
<td>0.04</td>
<td>.068</td>
</tr>
<tr>
<td>Older adult × activity (REF: young adult and Sit)</td>
<td>.953</td>
<td>.011</td>
<td>.262</td>
</tr>
<tr>
<td>Older adult: ball</td>
<td>0.003</td>
<td>0.06</td>
<td>.958</td>
</tr>
<tr>
<td>Older adult: Stand</td>
<td>−0.01</td>
<td>0.08</td>
<td>.905</td>
</tr>
<tr>
<td>Older adult: Sit-walk</td>
<td>−0.02</td>
<td>0.04</td>
<td>.689</td>
</tr>
<tr>
<td>Older adult: Sit-stand</td>
<td>−0.03</td>
<td>0.05</td>
<td>.550</td>
</tr>
</tbody>
</table>

Abbreviations: reference group = REF; fixed effects estimates = EST, standard error = SE, and p-value = P.
Table 3. Adjusted means and effect sizes for EE (net kcal) and MA (% normalized MVC) during sitting and the SB alternatives.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Sit (Mean ± SD)</th>
<th>Ball (Mean ± SD)</th>
<th>ES</th>
<th>Stand (Mean ± SD)</th>
<th>ES</th>
<th>Sit—walk (Mean ± SD)</th>
<th>ES</th>
<th>Sit—stand (Mean ± SD)</th>
<th>ES</th>
</tr>
</thead>
<tbody>
<tr>
<td>EE (kcal min⁻¹)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>0.204 ± 0.277</td>
<td>0.307 ± 0.295</td>
<td>0.77</td>
<td>0.450 ± 0.342</td>
<td>1.29</td>
<td>0.544 ± 0.328</td>
<td>1.28</td>
<td>0.258 ± 0.262</td>
<td>0.25</td>
</tr>
<tr>
<td>Young Adult</td>
<td>0.234 ± 0.232</td>
<td>0.335 ± 0.249</td>
<td>1.02</td>
<td>0.485 ± 0.311</td>
<td>1.37</td>
<td>0.582 ± 0.308</td>
<td>2.56</td>
<td>0.304 ± 0.272</td>
<td>0.29</td>
</tr>
<tr>
<td>Older adult</td>
<td>0.174 ± 0.311</td>
<td>0.279 ± 0.335</td>
<td>0.63</td>
<td>0.415 ± 0.378</td>
<td>1.17</td>
<td>0.505 ± 0.348</td>
<td>0.96</td>
<td>0.213 ± 0.255</td>
<td>0.24</td>
</tr>
<tr>
<td>Upper body MA (% normalized MVC)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>3.425 ± 1.656</td>
<td>4.082 ± 2.063</td>
<td>0.504</td>
<td>3.251 ± 1.768</td>
<td>−0.088</td>
<td>7.234 ± 3.710</td>
<td>1.060</td>
<td>3.609 ± 1.580</td>
<td>0.139</td>
</tr>
<tr>
<td>Young adult</td>
<td>2.805 ± 1.353</td>
<td>3.930 ± 2.096</td>
<td>0.706</td>
<td>2.936 ± 1.940</td>
<td>0.057</td>
<td>4.799 ± 2.112</td>
<td>0.836</td>
<td>2.919 ± 1.602</td>
<td>0.081</td>
</tr>
<tr>
<td>Older adult</td>
<td>4.045 ± 1.914</td>
<td>4.234 ± 2.033</td>
<td>0.253</td>
<td>3.565 ± 1.582</td>
<td>−0.270</td>
<td>9.670 ± 4.802</td>
<td>1.495</td>
<td>4.299 ± 1.555</td>
<td>0.193</td>
</tr>
<tr>
<td>Lower body MA (% normalized MVC)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>1.515 ± 1.707</td>
<td>1.968 ± 2.444</td>
<td>0.260</td>
<td>1.472 ± 1.013</td>
<td>−0.037</td>
<td>10.761 ± 5.356</td>
<td>1.746</td>
<td>1.834 ± 2.369</td>
<td>0.220</td>
</tr>
<tr>
<td>Young adult</td>
<td>1.750 ± 2.003</td>
<td>1.602 ± 1.751</td>
<td>−0.108</td>
<td>1.434 ± 0.985</td>
<td>−0.222</td>
<td>9.298 ± 2.570</td>
<td>4.518</td>
<td>1.855 ± 1.844</td>
<td>0.105</td>
</tr>
<tr>
<td>Older adult</td>
<td>1.279 ± 1.347</td>
<td>2.334 ± 2.978</td>
<td>0.552</td>
<td>1.511 ± 1.038</td>
<td>0.299</td>
<td>12.225 ± 7.124</td>
<td>1.552</td>
<td>1.814 ± 2.799</td>
<td>0.293</td>
</tr>
</tbody>
</table>

Cohen’s $d$ effect size (ES) is determined from the mean individual difference between each respective task with Sit.
participants can be found in table 1. Notable significant differences between age groups included height and percent body fat (%BF) ($p < 0.05$).

**EE during tasks**

On average, net EE was highest for S/W (0.544 kcal min$^{-1}$), followed by Stand (0.450 kcal min$^{-1}$), Ball (0.307 kcal min$^{-1}$), S/S (0.258 kcal min$^{-1}$) and Sit (0.204 kcal min$^{-1}$). The net EE across the tasks differed significantly with a $p$-value $<.001$. Specifically, Ball, Stand and S/W tasks provided significantly greater net EE than Sit, with $p$-values of .021, $<.001$ and $<.001$, respectively. However, no significant difference was found between S/S and Sit tasks ($p = .462$). In addition, S/W and Stand tasks both resulted in significantly greater net EE than S/S and Ball tasks. All other pairwise differences across tasks were not significant. Although older adults had slightly lower net EE across all tasks than their younger counterpart, this difference was not significant ($p = .615$). And the difference in net EE across tasks did not differ between older and young adults ($p = .953$). Results from the linear mixed effects models are presented in table 2. Cohen’s d effect sizes to compare each of the tasks to Sit are presented in table 3.

**MA during tasks**

Upper body MA differed significantly across tasks with for both young ($p = .009$) and older adults ($p < .001$), respectively. However, the degree of difference for upper body MA across tasks was not the same for both age groups ($p = .011$). Specifically, older adults required approximately double the upper body MA during S/W compared to younger adults with % MVC values of 9.670 and 4.799, respectively ($p = .006$). For older adults, S/W provided
significant greater upper body MA compared to Sit and all other tasks \((p < .001)\). Please note that Sit, Ball, Stand and S/S did not differ with respect to upper body MA significantly for the older adults. Although, upper body MA was found to be significantly different across the tasks for younger adults, no pairwise difference between tasks were found to be statistically significant after the Bonferroni adjustment.

For lower body muscles, S/W provided the greatest MA \((10.761\% \text{ MVC})\) with lower body MA remaining relatively low across all other activities ranging from 1.472 to 1.968\% MVC (table 3). Lower body MA significantly differed across tasks for both age groups \((p < .001, \text{table } 2)\). Specifically, S/W was the only task to yield significant increases in MA compared to Sit \((p < .001)\). Further, S/W provided significantly greater lower body MA than Ball, Stand, and S/S \((p < .001)\). All other pairwise differences across tasks in lower body MA were not significant. The differences in lower body MA between age groups were not significant \((p = .457)\).

Figure 1 shows representative EMG data recorded over each tested muscle group during an interrupted walking bout (S/W) and interrupted standing bout (S/S). The 6 min sample recording from the 20 min data collection window provides a visual representation of the differences in MA between two common postural interruptions. Specifically, the walking interruption during S/W (figure 1(i)) provided visible differences in EMG amplitudes compared with the adjacent seated periods and with that of the standing interruption during S/S (figure 1(ii)).

Discussion

The primary findings of this study indicate that among popular SB alternatives, interrupting sitting time with 2 min of walking provided the greatest alterations in EE and MA in both age groups. On average, younger and older adults responded similarly to net EE and lower body MA across tasks with an interaction for age and task present in upper body MA. These findings are important considering the accumulating evidence linking poorer health outcomes with reduced EE and skeletal muscle inactivity during SB and the need for effective SB alternatives. Further investigations determining how each of these SB alternatives individually affects clinical outcomes will provide insight into whether the interruption of sitting or the quality of the interruption is important.

Observations that brief interruptions to prolonged sitting are protective against SB-associated health risks (Healy et al. 2008) has led to the development and marketing of several devices and public health strategies. In particular, standing desks have become increasingly popularized over the past decade with little evidence of their ability to alter health outcomes. Population-based studies have identified a beneficial curvilinear dose–response between standing time and mortality risk with the greatest benefits observed at the lower end of the continuum before plateauing, similar to physical activity (Katzmarzyk 2014). However, there should be caution that prolonged standing could introduce its own health risks that may contribute to the plateau of benefits during increased standing durations (Halim et al. 2011). This evidence has led to recent recommendations to break up sitting time by accumulating two to 4 h of standing or other light intensity physical activities to reduce the risks associated with continuous sitting (Buckley et al. 2015). The findings from the current study agree with previous measurements indicating that standing alone is on the lower end of the EE continuum (Ainsworth et al. 1993) and health benefits linked to standing breaks are not likely mediated by changes in EE alone.

While this study alone does not fully elucidate the connection between SB alternatives and health, the findings of this study indicate quantitative differences in the physiological
responses between common SB alternatives. For example, both Stand and S/W provided a significant 120% and 155% increase in net EE compared to Sit, respectively, and S/W was the only task to provide a significant increase in MA in the observed muscles. Also, Ball significantly increased net EE by approximately 50% with non-significant minimal alterations in MA. S/S provided minimal alterations in EE and MA that were not statistically significant when compared to Sit. Lastly, while it is important to note that the small effect size of the S/S task suggests that the current study is underpowered to detect a significant difference relative to Sit, the comparative effects of the other tasks in this study indicate that it is unlikely that sitting interrupted by brief bouts of standing will provide substantial increases in EE or MA.

Interestingly, although EE was significantly increased during continuous standing there was little difference in MA compared to continuous sitting. Possible explanations for the increased EE during continuous standing may have occurred through circulatory changes due to the effects of gravity and/or a relative increase in episodic, low amplitude bursts of muscle activity between antagonistic stabilizer muscles that may not have been detected using the current method and muscle groups. This is in contrast to the high frequency of greater amplitude bursts of MA observed in the muscle groups selected for this study during S/W (see figure 1). Additionally, although the initial burst in MA to erect the body and the periodic, low-amplitude synergistic bursts to maintain a balanced upright position may not have provided a significant effect on MA during a standing interruption, the cumulative effect of these small perturbations may be sufficient to provide health benefits when performed periodically over long timeframes and should be further investigated. With limited alterations in MA for continuous standing and the potential exposure to other health risks, alternative approaches to continuous standing may be necessary to break up SB including, but not limited to, light ambulatory activities.

Recent experimental studies have suggested that brief interruptions in SB that incorporate bouts of light-to-moderate intensity physical activity may provide improved glucose, insulin, and blood lipid control (Dunstan et al 2012, Peddie et al 2013). The significant increase in MA observed in the current study during the brief bout of walking at an intensity of less than three METs may explain the improved metabolic responses observed in previous studies. Among animal models, a low-intensity activity including treadmill walking provided nearly an eight-fold increase in skeletal muscle LPL activity which is suggestive of altered lipid metabolism and insulin sensitivity. Potential mechanisms to explain this include periodic loading of the muscle that may lead to the release of myokines that regulate cellular expression and alter metabolic regulation (Bey and Hamilton 2003, Hamilton et al 2007). Collectively, this highlights the necessity to introduce periodic light-to-moderate intensity large skeletal muscle contractions, not only for increasing EE to improve caloric balance, but to augment a sedentary physiological state that reduces lipid metabolism and predisposes to traits specific to obesity, metabolic syndrome, type-II diabetes, advanced aging, muscle wasting, and mortality (Bey and Hamilton 2003, Hamilton 2007). Whether the high amplitude and high frequency MA observed during walking interruptions in the current study provide the necessary alterations to contribute to improved metabolic control and markers of health outcomes needs to be further investigated.

The findings of this study are consistent with previous literature that has assessed either EE or MA during various SB alternatives (Gregory et al 2006, McGill et al 2006, Swartz et al 2011, Altenburg et al 2013, Tikkanen et al 2013). When extrapolating the results of this study across a 40 h work week, individuals performing standing breaks every 20 min, continuously sitting on a stability ball, continuously standing, and using walking breaks every 20 min may increase net EE by approximately 130, 247, 590, and 816 kcal per week when compared to continuously sitting, respectively. Previous work to quantify net increases in
EE using self-paced walking of 5 min every hour equated to 660 kcal increases, respectively, when extrapolated across a 40 h work week (Swartz et al. 2011). It is important to note that current evidence has not indicated whether the act of interrupting the physiological state of SB is sufficient to provide health benefits or if activities stratified by influences on MA and EE provide varying health effects. However, considering the estimated 142 kcal d−1 (710 kcal/week) deficit in occupational PA-related EE that is predictive of the trends in obesity over the past 50 years (Church et al. 2011), the approximate values of caloric expenditure during certain activities may be clinically relevant for energy balance.

The observations in MA of the upper and lower body in this study are congruent with those in other MA studies. Previous work investigating MA of the m. erector spinae during prolonged office chair sitting with a backrest found mean values not exceeding 2% and amplitudes not exceeding 8% of MVC (van Dieen et al. 2001, Beach et al. 2003). Additionally, little difference in MA has been observed in the m. erector spinae when incorporating a stability ball (Gregory et al. 2006, McGill et al. 2006). Median values of the m. trapezius were below 16% of MVC across all tasks performed in an office work day while using various dynamic office chairs (Ellegast et al. 2012). Therefore, it appears that alternative postures and sitting apparatus provide little consequence in altering upper body MA. Interestingly, there was a potential interaction for age and task in upper body MA which was primarily driven by discrepancies in MA during S/W. Proposed reasons for this discrepancy include more exaggerated MA responses from greater disuse in the upper body muscles of older adults and/or compromised balance with increased efforts by the upper limbs.

Lastly, lower body MA responses were consistent with a previous study that measured MA during activities of daily living. In particular, Tikkanen et al. (2013) observed a 2.5- and 7.5-fold increase in lower limb MA during activities of daily living like standing and walking, respectively. The observations in the current study showed that lower body MA remained relatively unchanged until a walking bout was initiated which resulted in an 8.3-fold increase in MA of the lower limb muscles. No other task was able to effectively increase MA beyond levels consistent with continuous sitting.

There are key strengths and limitations to address in this study. Among the strengths, this is the only study to our knowledge that collectively addresses the acute EE and MA responses of SB and its alternatives. This is an initial step into performing long-term studies on how EE and MA may affect metabolic markers and CVD risk factors. Additionally, this is the first study to our knowledge that has investigated SB alternative responses in two distinct age groups. Older adults are a segment of the population most at risk for SB prevalence and its associated health risks. Lastly, the dependent variables in this study were collected using objective, reliable, and valid methods of measurement.

A key limitation of this study is the small sample size. Consequently, a post-hoc power analysis with the observed effect sizes (presented in table 3) was conducted which showed that the study sample was sufficiently powered (of at least 80%) to detect overall difference across tasks for the net EE and MA outcomes. However, the study sample is not sufficiently powered to detect differences between age groups and the interaction effect of age and tasks. Specifically, to obtain 80% power for detecting the interaction effect of age and task for the upper body MA with an alpha level of .05, a sample of approximately 24 per age group will be needed. Another potential limitation is that the current study only observed four muscle groups to collect MA data which may have limited our ability to detect MA from multiple muscle sites and antagonistic muscle groups. However, the four muscle sites selected were relevant to the tasks performed as indicated in previous studies. Also, the portable surface EMG equipment used in this study may not have been as sensitive to small amplitude changes as other laboratory-based systems, though the system has been validated and used during free-living
situations (Walters et al 2013). Lastly, the analysis of the data included a summarized effect for each task across a 20 min window and we did not collect biomarkers. Therefore, we are unaware if the minimal changes in MA during certain low-stimulus activities are able to provide a protective benefit.

Conclusion

While comparing common SB alternatives, there were quantifiable differences in their ability to alter both EE and MA with brief walking interruptions providing the greatest effect when compared to stability ball use, continuous standing, and standing interruptions. Introducing 2 min of self-paced walking to interrupt sitting bouts in 20 min intervals has the potential to effectively stimulate the musculature of the body and increase gross EE by 25%, or 163 kcal, during an 8 h work day. Future SB interventions should be directed toward advocating for breaks that include short, frequent self-paced walking bouts to break up sitting time in office and home settings in all age groups and whether these acute effects transfer to positive health outcomes.

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