Three minutes of moderate-intensity stair walking improves glucose and insulin but not insulin sensitivity or total antioxidant capacity

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Abstract  Background and aims: This study examined the effect of moderate intensity stair stepping exercise on the glycemic response, and antioxidant capacity (TAC) during an oral glucose tolerance test (OGTT).

Methods and results: Thirty participants (women N 12) completed 4 OGTTs during rest or stair walking bouts of 1, 3, and 10 min in a randomized order. Blood was collected at baseline and 30 min during the OGTTs and analyzed for glucose, insulin, TAC, and lactate. Glucose concentrations were decreased following the 10 min (22.69 (234.66 to 10.72) mg/dL, p < 0.002) and 3 min (15.37 (225.05 to 5.69) mg/dL, p < 0.004) bouts but not the 1 min bout (6.18 (219.54 to 7.18) mg/dL, p = 0.352). Insulin concentrations were decreased following the 10 min (6.11 (28.86 to 3.36) mIU/dL, p < 0.001) and 3 min (2.589 (24.54 to 0.63) mIU/dL, p < 0.012) bouts but not the 1 min bout (0.37 (21.87 to 1.13) mIU/dL, p = 0.616). Insulin sensitivity index values showed a significant increase in the 10-min trial (1.81 (20.03 to 3.58), p < 0.048), but not during the 3 min (0.65 (20.66 to 1.96) p = 0.317) or 1 min trial (0.13 (21.58 to 1.84) p = 0.878). There was no omnibus effect for trial in TAC (p = 0.132, f2 = 0.07). There was no interaction between trial and time for blood lactate (p = 0.621, f2 = 0.02).

Conclusion: This study provides evidence bouts as short as 3 min decrease postprandial blood glucose and insulin levels but longer bouts are needed to affect insulin sensitivity.

Introduction

Type-II diabetes mellitus (T2DM) is the most common form of diabetes in the United States, affecting more than 30 million Americans. While a clinical diagnosis relies on ordinal thresholds, the pathology is a continuous progression of worsening insulin resistance and sensitivity.

Factors associated with the development of T2DM include postprandial hyperglycemia, hyperinsulinemia, and oxidative stress [1–3]. Pharmacological and non-
pharmacological interventions have proven to be effective in reducing postprandial glycemic and oxidative responses [4]. An effective non-pharmacological countermeasure to postprandial glycemic and oxidative responses is exercise. Muscular activity can enhance blood glucose uptake from systemic circulation via translocation of non-insulin dependent GLUT-4 transporters. Individuals with and without diabetes can utilize this process through exercise to acutely lower postprandial blood glucose levels [5–7]. Bouts of exercise, lasting as little as 20 min, have also been shown to increase endogenous total antioxidant capacity (TAC) [8]. During moderate intensity exercise this effect is additive to insulin mediated glucose uptake via independent and synergistic mechanisms leading to increased glucose tolerance and insulin sensitivity [9]. High or very high intensity exercise, such as high-intensity interval training (HIIT) or reduced-exertion high-intensity interval training (REHIT), can be of much shorter duration and still elicit beneficial effects on postprandial blood glucose [10–12], however this is mostly unsuitable to conditions outside of controlled laboratory environments. However, while exercise is known to be an effective means of attenuating the various stresses associated with the postprandial response, adherence is low with nearly 80% of Americans failing to meet the physical activity recommendations established by the CDC [13]. In order to overcome poor adherence, approaches using exercise to target the postprandial response should consider the common barriers to exercise participation such as time, perceived effort, intensity, convenience, equipment, and location [14,15].

It has previously been shown that as little as 1–3 min of moderate intensity stair stepping can reduce peak postprandial blood glucose responses. While these bouts were of moderate intensity based on %VO2, subjects rated them as low intensity via ratings of perceived exertion (RPE) suggesting an underestimation of true intensity [6,7]. Moderate intensity has been used as a descriptor for these bouts throughout the manuscript. These bouts are also without sex differences or moderation by cardiorespiratory fitness levels [16,17]. The effect of these short, single bouts on insulin, TAC, and blood lactate are unknown. Therefore, the purpose of the present study is to examine the effect of short duration, moderate intensity stair stepping of different durations on glycemic control (i.e. glucose, insulin, and insulin sensitivity following a standard glucose challenge). We hypothesized that the moderate intensity exercise would result in insulin sensitizing and overall glucose lowering effects as well as increase TAC in response to normal postprandrial rises in blood glucose.

Methods

Subjects

Thirty-four healthy adult participants were enrolled in this study with a total of 30 (males n = 18, females n = 12, Table 1) completing the study due to 2 participants withdrawing because of scheduling difficulties and 2 unable to provide venous blood for biomarker analysis. The present study is a secondary data analysis of a previously published intervention [6], therefore no power calculation or participant recruitment stopping point were determined a priori. All participants were healthy by self-report, recruited from the San Diego State University area, and eligibility criteria included a fasting blood glucose value between 80–125 mg/dL as established by the American Diabetes Association. Females who were pregnant or planning to become pregnant were excluded from this study. All participants were considered low risk for exercise participation per the American College of Sports Medicine screening which assesses the following factors: current physical activity levels; signs or symptoms of cardiovascular, renal, or metabolic disease; and planned exercise intensity [18]. Prior to the study, participants were asked to complete the Physical Activity Readiness Questionnaire (PAR-Q) to screen for potential cardiovascular risks. All participants provided written informed consent and the study was approved by the Institutional Review Board at San Diego State University.

Study protocol

In this crossover trial, participants were recruited from October 2016 through August 2017 and reported to the exercise physiology laboratory for a total of 5 visits. The first visit was to determine peak aerobic capacity (VO2peak) using a graded exercise test to volitional exhaustion, with results previously reported [6]. During the second visit, a resting oral glucose tolerance test (OGTT) was performed. All remaining visits consisted of an OGTT combined with 1, 3, or 10 min of self-selected intensity stair climbing/descending in randomized order, determined using a free, online random number generator.

Participants arrived to the laboratory 3 times for stair climbing/descending trials of 1 min, 3 min, and 10 min in randomized order. Prior to the first stair trial, participants were asked to determine a self-selected stepping pace between 90 and 110 steps per minute that they could comfortably maintain for 10 min. This pace was set to a metronome and held constant across all trials. The stair climbing bouts began at 18, 25, or 27 min after finishing the dextrose solution for the 10, 3, and 1-min climbs, respectively, in order to allow blood collection at the 30 min mark, which was the anticipated time of peak

<p>| Table 1: Participant descriptive statistics and baseline biochemical values. |
|---------------------------------|-----------------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th></th>
<th>Males (n = 18)</th>
<th>Females (n = 12)</th>
<th>Total (n = 30)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>26.8 (6.3)</td>
<td>25.3 (4.7)</td>
<td>26.2 (5.7)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>76.2 (8.1)</td>
<td>64.0 (6.4)</td>
<td>69.8 (14.6)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>24.4 (2.0)</td>
<td>24.1 (2.8)</td>
<td>24.3 (2.3)</td>
</tr>
<tr>
<td>VO2peak (mL/kg/min)</td>
<td>47.9 (15.5)</td>
<td>38.5 (5.0)</td>
<td>44.2 (13.1)</td>
</tr>
<tr>
<td>Glucose Baseline (mg/dL)</td>
<td>96.4 (11.6)</td>
<td>94.2 (8.8)</td>
<td>95.5 (10.5)</td>
</tr>
<tr>
<td>Insulin Baseline (µU/dL)</td>
<td>1.7 (0.9)</td>
<td>1.4 (0.8)</td>
<td>1.6 (0.9)</td>
</tr>
<tr>
<td>HOMA-IR (mg/dL)</td>
<td>43.1 (21.0)</td>
<td>48.5 (22.6)</td>
<td>45.2 (21.4)</td>
</tr>
<tr>
<td>HOMA-β Baseline (%)</td>
<td>1.0 (0.5)</td>
<td>0.9 (0.4)</td>
<td>0.9 (0.4)</td>
</tr>
</tbody>
</table>

* All values as Mean (SD).
glucose during an OGTT based on our pilot data. The stair stepping exercise was completed in a stairwell consisting of 21 steps that were ascended and descended continuously. Steps were 15 cm in height, in accordance with United States Occupational Safety and Health Administration guidelines [19], and located in the Exercise and Nutritional Sciences building of San Diego State University. Participants provided ratings of perceived exertion based on the modified Borg scale at the end of each exercise bout [20]. All visits were 48 h to one week apart, conducted at the same time of day (between 8 am to 11 am and with subsequent visits ≤ 1 h of previous visits), and the participants were asked to maintain the same diet and exercise habits 48 h before each trial. Participants were non-smokers and abstained from alcohol and caffeine 48 h prior to each trial. While adherence to dietary and lifestyle instructions cannot be assured, the randomized crossover design would be expected to balance out any differences. 

VO_{2peak} values were determined using a treadmill ramp test, as described previously [6]. For all follow up laboratory visits, participants were asked to fast to overnight for a minimum of 10 h, with water allowed ad libitum. Following VO_{2peak} testing, participants returned to the lab within one week for a 60-min OGTT without exercise, which served as the control condition and confirmed that they were normoglycemic before continuing the intervention trials. The 60-min OGTT was selected over longer duration OGTTs as pilot data suggested a greater duration of values at that timepoint and previous studies have validated the 60-min OGTT for risk prediction [21,22]. Prior to all tests, participants were fitted with a heart rate monitor (Polar T31 Transmitter, Polar USA) around their chest and were asked to sit quietly. At the beginning of testing, 5 mL of venous blood was collected into an EDTA coated tube from a vein in the antecubital space. Blood was centrifuged at 2300 × g for 10 min at 4 °C. Plasma was then aliquoted and stored at −80 °C for later analysis. Participants then consumed 75 g of dextrose powder dissolved in 160z of water, within 5 min or less. Upon finishing the dextrose solution, timing of the trial began. A single follow-up venous blood sample was collected 30 min following dextrose consumption, and processed the same as the baseline sample. Participants remained seated quietly until the 60-min time point, which signaled the end of the trial.

**Sample analyses**

Venous blood samples were later analyzed for glucose [Stanbio Glucose Liquicolor], insulin [ALPCO Ultrasensitive Insulin ELISA], TAC [Cayman Chemical Antioxidant Assay Kit], and lactate using commercially available kits [EKF Biosen C-Line Lactate Analyzer].

**Statistical analyses**

Statistical analyses were performed using SPSS, version 24. Insulin indices were calculated using the following equations:

\[
HOMA_{IR} = \frac{\text{Glucose} \times \text{Insulin}}{405}
\]

\[
HOMA_\beta = \frac{360 \times \text{Insulin}}{\text{Glucose} - 63}
\]

\[
ISI = \frac{\text{fasting glucose} \times \text{fasting insulin}}{\text{mean glucose} \times \text{mean insulin during OGTT}}
\]

Changes in glucose, TAC, and insulin (Δglucose, ΔTAC, and Δinsulin, respectively) were then calculated using the following equation:

\[
\Delta = 30 \text{ minute value – baseline value}
\]

These data were checked for normality, then analyzed using a one-way repeated measures analysis of variance (ANOVA) with LSD adjustments for post hoc pairwise comparisons tests. Violations of the assumption of sphericity were adjusted using the Greenhouse-Geisser correction if estimated epsilon (ε) was <0.75 and the Huynh-Feldt correction if > 0.75. The α-level was set a priori at 0.05 to determine statistical significance. Results are presented as mean (95% CI) unless indicated otherwise.

**Results**

**Baseline measurements**

Participants were normoglycemic with no difference in fasting blood glucose, insulin, ISI, HOMA-IR, HOMA-β, or TAC at baseline across conditions (Table 1). There were no interactions between sex and Δglucose, Δinsulin, ISI, or ΔTAC (p > 0.05).

**Glucose**

Results for Δglucose response during moderate intensity stair stepping exercise based on VO_{2peak} data revealed significant differences over the course of the experiment [F (3,87) = 5.70, \( p < 0.002 \), \( \eta^2 = 0.16 \)]. The LSD post hoc testing showed a smaller delta score for peak glucose during the 10 min exercise condition (22.69 (10.72–34.66), \( p < 0.002 \)) and the 3 min exercise condition (15.37 (5.69–25.05), \( p < 0.004 \)) as compared to control. No differences were seen between 1 min exercise and the control condition (6.18 (−7.18 to 19.54), \( p = 0.352 \)) (Figs. 1A and 2A).

**Insulin**

Results for Δinsulin response during moderate intensity stair stepping exercise revealed significant differences over the course of the experiment using the Huynh-Feldt adjusted values due to a violation of sphericity (\( p < 0.009, \eta^2 > 0.75 \)) [F (2.385, 69,171) = 12.63, \( p < 0.001 \), \( \eta^2 = 0.30 \)]. LSD post hoc testing showed a smaller delta score for peak insulin levels during the 10 min exercise (6.11 (3.36–8.86), \( p < 0.001 \)) than the 3 min exercise condition (2.59 (0.63–4.54), \( p < 0.012 \)) as compared to...
control. No differences were seen between 1 min exercise and the control condition (0.37 (−1.13 to 1.87), \(p = 0.616\)) (Figs. 1B and 2B).

**Insulin sensitivity index**

Results for ISI during moderate intensity stair stepping exercise revealed significant differences over the course of the experiment [\(F(3, 87) = 3.651, p < 0.017, \eta^2 = 0.11\)]. LSD post hoc testing showed a significant increase in the 10-min trial compared to the control (1.81 (0.03 to 3.58), \(p < 0.048\)). No differences were seen in the 3-min trial (0.65 (−0.66 to 1.96) \(p = 0.317\)) or 1-min trial (0.13 (−1.58 to 1.84) \(p = 0.878\)) compared to the control (Figs. 1C and 2C).

**Total antioxidant capacity**

Results for ΔTAC response during moderate intensity stair stepping exercise revealed no significant differences over the course of the experiment using the Huynh-Feldt adjusted values due to a violation of sphericity (\(p < 0.008, \varepsilon > 0.75\)) [\(F(2.497, 72.426) = 2.00, p = 0.132, \eta^2 = 0.07\)] (Figs. 1D and 2D).

**Lactate**

Results for blood lactate revealed no main effect for trial [\(F(3, 60) = 2.83, p = 0.064, \eta^2 = 0.12\)] or interaction between trial and time [\(F(3, 60) = 0.49, p = 0.621, \eta^2 = 0.02\)] but a main effect for time [\(F(1, 20) = 4.58, p < 0.005, \eta^2 = 0.35\)]. Greenhouse-Geisser adjusted values were used for trial and interaction between trial and time due to a violation of sphericity (\(p < 0.05, \varepsilon < 0.75\)).

**Discussion**

Moderate intensity stair stepping exercise lasting 3 and 10 min decreased both blood glucose and insulin (Fig. 1A)

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and B). No changes were observed with 1 min of stair stepping with at least 10 min of stair stepping required to improve insulin sensitivity. No effects were seen for TAC. Other studies utilizing short, exercise bouts report physical activities such as standing, walking [23,24], simple resistance training [24], and stair walking [25] to be effective interventions for decreasing blood glucose. However, all of these studies required repeated bouts of exercise (versus single bouts in the current study) or longer durations to show any significant effect on postprandial glycemic response and none report measurements of TAC. This study is one of the few to investigate the effects of short stair stepping trials on postprandial insulin through insulin indices. The results of ISI showed a significant improvement in insulin sensitivity in the 10-min stair stepping trial. This improvement resulted from the blunted postprandial glucose and insulin peak. While other research has also shown exercise has the ability to significantly reduce postprandial glucose and insulin in a time dependent manner, this study illustrates the impact of an exercise intervention of very short duration.

Lifestyle interventions incorporating exercise are a fundamental part of the treatment for T2DM. While insulin resistance is often the cause of hyperinsulinemia, hyperinsulinemia itself contributes to increasing insulin resistance via homologous desensitization and promotion of receptor degradation [26]. Because each insulin receptor has two binding sites, one of high and one of low affinity, as insulin concentrations and occupation of binding sites increases, the average affinity diminishes [26–28]. Its also been shown exposure to insulin increases internalization and degradation of hormone-occupied receptors [26,29].

Physical activity may offer a means of breaking the positive feedback loop between hyperinsulinemia and insulin resistance by reducing blood glucose via non-insulin dependent pathways, improving insulin sensitivity, and ultimately reducing circulating insulin levels [30]. We were able to improve all three of these factors (PBG, ISI, and insulin) with our stair stepping intervention.

Among those at risk, the postprandial glucose response is an independent predictor of diabetes risk factors [31], cardiovascular events, cardiovascular disease, and cardiovascular and all-cause mortality [32]. The association of postprandial glucose response and various diseases is often linear and without a threshold, unlike fasting glucose levels, extending its usefulness to non-diabetic and apparently healthy individuals as well [33]. This highlights the potential benefits of postprandial glucose lowering interventions for individuals with normal and impaired glucose tolerance. In this analysis of venous blood samples we confirmed the glucose lowering effects of single, short stair stepping bouts shown in a previous analysis which relied on finger stick samples. However, the gold standard for overt diabetes and long-term glucose control is glycosylated hemoglobin (HbA1c) [34]. The contribution of postprandial glucose to HbA1c is positively associated with control of diabetes as those with good glucose control, defined as HbA1c <7.3%, postprandial glucose was found to contribute to 70% of HbA1c [35]. HbA1c was not assessed in this study and it is unlikely that given the

Figure 2  Pre and Post Glucose (A), Pre and Post Insulin (B), ISI (C), and Pre and Post TAC (D) Values During Moderate Intensity Stair Walking with Connecting Lines. Symbols (C, 1, 3, or 10) indicates a difference (p < 0.05) from that trial (difference in delta for A, B, and D).
general health profile of the participants that they would have elevated HbA1c levels.

We chose stair stepping due to its low cost, short duration required, and the fact that it is a readily available mode of exercise for most people. Stair stepping has the additional advantage of being perceived as lower intensity than objective measures indicate [6]. Stair stepping at a self-selected, comfortable pace that elicited moderate-vigorous intensity by assessment of VO2, was indeed perceived as moderate intensity by RPE [6]. Here we confirm moderate intensity was achieved by lactate values, which were between 7.5 and 8 mmol/L, similar to levels seen in other studies during moderate and high intensity exercise bouts [36–38]. This again highlights the suitability of short stair stepping bouts as a physical activity recommendation, since people are more likely to accept physical activity that is convenient and with lower perceived effort [39–41]. An additional advantage of stair stepping is the larger magnitude of reduction in PBG compared to other exercise interventions of similar intensity and duration [42,43]. Together, these unique aspects of stair stepping may help overcome the poor compliance seen with other exercise interventions.

This study had several limitations. It was an exploratory expansion of a previous study that included additional measurements. The statistical results should therefore be seen with caution.

In analyzing TAC, we used plasma samples collected into EDTA coated tubes to prevent coagulation. The manufacturer recommends blood collection into citrate or heparin coated tubes rather than EDTA, however Kampa et al. [44] and Miller et al. [45] reported measuring TAC using EDTA, heparin, and citrate previously with acceptable results. In fact, Kampa et al. showed EDTA and heparin to yield similar TAC readings, with citrate being measured approximately 20% lower [44]. Nevertheless, we reported all outcomes as change scores (Δ) from 30 min to baseline measurements rather than as raw values to correct for this potential error. Hence, any consistent error associated with the anticoagulant should cancel out.

Additionally, TAC measurement takes into account all antioxidants in the body. This includes endogenous components such as superoxide dismutase, glutathione peroxidase, and uric acid, among others. TAC measurement also includes exogenous antioxidant components such as vitamins and phytochemicals taken in through the diet [3,46]. Therefore, if a participant’s recent food intake was inconsistent in antioxidant containing fruits and vegetables, measurement of TAC alone might not give an accurate assessment of the effect of our intervention [44]. We asked participants to not make changes to their diet during the course of the study and eat the same foods as much as possible in the days prior to each test in order to minimize potential confounding of food intake. Furthermore, randomization should have balanced out any variations stemming from changes in food intake. Given the null results for TAC it is unlikely that diet had a significant impact on the outcomes.

Only two timepoints were assessed with the timing based on the primary outcome of this study, blood glucose. Therefore, it is possible that changes in TAC were missed either with acute changes occurring and waning between the exercise intervention and post exercise blood draw or occurring after the blood draw. Although the time course between cytokines and oxidative stress can be as short as 5 min [47], changes in both pro- and anti-inflammatory cytokines appear to change after 30 min postprandially, but not before [48]. Collection of blood samples at minute 30 in this current study may have been to early to capture differences in TAC. Future studies could use more time points and standardize meals of the previous day.

We also were not able to do a full physical examination and had to rely on questionnaires. These can be subjective and influenced by self-reporting bias.

The present study evaluated postprandial effects using a standard 75 g of dextrose, a relatively large amount of carbohydrate typically not consumed in one sitting without the presence of fats and protein. Future studies should include a mixed meal to mimic everyday postprandial metabolic effects.

Lastly, our study examined only young (≤38 y), healthy participants. Therefore, caution must be used in generalizing results to all populations. Certain populations including those with physical disability or frailty may be unable to participate in stair stepping interventions. Future studies should investigate populations who have impaired glucose tolerance, insulin resistance, or overt diabetes who would be expected to see a greater benefit.

In conclusion, short duration, moderate intensity stair stepping causes a decrease in peak postprandial glucose and insulin levels with as little as 3 min but longer (10 min) stepping was necessary to also increase in insulin sensitivity after a standard glucose challenge. This intervention had no effect on TAC.

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Authors’ contributions

JM and EMB coordinated the study, carried out data collection including participant visits and assays, performed the statistical analysis, and drafted the manuscript. KW assisted in data collection and drafted the manuscript. JK conceived the study, performed the statistical analysis, and drafted the manuscript. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Declaration of competing interest

The authors report no conflict of interest.

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Effect of moderate intensity stair walking

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