



# Sex differences in the acute effect of stair-climbing on postprandial blood glucose levels: A randomized controlled trial

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## ABSTRACT

**Backgrounds and aims:** Single, short stair climbing and descending (SCD) bouts of low to moderate intensity effectively lower postprandial blood glucose but previous reports have found conflicting results on interactions by sex during exercise. We hypothesize that SCD at a self-selected intensity will be equally effective at lowering postprandial blood glucose in males and females. **Methods and Results:** Thirty subjects (age: 23.8 (3.0) years) performed 0, 1, 3, and 10 min of SCD following consumption of a mixed meal. SCD was performed at a self-selected comfortable pace and all bouts ended at minute 28. Postprandial blood glucose was measured every 15 min for 1 h and analyzed as glucose over time, area under the curve (AUC), and incremental AUC (iAUC) using mixed-design ANOVAs with repeated measures. Although there was no interaction between sex and condition or time ( $p = .129$  to  $.541$ ) for glucose over time, AUC, or iAUC, there was a main effect for sex for glucose over time ( $p = .004$ ) and AUC ( $p = .006$ ), but not iAUC ( $p = .125$ ). Females had higher blood glucose throughout each trial (22% (13 to 31%),  $p = .004$ ) but both males' and females' postprandial blood glucose was lowered following 10 min of SCD relative to the seated control condition. **Conclusions:** Males and females benefited equally from single, short SCD bouts of low to moderate intensity despite females having higher blood glucose at all time points. Previous findings of sex differences in the attenuating effect of exercise on postprandial blood glucose are likely due to the use of absolute workloads leading to varying relative intensities.

## 1. Introduction

Cardiometabolic diseases remain among the top causes of death in developed countries with an associated global economic burden of trillions of dollars. While physical activity ameliorates the risk of cardiometabolic disease, adherence to such interventions is often poor [1–3]. Postprandial blood glucose (PBG) is a compelling target for disease risk reduction due to its linear, independent association with disease and mortality risk in both diabetics and non-diabetics alike, unlike fasting glucose and glycosylated hemoglobin (HbA1c) [4–8]. Single, short, low to moderate intensity stair climbing and descending bouts (SCD) are an effective means of improving postprandial blood glucose, insulin levels, and insulin sensitivity following an oral glucose tolerance test (OGTT) and mixed meal [9–11] with fewer barriers, including time, perceived exertion, cost, and self-efficacy, than other modes of exercise [12]. Previous research has shown SCD interventions after an OGTT are equally effective for males and females, and regardless of

cardiorespiratory fitness levels [13,14]. Daily SCD has also been shown to be associated with a lower risk of metabolic syndrome [15]. Health organizations in developed countries have begun promoting SCD interventions to the general population [16–18]. However, it is important to ensure such recommendations are beneficial for the population as a whole, including those often underrepresented in research.

Potential differences in physiological responses by sex are often neglected for a variety of reasons. Whether there are sex differences in the postprandial glucose attenuation following exercise interventions is important and would allow for more targeted public health strategies if necessary. Evidence of sex differences in postprandial glucose lowering exercise interventions is mixed [14,19–23]. A previous study found no sex differences in the postprandial blood glucose lowering effects of SCD following an oral glucose tolerance test (OGTT) [14] but potential sex differences with this intervention following a mixed meal have yet to be determined. This previous intervention used an OGTT and thus lacked external validity as few individuals consume 75 g of dextrose without other food items or macronutrients. A mixed meal reflecting the average

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**Abbreviations list:**

SCD	stair climbing and descending
PBG	postprandial blood glucose
AUC	area under the curve
iAUC	incremental area under the curve
HbA1c	glycosylated hemoglobin
OGTT	oral glucose tolerance test
RPE	ratings of perceived exertion

macronutrient intake of Americans was used in this study to increase external validity and increase the applicability of the results to real-world scenarios. The main purpose of this paper is to determine whether there are sex differences in the effects of SCD on PBG following a mixed meal. We hypothesize SCD at a self-selected intensity will be equally effective at lowering PBG in males and females.

## 2. Methods

Thirty subjects (18 females, age 22.8 (2.8) years; 12 males, age 24.9 (3.4) years) (Table 1) participated. Participants were screened for cardiovascular risk using the Physical Activity Readiness Questionnaire [24] and deemed as low risk for exercise participation [25]. All participants provided written informed consent and the study was approved by the Institutional Review Board at San Diego State University.

This study was a randomized controlled crossover trial with 4 conditions: a seated control, 1 min SCD, 3 min SCD, or 10 min SCD after a mixed meal. Visits occurred in the morning between the hours of 7 am and 11 am. To minimize potential circadian-related variations subjects were required to schedule all visits at the same time of day (within 1 h). Subjects were also asked to keep the length of their overnight fast consistent (within 1 h), consume the same last meal the night before each visit, avoid caffeine the morning of, and maintain their usual diet and lifestyle habits throughout their participation. Visits were separated by a minimum of 48 h and a maximum of 1 week. The experiment was conducted in the Clinical Nutrition and Physiological Sciences Laboratory at San Diego State University. The lab was well-lit, quiet, and maintained at a temperature of 22 °C. Randomization was performed using a free online random number generator program.

Baseline measurements were obtained before participants were provided with a standardized meal as described below. Participants were asked to finish the entire meal within 15 min. Time to completion of the meal was noted and the subjects were encouraged to consume the meal in the same amount of time (within 1 min) at each subsequent visit. Completion of the meal was denoted as minute 0 and measurements were then taken every 15 min thereafter for 1 h. Participants remained seated for the entire visit except for the prescribed exercise condition.

All exercise bouts ended at minute 28 to allow enough time for measurements at minute 30. Therefore, the 1, 3, and 10 min SCD bouts started at minute 27, 25, and 18 respectively. SCD bouts were performed

**Table 1**  
Participant demographics.

	Age (y)	Weight (kg)	BMI (kg/m <sup>2</sup> )	Fasting Blood Glucose (mg/dL)
All (N = 30)	23.8 (3.0)	69.8 (12.8)	23.7 (3.0)	113 (10)
Male (n = 12)	24.9 (3.4)	80.0 (10.0)	24.9 (2.8)	118 (11)
Female (n = 18)	22.8 (2.8)	63.7 (9.3)	23.6 (3.0)	110 (7)

Fasting blood glucose was averaged from the participants' four visits. Data presented as mean (SD).

continuously using an indoor 21-step stairwell. Participants self-selected a comfortable SCD pace (90–110 steps per minute) that was held constant intra-individually for every visit. Adherence to this pace was ensured using a metronome and direct supervision of the participants by investigators.

The standardized meal was created to reflect the average macronutrient intake of adults in the United States. It was comprised of 1 cup of fortified breakfast cereal (Cheerios, General Mills), 1 cup of 2% cow's milk (Trader Joe's), 1 slice of 100% whole wheat bread (Western Hearth), 2 tablespoons of peanut butter (Jif), 1 tablespoon of blackberry jam (Smucker's), and 100 g of a fresh ripe banana (Chiquita) for a total of 650 kilocalories (53% carbohydrate, 33% fat, and 14% protein). The order of consumption of these food items was kept consistent within subjects to minimize the meal order effect [26,27].

Blood glucose measurements were obtained with finger sticks and a glucometer (Nova Max). Measurements were repeated at each time point until two measurements within 15 mg/dL were obtained and then averaged [28].

SPSS version 27 was used for all statistical analyses. Data for measures relating to blood glucose or lactate were normalized by body weight to account for size differences [14]. Blood glucose measurements were analyzed using a 4 (trial) by 5 (time) by 2 (sex) mixed design ANOVA with repeated measures. AUC and iAUC for blood glucose measurements were analyzed using a 4 by 2 mixed design ANOVA with repeated measures. Area under the curve was calculated using the trapezoid rule. Incremental area under the curve was calculated using the trapezoid rule and subtraction of baseline blood glucose levels. Post hoc pairwise comparisons were performed with LSD adjustments. Violations of the assumption of sphericity were corrected with the Greenhouse-Geisser correction if the estimated epsilon ( $\epsilon$ ) was <0.75 or the Huynh-Feldt correction if > 0.75. The alpha level was set a priori at  $\alpha = 0.05$  for significance in these secondary analyses of this pre-existing data set. Unless stated otherwise, data are presented as mean (95% CI). Power analysis conducted with G\*Power 3.1 [29] based on visually extracted group mean and SEM data from previously published work [30] for independent group comparison yields an estimated effect size of  $d = 1.12$ , which for an alpha error probability of 0.05 and two-tailed analysis results in a calculated power of 1-beta error probability >0.8 for a total Sample of N = 28. The current analysis is part of a larger study [9].

## 3. Results

There was a main effect for sex [ $F(1, 28) = 9.675, p = .004, \eta_p^2 = 0.257$ ] but no interaction between sex and any other tested variable (all  $p > .129$ ). Females' blood glucose was higher than males throughout each trial (22% (13% to 31%),  $p = .004$ ) (Fig. 1).

Among females, there was an interaction between trial and time [ $F(6.170, 104.896) = 7.911, p < .001, \eta_p^2 = 0.318$ ]. Compared to the control condition significant differences were seen at minute 30 for the 10 min (−30% (−42% to −19%),  $p < .001$ ) but not the 1 min (−5% (−13% to 4%),  $p = .275$ ) or 3 min (−6% (−15% to 2%),  $p = .128$ ) SCD bouts. The 10 min SCD bout also reduced PBG compared to the 1 min (−24% (−36% to −13%),  $p < .001$ ) and 3 min (−22% (−32% to −11%),  $p = .001$ ) SCD bouts. At minute 45, PBG was reduced compared to control following 1 min (−8% (−15% to −1%),  $p = .023$ ), 3 min (−7% (−12% to −2%),  $p = .008$ ), and 10 min of SCD (7% (−12% to −1%),  $p = .019$ ).

Among males, there was an interaction between trial and time [ $F(4.697, 51.672) = 5.133, p = .001, \eta_p^2 = 0.318$ ]. Compared to the control condition significant differences were seen at minute 30 for the 10 min SCD bout (−37% (−56% to −19%),  $p = .001$ ) but not the 1 min (−3% (−11% to 5%),  $p = .449$ ) or 3 min SCD bout (−8% (−16% to 0%),  $p = .056$ ). At minute 45, PBG was reduced significantly compared to control following the 10 min SCD bout (−16% (−26% to −6%),  $p = .006$ ) but not the 1 min SCD bout (−4% (−14% to 5%),  $p = .360$ ) or 3 min SCD bout (−6% (−14% to 1%),  $p = .090$ ). The 10min SCD bout also differed

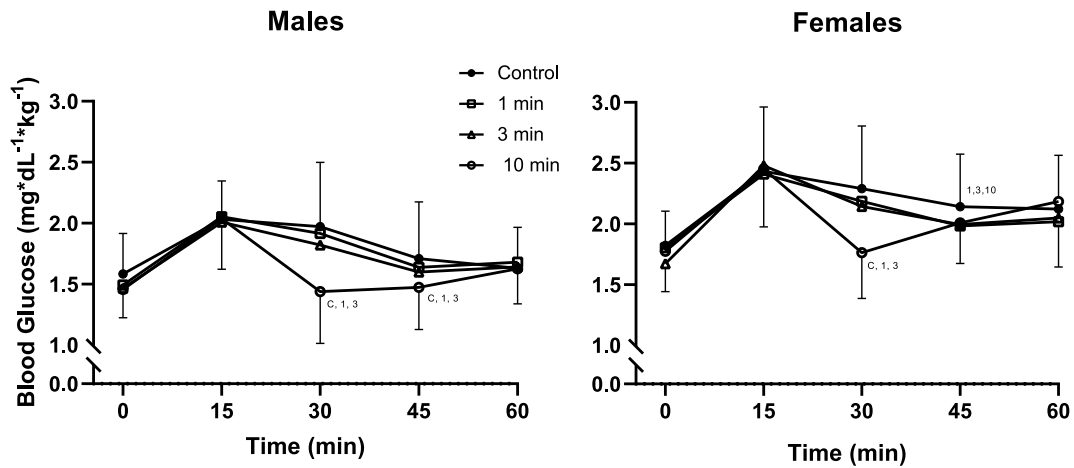


Fig. 1. Blood Glucose Over Time in Males and Females

Changes in blood glucose in males (n = 12) and females (n = 18) over the 60-min mixed meal tolerance test for the seated control, 1 min, 3 min, and 10 min stair climbing and descending conditions. The 1 min, 3 min, and 10 min stairclimbing bouts all ended at minute 28. Blood glucose was analyzed using a 4 (trial) by 5 (time) by 2 (sex) mixed design ANOVA with repeated measures. No significant interaction was detected (p > .129). Post hoc pairwise comparisons were performed with LSD adjustments. Symbols denote significant difference (p < .05) from that condition.

from the 1 min SCD bout at minutes 30 (-25% (-38% to -11%), p = .002) and 45 (-10% (-17% to -3%, p = .013), and the 3 min SCD bout at minutes 30 (-21% (-34% to -8%), p = .004) and 45 (-8% (-15% to -1%, p = .023).

There was no interaction between condition and sex [F (3, 84) = 0.723, p = .541,  $\eta_p^2 = 0.025$ ] but there was a main effect for sex [F (1, 28) = 8.895, p = .006,  $\eta_p^2 = 0.241$ ] (Fig. 2).

Females' AUC was higher than males' during the control (21% (4% to 37%), p = .014), 1 min SCD (18% (4% to 32%), p = .012), 3 min SCD (21% (4% to 39%), p = .016), and 10 min SCD (26% (11% to 41%), p = .001). Among females, there was a main effect for condition [F (3, 51) = 3.992, p = .013,  $\eta_p^2 = 0.190$ ]. Compared to the control condition the 10 min SCD bout significantly reduced PBG (-7% (-11% to -3%), p < .001) but the 1 min SCD (-4% (-9% to 1%), p = .131) and the 3 min

SCD (-4% (-9% to 1%), p = .092) bouts did not. There was also a nonsignificant reduction following the 10 min compared to the 1 min (-3% (-7% to 0%), p = .070) condition.

Among males, there was a main effect for condition [F (3, 33) = 6.826, p = .001,  $\eta_p^2 = 0.383$ ]. Compared to the control condition there was a significant reduction following the 3 min (-5% (-9% to 0%), p = .041) and 10 min (-11% (-19% to -4%), p = .005) but not 1 min SCD (-2% (-7% to 4%), p = .498) bouts. The 10 min SCD bout also reduced AUC compared to the 1 min (-10% (-17% to -2%), p = .015) and 3 min SCD (-7% (-13% to -1%), p = .031) conditions.

There was no interaction between condition and sex [F (3, 84) = 1.398, p = .249,  $\eta_p^2 = 0.048$ ] nor a main effect for sex [F (1, 28) = 2.503, p = .125,  $\eta_p^2 = 0.082$ ] for iAUC (Fig. 3).

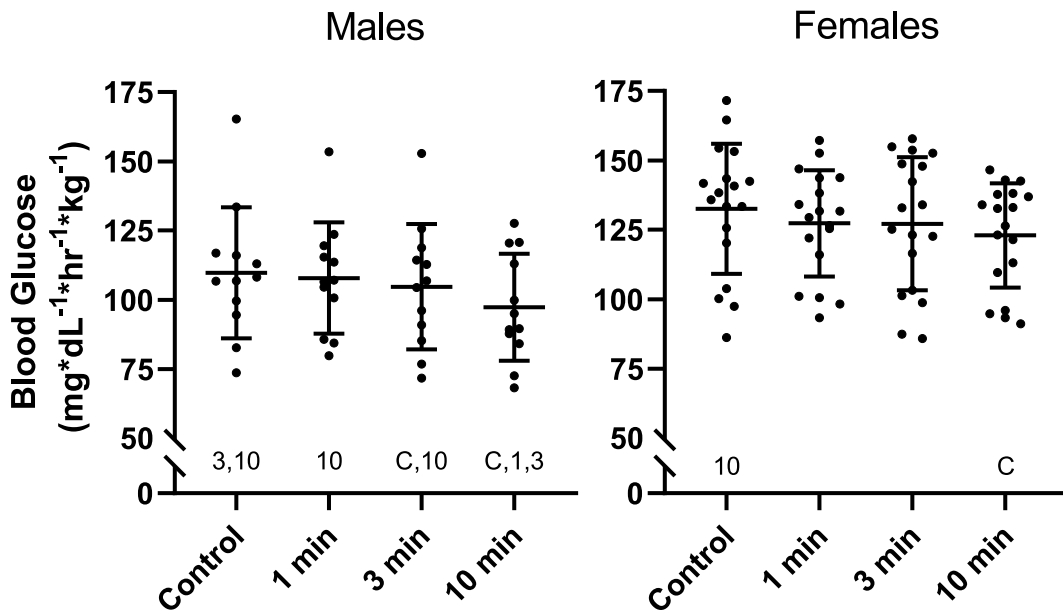
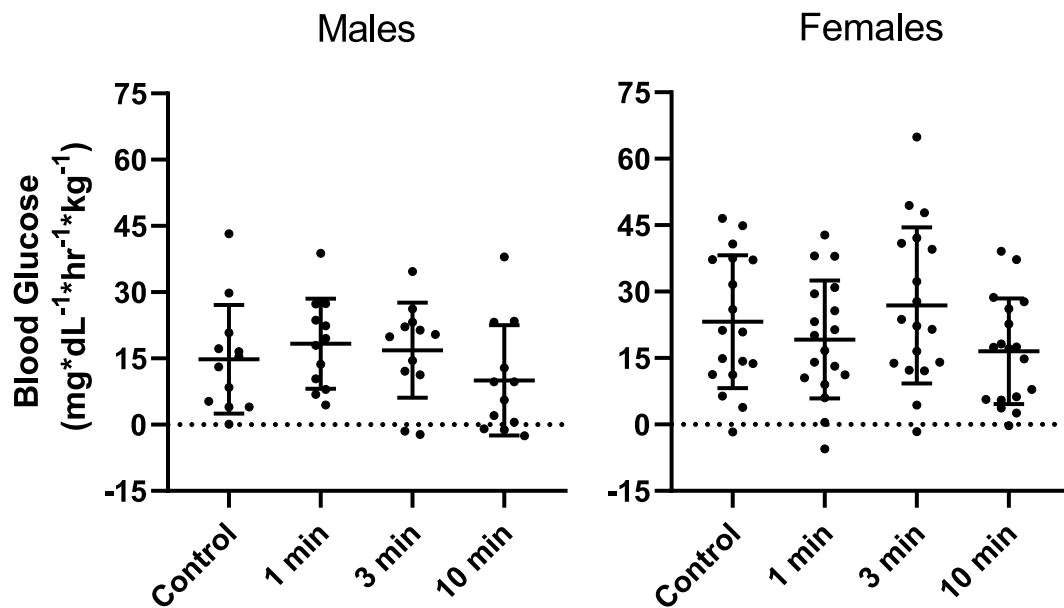


Fig. 2. Area Under the Curve for Blood Glucose in Males and Females

Blood glucose excursion in males (n = 12) and females (n = 18) represented by the area under the curve (AUC) over the 60-min mixed meal tolerance test for the seated control, 1 min, 3 min, and 10 min stair climbing and descending conditions. AUC for blood glucose was analyzed using a 4 by 2 mixed design ANOVA with repeated measures. Area under the curve was calculated using the trapezoid rule. Post hoc pairwise comparisons were performed with LSD adjustments. Symbols denote significant difference (p < .05) from that condition.



**Fig. 3.** Incremental Area Under the Curve for Blood Glucose in Males and Females

Blood glucose excursion in males ( $n = 12$ ) and females ( $n = 18$ ) represented by the incremental area under the curve (iAUC) over the 60-min mixed meal tolerance test for the seated control, 1 min, 3 min, and 10 min stair climbing and descending conditions. iAUC for blood glucose was analyzed using a 4 by 2 mixed design ANOVA with repeated measures. Area under the curve was calculated using the trapezoid rule. Incremental area under the curve was calculated using the trapezoid rule and subtraction of baseline blood glucose levels. Post hoc pairwise comparisons were performed with LSD adjustments. Symbols denote significant difference ( $p < .05$ ) from that condition.

#### 4. Discussion

The lack of an interaction between sex and condition or time suggests that females and males benefit equally from the PBG attenuation provided by single SCD bouts after a mixed meal. This corroborates previous findings in which females and males benefitted equally from a similar intervention following an OGTT [14], as well as others using light and moderate intensity walking [19,20], and light intensity treadmill desk walking [22], but contradicts findings by others who found an interaction by sex after light intensity walking but not simple resistance activities [21] and moderate and vigorous intensity walking [23].

In Dempsey et al. a significant interaction by sex was found after light walking ( $p = .045$ ) with the reduction in glucose compared to seated control being 2-fold greater in women than men ( $-58\%$  versus  $-26\%$ ). While the interaction by sex was similar in magnitude following simple resistance activities compared to seated control ( $-53\%$  versus  $-31\%$ ) it did not reach significance ( $p = .17$ ). The light walking intervention consisted of 3 min of treadmill walking (zero gradient,  $3.2 \text{ km} \cdot \text{h}^{-1}$ ) every 30 min for a total of 12 times [21]. Notably, subjects all performed the treadmill walking at the same absolute speed whereas in our current study subjects were allowed to self-select their SCD pace. This likely led to women performing at a higher relative intensity due to their generally lower VO<sub>2</sub> max, muscle mass, and stature. Allowing for self-selection of the exercise intensity increased the external validity of our current study and applicability for public health interventions. The notion that the interaction by sex is an artifact of the differences in relative intensity is further supported by Dempsey et al.'s findings of no interaction by sex after the simple resistance activities protocol which was comprised of body weight exercises [21].

Bhammer et al. also found a significant interaction between sex and condition with women having a 6%, 13%, and 13% reduction and men having a 3% reduction and 6% and 7% increase in blood glucose following the 3 exercise conditions compared to the seated control. Conditions in their study consisted of a seated control, 30 min of submaximal moderate-intensity walking at 65–75% HR max, 2 min of moderate intensity walking every 20 min (zero gradient,  $3.0 \text{ miles} \cdot \text{h}^{-1}$ ), and 2 min of vigorous intensity walking every hour at 3 mph with

a gradual increase in grade to 25% or maximum grade reached in participants VO<sub>2</sub> max test [23]. While relative intensity may have been equated in the 30 min of submaximal moderate-intensity condition it was likely different in the other two exercise conditions. Without further analyses into interactions by sex within each condition we can only speculate, however its possible an interaction in one or both of the latter two conditions which did not equate relative intensity drove the overall sex by condition interaction.

Dunstan et al. found no interaction between sex and condition ( $p = .113$ ) comparing light and moderate activity breaks to a seated control. Light activity breaks consisted of 2 min of light (RPE 6 to 9) treadmill walking at  $3.2 \text{ km/h}$  every 20 min for 5 h. Moderate activity breaks consisted of 2 min of moderate (RPE 12 to 14) treadmill walking at  $5.8\text{--}7.9 \text{ km/h}$  every 20 min for 5 h. A similar relative intensity could have been achieved with their RPE range, however the speed was kept constant for the light activity break condition [20]. Using the same intervention as Dunstan et al. Bailey et al. found no interaction between sex and condition. Their sample size of  $N = 13$  is likely not powered to determine whether sex differences truly exist with this intervention [19]. Champion et al. found no interaction between sex and condition with 20 min of light intensity treadmill walking every hour over 6.5 h for a total of 2 h of walking compared to a seated control [22]. Unlike Bhammer and Dempsey, and similar to our intervention, participants were allowed to self-select their intensity with a walking speed between 1.2 and 3.5 km/h.

While there were many differences between these various interventions and ours including total amount of time of the intervention, total amount of time glucose was measured over, time between glucose measurements, and inclusion of a multiple meals, we find the most compelling reason for a presence of interaction by sex to be the non-individualized intensity of the exercise interventions. If the exercise intensity is not self-selected, but rather held constant for all subjects, women, having less muscle mass, lower VO<sub>2</sub> max, and shorter stature, would be working at a higher relative intensity potentially explaining the greater reductions in blood glucose. Furthermore, these other experiments did not adjust for bodyweight after giving identical amounts of food to participants resulting in smaller individuals, namely women,

being challenged with greater amounts of carbohydrates. In our current paper we normalized blood glucose by bodyweight in order to account for size differences and the standardized meal size as shown previously [14].

These SCD bouts were rated subjectively by participants as very light to light as described in a previous publication [9] though objective measures of this SCD intervention indicated a moderate intensity [10]. Among both females and males 3 min of SCD reduced post-exercise PBG with longer bouts producing greater reductions. While a single minute reduced PBG among females, the reduction was not statistically significant for males likely due to the smaller sample size and subsequent reduction in statistical power. The magnitude of the post-meal peak PBG reduction following 10 min of SCD was similar, if not greater, than that of similar intensity interventions including 30 min of cycling [31] and 40 min of walking [32]. The SCD bouts were planned to be performed immediately before the peak PBG but participants peaked earlier than expected as described in a previous publication [9]. It is possible this led to a partial flooring effect and even greater reductions may be possible had the exercise bouts preempted peak PBG as planned.

According to the reference ranges of the American Diabetes Association, the fasting glucose (113 (10) mg/dL) of our participants would indicate prediabetes. This in contrast to the participants' postprandial glucose response with males and females having a PBG of 126 (16) mg/dL and 127 (25) mg/dL, respectively, at 1-h. These values are below the American Diabetes Association's OGTT 2-h PBG threshold for prediabetes of 140 mg/dL [33]. Participants of the current study performed a mixed meal tolerance test, not an OGTT, but displayed similar responses to the participants in our previous study which did utilize an OGTT. In this previous study, a similar cohort of young adults in apparent good health had a fasting blood glucose of 109 (8) mg/dL and a 1-h OGTT PBG of 158 mg/dL [10]. Unpublished pilot data showed participants returned to baseline by 2 h after their OGTT. Compared to a different set of glucometers (Contour Next), the glucometers used in this experiment (NovaMax) had higher glucose levels and variability (mean (SD): 126 (12) vs 110 (3) mg/dL; mean difference (95% CI): 14% (6%–23%),  $p = .003$ ) from the same blood sample in a two-tailed student's t-test. Assuming the latter glucometer is correct, this discrepancy could account for the elevated values. While the average BMI was within the normal range, several participants would be categorized as overweight. Many of the participants in our study were students in the Exercise and Nutritional Sciences department and/or physically active. Thus, the BMI values could be skewed higher by higher than average muscle mass. Nevertheless, we can not rule out the possibility of participants having undiagnosed prediabetes. The CDC estimated a prediabetes prevalence of 28% for US adults between the ages of 18 and 44 years from 2017 to 2020 with 50% of these being undiagnosed [34]. However, whether or not people were (pre)diabetic based on fasting blood glucose should not affect the study outcomes or analysis as it represents a repeated measures design, and the effects of exercise are robust in people across the glucose tolerance spectrum.

Strengths of the current study include its randomized crossover design, the external validity of mixed meal matching population intake, and corroboration of previous findings in a separate cohort. There are several limitations to our study. The timing of the exercise intervention missed the peak PBG and thus likely underestimated the potential magnitude of glucose reduction. The homogenous cohort studied herein warrants replication in other populations to confirm our results. The presence of undiagnosed diabetes in our participants could not be confirmed in our study. Body composition measures were not taken and would have given a better insight into the possibility of undiagnosed diabetes and the accuracy of BMI classifications.

Future studies should examine the inter- and intra-individual variability of PBG to determine whether personalized timing of postprandial exercise interventions is feasible for public health strategies.

## 5. Conclusion

Stair climbing and descending at a self-selected comfortable pace reduces postprandial blood glucose in both men and women. SCD may not be suitable for populations at greater risks of falls or with preexisting joint issues, however, these results further highlight the potential value of SCD bouts as a public health intervention. The need for highly generalizable physical activity interventions is greatly needed as the CDC's 2022 National Diabetes Statistics Report estimates 49% of American adults have some form of diabetes [35].

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## Ethics approval

The study was approved by the Institutional Review Board at San Diego State University.

## Consent to participate

All participants provided written informed consent.

## Consent for publication

All authors approve of the submitted manuscript.

## CRedit authorship contribution statement

**Jeff M. Moore:** designed research, conducted research, analyzed data or performed statistical analysis; , wrote paper and, had primary responsibility for final content. **Cameron Vinoskey:** conducted research. **Hannah Salmons:** conducted research. **Shirin Hooshmand:** provided essential reagents and materials, analyzed data, or performed statistical analysis; and. **Jochen Kressler:** designed research, analyzed data or performed statistical analysis, wrote paper.

## Declaration of competing interest

None.

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