Acute effects of breaking up prolonged sitting with standing and light-intensity physical activity on cardiometabolic risk factors

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Breaking up prolonged sitting with light-intensity walking improves postprandial glycemia, but breaking up sitting with standing does not

Abstract

Objectives: To explore the effects of breaking up prolonged sitting time with standing or light-intensity walking on a range of cardiometabolic risk markers.

Design: A randomized three-period, three-treatment acute crossover trial.

Method: Ten non-obese adults took part in three trials: 1) uninterrupted sitting; 2) seated with 2-min bouts of standing every 20 min; and 3) seated with 2-min bouts of light-intensity walking every 20 min. Two standardised test drinks (total 80.3 carbohydrate, 50 g fat) were provided after an initial 1-h period of uninterrupted sitting. Plasma glucose and blood pressure were assessed hourly to calculate total area under the curve (AUC). Total cholesterol, HDL, and triglycerides were assessed at baseline and 5-h. ANOVAs were used to explore between-trial differences.

Results: Glucose AUC was lower in the activity-break condition compared to the uninterrupted sitting and standing-break conditions: mean AUC 18.5 (95% CI 17, 20), 22.0 (20.5, 23.5), and 22.2 (20.7, 23.7) mmol.L/5-h, respectively, $p<0.001$; no difference between uninterrupted sitting and standing-break conditions ($p>0.05$). Systolic and diastolic blood pressure AUC did not differ significantly between conditions, nor did responses in lipid parameters ($p>0.05$).

Conclusions: This study suggests that interrupting sitting time with frequent brief bouts of light-intensity activity, but not standing, imparts beneficial postprandial responses that may enhance cardiometabolic health. These findings may have importance in the design of effective interventions to reduce cardiometabolic disease risk.

Keywords: exercise; blood glucose; sedentary lifestyle; postprandial period

Introduction

A modern day sedentary lifestyle (prolonged sitting) may be a significant contributor to hypokinetic disease risk[1]. Individuals with high levels of sedentary time may have a 112%, 147%, 90%, and 49% increased relative risk of diabetes, cardiovascular events, cardiovascular mortality, and all-cause mortality, respectively[2]. To reduce disease risk, interventions typically focus on engagement in moderate-to-vigorous physical activity (MVPA)[3]. However, sedentary behaviour in itself is a risk factor for comorbidities and mortality regardless of physical activity level[2,4].

Government guidelines recommend engagement in ≥150 min/wk of MVPA accumulated in bouts of ≥10 min[5]. However, improvements in postprandial glycemia occur following light-intensity activity similar to that observed following moderate- and vigorous-intensity activity[6]. Observational data show that frequent interruptions to sitting time (transition from sedentary to an active state for ≥1 min) are beneficially associated with metabolic risk[4]. The mean duration of these breaks was approximately 4 min, which was characterised by light-intensity physical activity[4]. Importantly, these relationships persisted after accounting for MVPA, suggesting that frequent short breaks in sitting time may impart unique benefit to health. Indeed, experimental data show interrupting prolonged sitting with short bouts of walking improves postprandial glucose and insulin levels[7,8].

Interrupting sitting with standing could also impart health benefits[9], although experimental studies in humans is lacking. A combination of 4-h standing and 2-h walking per day for four days improves fasting lipid levels and insulin sensitivity compared to vigorous-intensity exercise for 1-h per day[10]. However, the independent effects of standing were not explored and the potential for interrupting sitting with standing should be investigated.

This study therefore investigates the acute effects of interrupting sitting with standing or light-intensity walking on cardiometabolic risk markers in healthy adults.

Methods

The study was approved by the Sport Science and Physical Activity departmental ethics review board at the University of Bedfordshire and conformed to the Declaration of Helsinki. Written, informed consent was obtained from participants before any testing procedures following a verbal and written explanation of the nature and risks involved in the experimental procedures.

Ten healthy (free of any known metabolic or cardiovascular disease) participants with no contraindications to physical exercise took part (7 men, 3 women; mean age, 24.0±3.0 y; mean BMI, 26.5±4.3 kg/m^2) in this randomised repeated measures cross-over design study. Participants attended a familiarisation session where they became accustomed to the light-intensity walking speed and familiarised with use of the Borg Rate of Perceived Exertion (RPE)[11]. During the familiarisation, RPE was recorded to ensure walking speed was equivalent to light-intensity activity for each participant (RPE of 6-9). Participants then made three separate visits to the laboratory to complete the 5-h trial conditions in a randomized order: 1) uninterrupted sitting; 2) sitting interrupted by standing breaks; and 3) sitting interrupted by light-intensity walking breaks. Because an acute bout of physical activity may enhance insulin sensitivity for up to 72 h[12], a minimum wash-out period of 6 days between each condition was used to eliminate potential carryover effects of the activity conditions.

Participants were instructed to refrain from any exercise, alcohol, or caffeine for 24 h prior to each of the trial conditions. They attended the laboratory at 0900 h after an overnight fast and sat for 1-h to achieve a steady state before a resting blood sample and blood pressure measures were taken. Two standardised test drinks with a total of 80.3 g carbohydrate were then consumed: 1) 75 g carbohydrate (100% dextrose monohydrate powder; Thornton & Ross Ltd, UK) in 200 mL of water; energy, 273 kcal, and 2) 100 mL drink consisting of 50 g fat (Calogen; Nutricia, UK); nutritional components were energy, 467 kcal; fat, 50.0 g; saturated fat, 5.3 g; carbohydrate, 4.3 g; sugars, 4.0 g; protein, nil; fibre, nil; and sodium, 7.0 mg. The fat and protein content were included to 1) better simulate a mixed meal and 2) help slow the ingested glucose production to spread the plasma glucose responses over more of the 5-h treatment period[13]. Following consumption, the 5-h testing

period commenced. Participants were guided through each trial and supervised at all times by a member of the research team to ensure full compliance with the protocols. Hourly blood samples were collected and hourly blood pressure readings taken prior to the standing or activity bouts during those respective conditions.

The trial conditions were as follows:

1. *Uninterrupted sitting*: participants remained seated throughout the experimental period and were instructed to minimise excessive movement, only rising from the chair to void.
2. *Sitting + standing breaks*: participants rose from the seated position every 20 min throughout the experimental period (three breaks per hour) and stood as still as possible for 2 min. They then returned to the seated position. This procedure was undertaken on 14 occasions, providing a total of 28 min standing.
3. *Sitting + light-intensity activity*: participants rose from the seated position every 20 min and completed 2-min bouts of light-intensity walking on a motorised treadmill (Woodway PPS55 Med-i, GmbH, Germany) with a level surface at 3.2 km/h, providing a total of 28 min activity. They then returned to the seated position.

Participants watched television or DVDs; read books, magazines, or newspapers; or worked on a laptop computer throughout the three conditions. Activity intensity during the sitting + activity breaks was monitored at the completion of each activity bout using the Borg RPE scale. Mean±SD (range: min–max) RPE was 6.7±0.9 (6–9).

Stature was measured to the nearest 0.1 cm using a stadiometer (Horltain Ltd, Crymych, UK) and body weight to the nearest 0.1 kg using electronic weighing scales (Tanita Corp., Tokyo, Japan). Blood pressure was measured in a seated position using an automatic device (Omron M5-I automated oscillatory device; Omron Matsusaka Co. Ltd., Matsusaka, Japan). Blood samples were obtained using a finger prick method and analysed immediately. Glucose was determined hourly using the YSI 2300 STAT plus glucose and lactate analyser (YSI Inc., Yellow Springs, Ohio, USA). The YSI uses a steady state

126 measurement methodology, where membrane based glucose oxidase catalyses the
127 oxidation of glucose to gluconic acid and hydrogen peroxide. The difference between the
128 sample generated plateau current and the initial baseline current is proportional to the
129 glucose concentration. The YSI was calibrated at the start of every day and every 45 min
130 thereafter. Total cholesterol, HDL, and triglycerides were obtained at baseline and 5-h and
131 determined using the Reflotron® Plus system (Roche Diagnostics, F. Hoffmann-La Roche
132 Ltd, Burgess Hill, UK). Reflotron® plus is a compact reflectance photometer for fully
133 automatic evaluation of Reflotron® tests. The instrument takes charge of all functions such
134 as heating, automatic calibration, test execution and evaluation and calculation of results.
135 The instrument has information on test principle and wavelength for each test and measuring
136 ranges. The YSI and Reflotron® systems were maintained according to manufacturers'
137 recommendations.

138 Sample size calculations were based on Dunstan et al[7] who reported a 24%
139 reduction in 5-h positive incremental AUC (iAUC) when interrupting sitting with 2 min of light-
140 intensity walking every 20 min compared with uninterrupted sitting. 9 individuals were
141 required to achieve 90% power to detect the minimum effect size between the three
142 interventions, given a two-sided significance level = 5%.

143 Analyses were completed using SPSS version 19.0 (SPSS Inc., Chicago, IL.). Data
144 are presented as mean (95% CI). One-way ANOVA assessed between-trial condition
145 differences in pre-trial weight and cardiometabolic risk variables. Total area under the curve
146 (AUC) for each 5-h trial was calculated for glucose, systolic blood pressure, and diastolic
147 blood pressure using the trapezoidal method and between-trial condition differences
148 assessed using One-way ANOVA. Repeated measures ANOVA assessed differences
149 across conditions for pre- and post-trial lipid parameters. Estimates of effect size for
150 condition, partial eta squared (η^2), were calculated for each dependent variable. Statistical
151 significance was accepted as $p<0.05$. Graphical representations of results are presented as
152 mean (SEM) to avoid distortion of the graphs.

153

Results

Biochemical and anthropometric data at baseline for each trial are shown in Table 1. There were no significant differences for baseline values between trials.

Figure 1 shows glucose response over time during each of the trial conditions. A significant effect of condition with a large effect size was observed (F=8.59, p=0.001, η^2=0.39) for glucose AUC. As shown in Figure 2, after sitting + activity breaks (mean AUC, 18.5; 95% CI 17.0, 20.0 mmol.L/5-h) the glucose response to the test drink was 15.9% and 16.7% lower (p<0.001) compared to uninterrupted sitting (22.0; 20.5, 23.5 mmol.L/5-h) and sitting + standing breaks (22.2; 20.7, 23.7 mmol.L/5-h), respectively.

There was no significant effect of condition and small effect size (F=0.45, p=0.65, η^2=0.03) for systolic blood pressure AUC: mean AUC, 601.5 (95% CI 565.5, 637.5), 585.3 (549.3, 621.3), and 608.1 (572.1, 644.1) mmHg/5-h for uninterrupted sitting, sitting + standing breaks, and sitting + activity breaks, respectively. There was no significant condition effect but a medium effect size (F=1.10, p=0.35, η^2=0.08) for diastolic blood pressure AUC: mean AUC, 356.7 (336.0, 377.4), 347.8 (327.1, 368.5), 335.6 (314.9, 356.3) mmHg/5-h for uninterrupted sitting, sitting + standing breaks, and sitting + activity breaks, respectively. Blood pressure responses over time are available as supplementary material (Appendices 1 and 2).

There was no significant main effect for condition on changes in total cholesterol (F=0.01, η^2=0.00), HDL (F=0.09, η^2=0.01), or triglycerides (F=1.45, η^2=0.10) from baseline to 5-h (Table 2), although a medium-large effect size was observed for triglycerides. There was no significant interaction effect for total cholesterol (F=1.79, p=0.19, η^2=0.12; medium-large effect size), HDL (F=0.41, p=0.67, η^2=0.03; small effect size), or triglycerides (F=2.74, p=0.08, η^2=0.17; large effect size).

Discussion

The main finding of this study was that interrupting sitting time with short bouts of light-intensity activity, but not standing, acutely lowers postprandial glycemia in healthy adults.

This supports recent observational and experimental data demonstrating the deleterious health consequences of prolonged sitting and the potential benefits of frequent short bouts of activity[4,7,8].

Prior to this study, the effect of interrupting sitting time with standing had not been explored. Studies in animals and humans show impaired insulin action from reduced standing and nonexercise ambulation[9], while increases in standing time are associated with reduced mortality rates[14]. It is postulated that energy demands to meet the requirements of standing and the transition from sitting to standing may increase substrate utilisation that has beneficial metabolic effects[9]. Improvements in insulin sensitivity have been reported following four consecutive days of 4-h walking and 2-h standing daily compared to energy-matched 1-h vigorous exercise daily or sitting for a full day[10]. Insulin action also increased over a 24-h period when sitting time was replaced with standing and low- to moderate-intensity walking[15]. However, these studies did not isolate the effects of standing from walking and the role of standing alone cannot be inferred. Recent evidence in office workers showed lower postprandial glucose AUC during an afternoon of working at a standing desk compared to an afternoon of seated work and this was concomitant with a 174 kcal increase in energy expenditure[16]. However, the current study revealed short frequent bouts of standing had no effect on cardiometabolic risk markers over a 5-h period. These findings may suggest that standing needs to be accrued in longer duration bouts or that a minimum threshold increase in energy expenditure is required. As energy expenditure was not measured the latter cannot be inferred from the current study.

In the current study, postprandial glucose AUC was lowered approximately 16% when sitting was interrupted with 2 min of light-intensity walking every 20 min compared to sitting + standing breaks or uninterrupted sitting. This is smaller than the 24-30% reduction observed in overweight/obese adults when sitting was interrupted with light- or moderate-intensity walking[7]. Dunstan et al[7] also examined a 5-h postprandial period and interrupted sitting with 2 min of activity every 20 min, thus disparities in magnitudes of change between studies may be attributable to sample characteristic differences. Another study showed

interrupting sitting with 1 min 40 s bouts of moderate-intensity walking every 30 min reduced glucose iAUC by 37% over a 9-h period compared to uninterrupted sitting[8]. These data provide compelling support for interrupting sitting time with physical activity.

Postprandial hyperglycemia is a cardiovascular risk factor in people with Type 2 diabetes and even in nondiabetics[17,18]. Reducing postprandial hyperglycemia improves inflammation and endothelial function and reduces carotid intima-media thickness[19,20] and was also associated with a 49% relative risk reduction in the development of cardiovascular events in individuals with impaired glucose tolerance[21]. The data from this current study and others[7,8] suggests that frequently interrupting sitting time with brief bouts of activity may be a simple and effective approach to ameliorate such consequences of postprandial hyperglycemia. Individuals who spend their working hours at a desk could reduce their postprandial glycemia by rising from their chair and walking up and down corridors or walking to other office areas to speak to colleagues instead of emailing or phoning. Development of smartphone applications that frequently remind people to get up and move around could also be a step forward in helping to interrupt prolonged sitting time.

The activity breaks in the current study accumulated to a total of 28 min of light-intensity activity. In overweight adults, no differences in postprandial glucose AUC were observed the morning after performing an acute 30 min bout of moderate-intensity aerobic or resistance exercise, although insulin AUC was significantly lower[22]. Furthermore, a 45 min moderate-intensity exercise session performed 30 min prior to a test meal resulted in lower glucose (6%) and insulin (20%) AUC compared to no exercise and performing the same exercise 17-h beforehand[23]. It thus appears that interrupting sitting time with frequent short bouts of activity has at least similar potential to continuous exercise bouts in lowering postprandial glycaemia. Although the mechanisms for this response are not clear, it is postulated that increases in carbohydrate oxidation may be important as this would augment clearance of glucose from the blood[8]. The frequent nature of the activity bouts may have also maintained increased permeability of muscle cells to glucose[24] and/or alter the expression of genes that regulate translocation of the glucose transporter protein GLUT-4[25].

There were no significant differences observed in pre- vs post-trial lipid parameters across conditions. Unfortunately, hourly measures were not taken and analysis of AUC responses thus not possible. A medium-large effect size was observed for triglycerides, though, and a larger sample size may have provided sufficient power to detect statistically significant difference between conditions. However, Peddie et al[8] reported no differences in postprandial triglyceride iAUC when interrupting sitting with frequent bouts of activity compared to uninterrupted sitting over a 9-h period. Postprandial hypertriglyceridemia is recognised to affect endothelial function, atherogenesis, and is associated with coronary artery disease[26,27]. A continuous bout of moderate-intensity walking performed 1-h[28] and 16 to 18-h[29] prior to meal consumption resulted in lower postprandial triglyceride AUC and this type of intervention may be preferred. The current study did not test triglyceride AUC responses and comparisons to the aforementioned studies are thus difficult.

This study found no significant differences between continuous sitting versus interruptions with standing or walking for systolic or diastolic blood pressure AUC, although a medium effect size was seen for diastolic. Lower systolic blood pressure has been observed the day following completion of either a continuous 30 min bout or ten 3 min bouts (30 min rest between each) of walking, thus suggesting how physical activity is accumulated may be unimportant[30]. More research is needed to further understand the effects of interrupting sitting on blood pressure and, as outlined previously, should incorporate larger sample sizes to ensure sufficient statistical power.

This study has some limitations. No measure of insulin was taken so it is difficult to infer the effects of interrupting sitting time on insulin sensitivity. However, previous research suggests improved postprandial insulin action in response to interrupting sitting with brief bouts of light- or moderate-intensity walking[7,8]. Participants were asked to refrain from any exercise 24 h prior to trial days. However, an acute bout of exercise may enhance insulin sensitivity for up to 72 h[12] and this should be considered in future studies. The small sample size may have resulted in under-powered *p* values and a larger sample may have detected significant effects in variables other than glucose. Energy expenditure was not measured

during the trials and this may have added important mechanistic insights regarding the observed differences between conditions. This study compared the effects of 1 day exposure of prolonged sitting to interrupted sitting and the consequences of long-term exposure cannot be extrapolated. Furthermore, activity and standing breaks of fixed frequency and duration were examined and it would be important to explore whether variations in these variables impart differential effects on cardiometabolic risk markers.

Conclusion

Frequent brief interruptions to sitting time with light-intensity activity, but not standing, imparts beneficial postprandial responses that may reduce risk of cardiometabolic disease. These findings add support for a public health focus on reducing and breaking up sitting time alongside recommendations currently in place for physical activity. Future research should explore effective and sustainable interventions to break up sitting time to inform potentially effective public health initiatives.

Practical implications

- Prolonged sitting has detrimental effects on postprandial glycemia
- Frequently interrupting sitting time with light-intensity activity, but not standing, improves postprandial glycemia
- Health-benefiting physical activity can be performed in bouts of as little as 2 minutes in duration

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Table 1: Participant characteristics before each trial

	Uninterrupted sitting	Sitting + standing breaks	Sitting + light-intensity activity breaks	*P* value
Weight (kg)	87.6 (71.2, 103.9)	87.8 (70.9, 104.6)	87.6 (71.3, 103.8)	1.00
Plasma glucose (mmol.L)	4.42 (4.09, 4.75)	4.32 (3.97, 4.67)	4.39 (4.04, 4.74)	0.89
Total cholesterol (mmol.L)	4.03 (3.34, 4.73)	3.95 (3.24, 4.65)	4.11 (3.32, 4.89)	0.94
HDL (mmol.L)	1.68 (1.20, 2.16)	1.52 (1.05, 1.99)	1.59 (1.22, 1.97)	0.85
Triglycerides (mmol.L)	0.83 (0.77, 0.90)	0.82 (0.76, 0.87)	0.87 (0.78, 0.96)	0.50
Systolic blood pressure (mmHg)	122.1 (113.9, 130.3)	117.1 (110.0, 124.2)	120.2 (109.5, 130.9)	0.66
Diastolic blood pressure (mmHg)	72.9 (64.9, 80.9)	73.9 (68.9, 78.9)	70.2 (62.1, 78.3)	0.70

Data presented as mean (95% CI). HDL, high-density lipoprotein cholesterol.

Figure legends

Figure 1: The effect of the three trial conditions on 5-h postprandial plasma glucose levels.

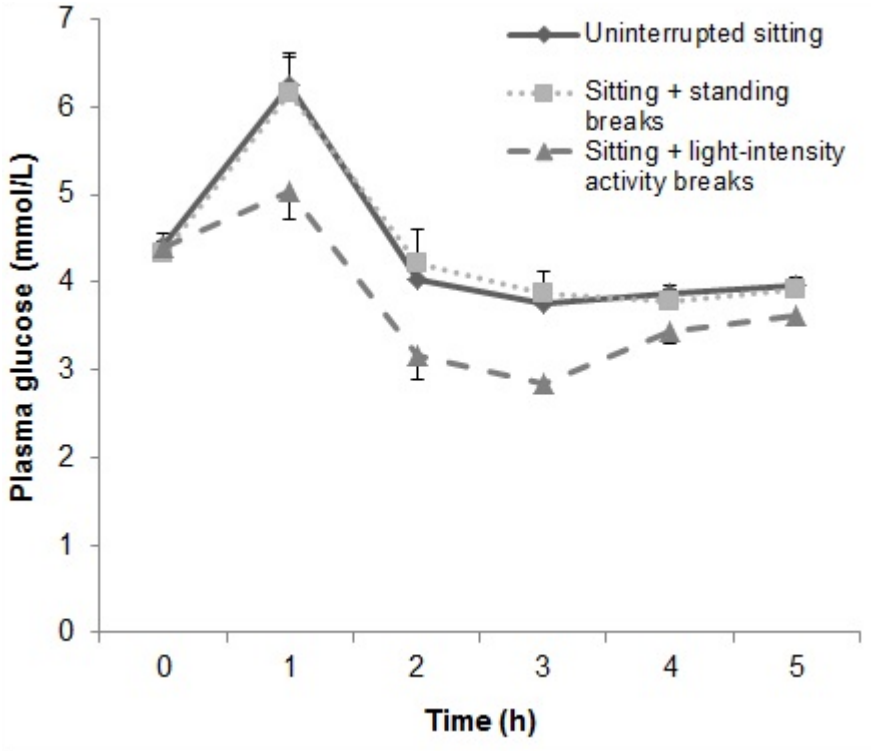
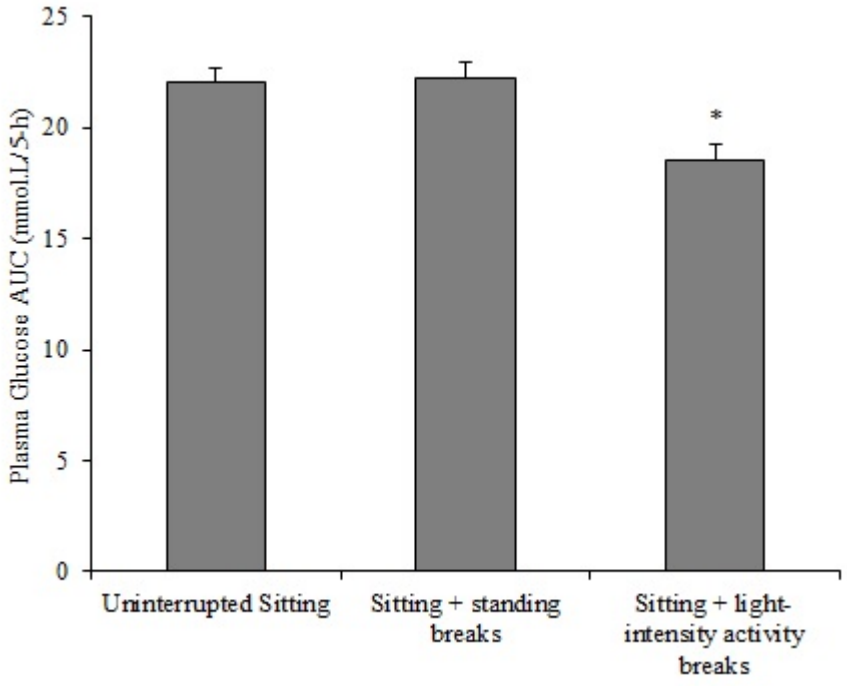


Figure 2: Postprandial plasma glucose area under curve (AUC) for the three trial conditions. Data shown as mean and SE. *significantly different from sitting and sitting + standing breaks (p<0.001).



Appendix 1: The effect of the three trial conditions on 5-h systolic blood pressure levels.

Appendix 2: The effect of the three trial conditions on 5-h diastolic blood pressure levels