

1 **Reducing prolonged sedentary time using a treadmill desk acutely improves**  
2 **cardiometabolic risk markers in male and female adults**

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18 **Abstract**

19 The objectives of this study were to evaluate the acute effects of interrupting prolonged sitting  
20 with an accumulated 2 h of light-intensity walking on postprandial cardiometabolic risk  
21 markers. In this randomised crossover trial, 24 participants (twelve males) aged 18-55 years  
22 took part in two, 6.5 h conditions: 1) prolonged sitting (SIT) and 2) sitting interrupted hourly  
23 with 20 min light-intensity treadmill desk walking at between 1.2-3.5 km/h<sup>-1</sup> (INT-SIT).  
24 Standardized meals were provided at 0 h and 3 h. Blood samples and blood pressure  
25 measures were taken hourly. Statistical analyses were completed using linear mixed models.  
26 Postprandial incremental area under the curve responses (mmol/L·6.5 h) for glucose (4.52  
27 [3.47, 5.56] and 6.66 [5.62, 7.71] for INT-SIT and SIT, respectively) and triglycerides (1.96  
28 [0.96, 2.96] and 2.71 [1.70, 3.71] mmol/L·6.5 h, for INT-SIT and SIT, respectively) were  
29 significantly lower in INT-SIT than SIT. Mean systolic and diastolic blood pressure responses  
30 were lower by 3% and 4%, respectively, in INT-SIT than SIT (P<0.05). There was no significant  
31 condition x sex interaction effect for any outcomes (P>0.05). These findings suggest that  
32 interrupting sitting with an accumulated 2 h of light-intensity walking acutely improves  
33 cardiometabolic risk levels in males and females compared with prolonged sitting.

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35

36 **Keywords:** Sedentary bout; sedentary time; physical activity; cardiometabolic risk;

37 cardiorespiratory fitness

## 38 **Introduction**

39 Elevated postprandial glucose and triglycerides are significant risk factors for cardiovascular  
40 disease and Type 2 diabetes (D'Agostino et al., 2004; Einarson, Machado, & Henk Hemels,  
41 2011). Evidence supports the notion that impaired levels of these cardiometabolic risk markers  
42 are associated with high amounts of sedentary behaviour (Healy, Matthews, Dunstan, Winkler,  
43 & Owen, 2011), which is defined as any waking behaviour characterized by an energy  
44 expenditure  $\leq 1.5$  metabolic equivalents (METs), while in a sitting, reclining, or lying posture  
45 (Tremblay et al., 2017).

46

47 Experimental research has reported that prolonged sedentary behaviour leads to an acute  
48 impairment in cardiometabolic risk markers (Stephens, Granados, Zderic, Hamilton, & Braun,  
49 2011). This may be particularly relevant to office-based workers who spend  $>70\%$  of their  
50 working hours seated (Clemes, O'Connell, & Edwardson, 2014). Breaking up prolonged sitting  
51 with short, frequent bouts of light-intensity walking imparts beneficial postprandial  
52 cardiometabolic responses (Bailey & Locke, 2015; Dunstan et al., 2012; Larsen et al., 2014).  
53 In light of such evidence, an expert statement on reducing prolonged periods of sedentary  
54 work recommended that desk-based employees should initially accumulate a minimum of 2  
55 h/day of light-intensity activity (standing or light walking) during working hours (Buckley et al.,  
56 2015). There is currently limited research evaluating the effects of accumulating  $\geq 2$  h of light-  
57 intensity walking over a single work day on postprandial cardiometabolic risk (Zeigler, Mullane,  
58 Crespo, Buman, & Gaesser, 2016; Zeigler, Swan, Bhammar, & Gaesser, 2015) and none of  
59 these studies have examined glucose, insulin, or triglyceride responses. Furthermore, there  
60 is limited understanding regarding the influence of sex on cardiometabolic responses to  
61 interrupting sedentary time (Dempsey et al., 2016a; Dunstan et al., 2012). One study reported  
62 a greater suppression in postprandial glucose in females than males with Type 2 diabetes in  
63 response to interrupting sitting (Dempsey et al., 2016a), whereas Dunstan et al. (2012) did not  
64 observe any difference in postprandial glucose or insulin responses between male and  
65 females who were overweight and obese.

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67 The objectives of this study were, therefore, to evaluate the effects of interrupting prolonged  
68 sitting with an accumulated 2 h of light-intensity walking during a simulated work day on  
69 postprandial cardiometabolic risk marker responses in sedentary male and females. It was  
70 hypothesised that sitting interrupted with 2 h of light-intensity walking would lead to beneficial  
71 acute postprandial cardiometabolic responses in both males and females compared with  
72 prolonged sitting.

73

## 74 **Methods**

### 75 *Study overview*

76 This two-way randomised crossover design study was ethically approved by the University of  
77 Bedfordshire School of Sport Science and Physical Activity Ethics Review Committee. All  
78 study procedures were undertaken at the University of Bedfordshire Sport and Exercise  
79 Science Laboratories. Subsequent to a preliminary testing visit, participants completed two  
80 experimental conditions: (1) prolonged sitting and (2) sitting interrupted hourly with 20 min  
81 light-intensity treadmill desk walking. Each condition was separated by  $\geq 6$  days. Order of the  
82 experimental conditions was randomised using a simple computer generated randomisation  
83 method ([www.randomizer.org](http://www.randomizer.org)). Due to the transient changes that occur in glucose metabolism  
84 during the female menstrual cycle (Valdes & Elkind-Hirsch, 1991), females were tested in the  
85 follicular phase only.

86

### 87 *Participants*

88 Twelve male and twelve female participants aged 18-55 years gave informed consent to take  
89 part prior to any test procedures. Participants were required to be sedentary for  $\geq 7$  h/day.  
90 Exclusion criteria were self-reported diabetes, any known blood borne disease, pregnancy,  
91 current or recent smoker, allergy or dislike to foods included in the experimental test meals,  
92 and any other health issues that would limit the participant's ability to engage in the activity  
93 bouts.

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*Sample size calculations*

The primary outcome was postprandial glucose incremental area under the curve (iAUC). Allowing for an intervention effect of 16% change in glucose iAUC, 10% within-group error variance, a within-person correlation of 0.6, 90% power, and an  $\alpha$  of 0.05, it was estimated that 22 participants (eleven male and eleven female) would be required for this two-group, two-treatment crossover design. These estimates were based on previous experimental research reporting a significant reduction in postprandial glucose total area under the curve (AUC) in response to interrupting sitting with light-intensity walking (Bailey & Locke, 2015). The study was also powered to detect a main effect of sex based on a difference of 32% change in glucose iAUC between males and females (Dempsey et al., 2016b), 10% within-group error variance, a within-person correlation of 0.6, 95% power, and an  $\alpha$  of 0.05

*Preliminary measures*

Stature and weight were measured using a stadiometer (Harpenden 98.602, Holtain Ltd., Crymych) and electronic weighing scales (Tanita Corp., Tokyo, Japan), respectively. Participants were then familiarised with the Borg Rating of Perceived Exertion (RPE) scale (Borg, 1982) and the Lifespan TR800-DT5 treadmill desk (LifeSpan, Salt Lake City, UT, USA) that was used during the experimental conditions. Participants then walked on the treadmill desk to determine a perceived light-intensity walking speed (RPE of 6-9) and this speed was then used for that respective participant in the relevant experimental condition. The treadmill desk walking speeds selected by the participants ranged between 1.2 and 3.5 km/h<sup>-1</sup>. Once the appropriate walking speed had been determined, participants walked at this speed for 15 min whilst typing about something meaningful to them on a laptop computer. The purpose of this was to confirm that the desk height and walking speed selected would be comfortable for the walking bouts performed in the relevant experimental condition (Alderman, Olson, & Mattina, 2014).

122 *Experimental protocol*

123 Figure 1 shows the experimental protocol. The 6.5 h experimental conditions were as follows:

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125 (1) Prolonged sitting (SIT): participants remained seated at a desk and were instructed to  
126 minimise excessive movement.

127 (2) Interrupted sitting (INT-SIT): participants interrupted their sitting with 20 min of light-  
128 intensity walking on a treadmill desk at 20 min, 80 min, 140 min, 200 min, 260 min,  
129 and 320 min. This resulted in an accumulation of 2 h of light-intensity walking, which  
130 was based on recommendations for reducing sedentary work in desk-based  
131 employees (Buckley et al., 2015).

132

133 Participants attended the laboratories at ~08:30 after an overnight fast. Participants were  
134 asked to refrain from caffeine and alcohol for 24 h and avoid exercise for 72 h before  
135 experimental conditions based on evidence that a single session of exercise may enhance  
136 insulin sensitivity for at least the next 48 h (Mikines, Sonne, Farrell, Tronier, & Galbo, 1988).  
137 Participants were asked to weigh and record all food and drink consumed for 24 h preceding  
138 the first experimental condition and replicate the quantity and timings of eating for the 24 h  
139 period prior to the second experimental condition (Bailey et al., 2016). Participants were asked  
140 to travel to the laboratories via motorised transport to minimise physical activity prior to the  
141 experimental conditions.

142

143 Upon arrival, participants sat for a minimum of 10 min and resting blood pressure (BP) was  
144 then measured. Body fat% was then estimated using the Tanita BC-418 Segmental Body  
145 Composition Analyzer (Tanita Corp., Tokyo, Japan); this occurred during the first experimental  
146 condition only. An activPAL device (PAL Technologies, Glasgow, Scotland) was then attached  
147 to the participants' left thigh to be worn during the experimental period. A fasting blood sample  
148 was then taken immediately before consumption of a standardised breakfast. The 6.5 h  
149 experimental condition began upon the first mouthful of the breakfast meal. Breakfast and

150 lunch were provided at 0 h and 3 h, respectively, during each experimental condition. During  
151 conditions, participants were permitted to read, talk, or work on a laptop computer; this  
152 included the treadmill desk walking bouts. To ensure participants remained sedentary during  
153 sitting periods, they were pushed in a wheelchair by a researcher when visiting the toilet and  
154 the food consumption area.

155

#### 156 *Meals and water consumption*

157 The standardised breakfast and lunch meals each provided 30% of estimated daily energy  
158 requirements for each participant. Energy requirements were estimated for each individual  
159 based on body mass using the Mifflin equations (Mifflin et al., 1990). A physical activity factor  
160 of 1.4 was applied to represent a sedentary day. Breakfast consisted of cornflakes and whole  
161 milk providing 57% carbohydrate, 29% fat and 14% protein. Lunch consisted of a chicken  
162 sandwich, salted crisps and chocolate providing 47% carbohydrate, 39% fat, 14% protein. The  
163 glycaemic index of the breakfast and lunch meals was 87 and 71, respectively, which was  
164 calculated using weighted means of the glycaemic index values for the component foods  
165 (Wolever & Jenkins, 1986). Participants were asked to consume each meal within 15 min. The  
166 time taken to consume each meal during the first experimental condition was recorded and  
167 participants were asked to replicate this as closely as possible during their second  
168 experimental condition. During the first condition, water was provided *ad libitum* and the total  
169 volume consumed was recorded. This quantity was replicated during the second condition by  
170 provision of three equal volumes of water at 0, 120 and 240 min.

171

#### 172 *Blood collection and biochemistry*

173 During experimental conditions, eight capillary finger prick blood samples were collected using  
174 a lancet (Haemolance Plus Lancet, Prospect Diagnostics, Dronfield, UK). The first sample was  
175 taken in a fasted state followed by subsequent samples at 45, 105, 165, 225, 285, 345 and  
176 390 min into two EDTA-containing microvettes (Microvette CB300 EDTA, Sarstedt Ltd,  
177 Leicester, UK). Approximately 600  $\mu$ L of whole blood was collected at each time point. From

178 one microvette, 30  $\mu$ L of whole blood was used to immediately analyse blood glucose  
179 concentration using the YSI 2300 STAT plus glucose and lactate analyzer (YSI Inc., Yellow  
180 Springs, OH, USA). The remaining whole blood from both microvettes was centrifuged  
181 (Heraeus Pico 17 microcentrifuge, Thermo Scientific, Loughborough, UK) at 2000  $\times$   $g$  for 5  
182 min. Plasma was then extracted and stored at -80  $^{\circ}$ C for later batch analysis of insulin and  
183 triglyceride concentrations. Plasma insulin concentrations were determined using an enzyme  
184 linked immunosorbent assay technique (Mercodia, Uppsala Sweden) and plasma triglyceride  
185 concentrations were determined spectrophotometrically using the lipase hydrolysis method  
186 (GOP-PAP; Randox, Crumlin, Ireland). Samples from each participant were analysed in the  
187 same run to eliminate inter-assay variation.

188

#### 189 *Blood pressure measurements*

190 During experimental conditions, resting brachial BP was measured on the left arm with  
191 participants seated in an upright position using an automatic device (Omron M5-I, Omron  
192 Matsusaka Co. Ltd., Matsusaka, Japan). To determine baseline values, BP was measured  
193 three times with a 2 min rest between each measure and an average of the three readings  
194 was taken. Single measures were then taken at 60, 120, 180, 240, 300, 360, and 390 min.

195

#### 196 *Calculation of outcome variables*

197 For physical activity outcomes, activPAL manufacturer software (ActivPAL<sup>TM</sup> Professional  
198 V7.2.32) was used to classify data into sitting, standing and stepping categories and generate  
199 csv event files for each experimental condition. Data was then trimmed based on condition  
200 start/end times prior to data extraction using tailored Microsoft Excel 2017 formulas. Light and  
201 moderate-intensity stepping was classified as <3 Metabolic Equivalent (METs) and  $\geq$ 3 METs,  
202 respectively. Postprandial glucose, insulin, and triglyceride iAUC was calculated for each 6.5  
203 h experimental period using the trapezoidal rule. Mean arterial pressure (MAP) was calculated

204 as:  $MAP \cong P_{Dias} + \frac{1}{3}(P_{Sys} - P_{Dias})$ .

205



## 206 *Statistical analyses*

207 Statistical analyses were performed using SPSS v23.0 (SPSS Inc., Armonk, N.Y., USA).  
208 Normality was checked using standard graphical procedures (Grafen & Hails, 2002). Insulin  
209 iAUC was non-normally distributed and was log transformed prior to analysis. The data for this  
210 variable was then back-transformed to natural units for reporting to provide meaningful  
211 information. Linear mixed models were used to assess the main effect of condition and sex  
212 and the condition x sex interaction for the cardiometabolic outcomes. Condition and sex were  
213 fixed factors and participants were random factors and these models adjusted for potential  
214 confounders (age, body fat% and baseline outcome values). For analysis of physical activity  
215 outcomes, linear mixed models were used to assess the main effect of condition, with  
216 condition as a fixed factor and participants as random factors. These models did not adjust for  
217 any confounders. A two-tailed significance level of  $\leq 0.05$  was set. Cohens' d effect sizes were  
218 calculated to describe the magnitude of differences between conditions; 0.2, 0.5 and 0.8  
219 indicated a small, medium or large effect, respectively (Cohen, 1988). All data are expressed  
220 as mean (95% confidence interval [CI]) unless stated otherwise.

221

## 222 **Results**

223 Descriptive characteristics of the participants are reported in Table 1. Participants spent  
224 significantly less time sitting and significantly higher time in light and moderate-intensity  
225 stepping in INT-SIT compared with SIT (Table 2).

226

227 Baseline and iAUC values for each cardiometabolic outcome can be seen separately for males  
228 and females in Table 3. Baseline concentrations of insulin were significantly higher in INT-SIT  
229 than SIT (12.4 [10.4, 14.7] and 9.3 [7.8, 11.0]  $\mu\text{U/mL}$ , respectively) and significantly higher in  
230 males than females (13.7 [10.8, 17.3] and 8.4 [6.6, 10.6]  $\mu\text{U/mL}$ , respectively). There were no  
231 significant differences in baseline values between SIT and INT-SIT for glucose (4.39 [4.24,  
232 4.55] and 4.45 [4.30, 4.61]  $\text{mmol/L}$ , respectively), triglycerides (0.88 [0.67, 1.10] and 0.97  
233 [0.76, 1.19]  $\text{mmol/L}$ , respectively), systolic BP (119 [114, 123] and 120 [115, 124]  $\text{mmHg}$ ,

234 respectively), and diastolic BP (78 [74, 81] and 78 [75, 81] mmHg, respectively). Males had  
235 significantly higher baseline values than females for glucose (4.75 [4.53, 4.96] and 4.10 [3.88,  
236 4.31] mmol/L, respectively), triglycerides (1.36 [1.08, 1.63] and 0.50 [0.22, 0.78] mmol/L,  
237 respectively), systolic BP (129 [123, 136] and 109 [103, 116] mmHg, respectively), and  
238 diastolic BP (84 [80, 89] and 71 [67, 76] mmHg, respectively).

239

240 Figure 2 shows glucose, insulin, triglyceride, and BP responses over time for each condition.  
241 There was a significant main effect of condition for glucose iAUC with concentrations being  
242 38% lower in INT-SIT compared with SIT (4.52 [3.47, 5.56] and 6.66 [5.62, 7.71] mmol/L·6.5  
243 h, respectively); large effect size ( $d=1.07$ ). The main effect of sex was not significant (6.74  
244 [5.19, 8.29] and 4.44 [2.89, 5.99] mmol/L·6.5 h for males and females, respectively) and  
245 neither was the condition x sex interaction for glucose iAUC.

246

247 The main effect of condition (138.0 [109.9, 173.4] and 160.7 [127.8, 201.7]  $\mu\text{U}/\text{mL}\cdot 6.5$  h for  
248 INT-SIT and SIT, respectively) and the condition x sex interaction effect for insulin iAUC were  
249 not significant. There was a significant main effect of sex for insulin iAUC with females having  
250 lower concentrations than males (91.2 [65.3, 127.4] and 242.7 [173.9, 339.1]  $\mu\text{U}/\text{mL}\cdot 6.5$ ,  
251 respectively).

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253 There was a significant main effect of condition for triglyceride iAUC with concentrations being  
254 32% lower in INT-SIT compared with SIT (1.96 [0.96, 2.96] and 2.71 [1.70, 3.71] mmol/L·6.5  
255 h, respectively); medium effect size ( $d=0.38$ ). There was a significant main effect of sex with  
256 females having lower triglyceride iAUC responses than males (-0.60 [-2.13, 0.93] and 5.27  
257 [3.74, 6.79] mmol/L·6.5 h, respectively). The condition x sex interaction was not significant.

258

259 There was a significant main effect of condition for mean resting systolic BP, diastolic BP, and  
260 MAP. Systolic BP was 3% lower in INT-SIT than SIT (118 [116, 119] and 122 [120, 124]  
261 mmHg, respectively;  $d=1.15$ ), while diastolic BP was 4% lower (74 [73, 76] and 77 [75, 78]

262 mmHg, respectively;  $d=0.70$ ) and MAP 2% lower (89 [87, 90] and 91 [90, 93] mmHg,  
263 respectively;  $d=0.91$ ) in INT-SIT than SIT. The effect size for each of these differences was  
264 large. There was a significant main effect of sex for each of these variables with females  
265 having lower systolic BP (117 [115, 119] and 123 [120, 125] mmHg, respectively), diastolic BP  
266 (74 [71, 76] and 77 [75, 80] mmHg, respectively) and MAP (87 [85, 89] and 93 [91, 95] mmHg,  
267 respectively) compared with males.

268

## 269 **Discussion**

270 The main findings of this study were that interrupting sitting with an accumulated 2 hours of  
271 light-intensity treadmill desk walking leads to an acute improvement in postprandial glucose,  
272 triglycerides and BP in sedentary males and females.

273

274 The total accumulated 2 h volume of light-intensity walking was based on recommendations  
275 that desk-based employees should initially accumulate a minimum of 2 h/day of light-intensity  
276 activity during working hours to benefit their health (Buckley et al., 2015). There is limited  
277 evidence evaluating the cardiometabolic response to accumulating  $\geq 2$  h of light activity in a  
278 single work day (Buckley, Mellor, Morris, & Joseph, 2014; Hawari, Al-Shayji, Wilson, & Gill,  
279 2016; Thorp et al., 2014; Zeigler et al., 2016; Zeigler et al., 2015). The majority of these studies  
280 evaluated responses to standing protocols (Buckley et al., 2014; Hawari et al., 2016; Thorp et  
281 al., 2014). Standing continuously for 185 min in an afternoon significantly attenuated  
282 postprandial glucose responses by 43% (Buckley et al., 2014), whereas alternating between  
283 a sitting and standing posture every 30 min (2 h standing in total) significantly attenuated  
284 postprandial glucose by 11% (Thorp et al., 2014). However, accumulating 4 h of standing in  
285 prolonged bouts (alternating between sitting and standing every 15 min) or short intermittent  
286 bouts (standing for 90 s at a time interspersed with 30 s sitting) did not lead to any significant  
287 differences in postprandial glucose, insulin or triglycerides compared with prolonged sitting  
288 (Hawari et al., 2016). It is possible that the standing bouts were not long enough in duration in  
289 the study by Hawari et al. (2016) to elicit a beneficial response. In the present study, engaging

290 in shorter light-intensity walking bouts (20 min) was sufficient to significantly attenuate  
291 postprandial glucose and triglycerides by 38% and 32%, respectively, potentially due to  
292 increased muscular-contraction mediated disposal of these metabolites (Bailey & Locke,  
293 2015). Similar to the current study, engaging in progressively longer treadmill desk walking  
294 bouts over the course of the day (from 10 min up to 30 min; total volume of 2.5 h) significantly  
295 lowered systolic and diastolic BP compared with prolonged sitting (Zeigler et al., 2016; Zeigler  
296 et al., 2015). The study by Zeigler et al. (2015) that was performed in the participants' normal  
297 office environment also reported a significant decrease in fatigue following the treadmill desk  
298 walking day. These findings suggest that treadmill desk walking may be an effective  
299 intervention for reducing cardiometabolic disease risk in office workers.

300

301 Although several studies have reported beneficial cardiometabolic responses to  
302 accumulating  $\geq 2$  h of light activity in a single work day, interrupting sitting with a lower total  
303 volume of light activity may also be effective. Several studies report attenuations in glucose  
304 when non-overweight, overweight/obese, and dysglycaemic participants engage in light-  
305 intensity walking for 2-5 min every 20-30 min (Bailey & Locke, 2015; Bergouignan et al.,  
306 2016; Dunstan et al., 2012; Henson et al., 2016; Pulsford, Blackwell, Hillsdon, & Kos, 2017).  
307 However, some studies did not observe significant changes in glucose in response to 2 min  
308 light-intensity walking every 20 min (Bailey et al., 2016; Hansen, Andersen, Vinther,  
309 Pielmeier, & Larsen, 2016). It is difficult to explain the disparity in findings from Bailey et al.  
310 (2016) and Hansen et al. (2016) as these studies used similar designs and study samples to  
311 other studies (Bailey & Locke, 2015; Pulsford et al., 2017), however, this may be due to  
312 differences in the composition of the meals provided during the experimental conditions. It is  
313 unknown whether the participants in the studies that reported negligible responses would  
314 have benefited from longer duration light-intensity walking bouts and further research is  
315 required to elucidate the differential effects of interrupting sitting with varying frequency and  
316 duration of physical activity.

317

318 Unlike the present study, previous research has reported attenuated insulin responses to  
319 interrupting sitting with 2-5 min of light-intensity walking every 20-30 min (Dunstan et al.,  
320 2012; Henson et al., 2016; Pulsford et al., 2017). The sample in the current study were in  
321 good general health and may have been more insulin sensitive than the participants in the  
322 studies by Dunstan et al. (2012) and Henson et al. (2016). This may thus explain the lack of  
323 change in insulin in the present study. However, the participants in the study by Pulsford et  
324 al. (2017) were of a similar health status to the present study. The use of capillary blood for  
325 determination of plasma insulin concentrations in the present study, rather than venous  
326 blood as used in previous studies, could therefore partly explain the disparity in findings.  
327 Indeed, prior exercise may alter the difference between arterialed and venous insulin  
328 sensitivity responses (Edinburgh et al., 2017), which may limit direct comparisons being  
329 made between studies.

330

331 Research evaluating BP responses to interrupting sitting with light-intensity activity is limited.  
332 In addition to the studies by Zeigler et al. (Zeigler et al., 2016; Zeigler et al., 2015) discussed  
333 above, Larsen et al. (2014) observed a significant reduction in systolic and diastolic BP in  
334 response to 2 min light-intensity walking every 20 min. It is likely that a complex interaction of  
335 exercise-induced mechanisms can account for the reduced BP responses, including changes  
336 in cardiac output and peripheral vascular resistance that are regulated by thermoregulation,  
337 blood volume, sympathetic and afferent nerve activity, and vasoactive substances  
338 (MacDonald, 2002). However, there were no differences in MAP in the study by Larsen et al.  
339 (2014), which is in contrast to the present study. It is possible that the longer walking bouts in  
340 the present study caused more pronounced vascular responses.

341

342 In the limited research evaluating triglyceride responses to interrupting sitting with light-  
343 intensity activity, 3-5 min of light-intensity walking every 30 min did not result in a significant  
344 attenuation compared with prolonged sitting in Type 2 diabetes and dysglycaemic participants  
345 (Dempsey et al., 2016a; Henson et al., 2016). This is in contrast to the current study that

346 demonstrated a significant 32% triglyceride attenuation in the interrupted sitting condition. This  
347 might suggest that interrupting sitting with longer bouts of light-intensity walking may be more  
348 effective in attenuating the rapid inactivity-induced decrease in lipoprotein lipase activity that  
349 occurs in animal models (Bey & Hamilton, 2003). Future research should therefore investigate  
350 lipoprotein lipase responses to the experimental protocols in the present study to provide  
351 mechanistic explanations. Furthermore, the potential for interrupting sitting with longer bouts  
352 of light-intensity walking should be studied as a potential therapeutic intervention in at-risk  
353 populations, such as Type 2 diabetes and dysglycaemia.

354

355 There was no significant condition x sex interaction effect in the present study for any of the  
356 cardiometabolic outcomes, indicating that males and females responded similarly to  
357 interrupting sitting. This is in contrast to Dempsey et al. (2016a) who observed a significant  
358 condition x sex interaction for the difference in glucose responses between prolonged sitting  
359 and interrupting sitting with light-intensity walking (no condition x sex interactions were  
360 observed for insulin or triglycerides). The results indicated that the magnitude of attenuation  
361 from interrupting sitting was greater in women than in men (Dempsey et al., 2016a). Previous  
362 research also suggests that young women have greater protection from adverse  
363 macrovascular responses to prolonged sitting, whereas young men exhibit more consistent  
364 declines in flow mediated dilation (Vranish et al., 2017). More research is required to establish  
365 sex differences in response to interrupting sitting to identify mechanistic explanations of any  
366 differences observed and appropriately inform intervention strategies targeting population  
367 subgroups.

368

369 As elevated postprandial glucose and triglyceride responses are associated with oxidative  
370 stress-induced atherogenic changes and increases in cardiometabolic disease risk (O'Keefe  
371 & Bell, 2007), the findings of the present study have potential clinical importance. The 3-4  
372 mmHg lower systolic and diastolic BP responses in the current study could be clinically  
373 meaningful if they were sustained, which could extrapolate to a reduced risk of stroke and

374 ischemic heart attacks by 15% and coronary heart disease by 6% (Cook, Cohen, Hebert,  
375 Taylor, & Hennekens, 1995). Interrupting sitting with light-intensity treadmill desk walking  
376 could be an effective strategy to reduce cardiometabolic disease risk in office workers. Studies  
377 are now needed to determine postprandial cardiometabolic responses to longer-term  
378 interventions targeting reductions in prolonged sitting.

379

380 This study has some limitations that should be considered. Although the purpose of the  
381 study was to examine cardiometabolic responses to standardised meals, normal dietary  
382 intake is likely to vary in free-living settings with regards to macronutrient composition,  
383 glycaemic index, meal size and frequency. Thus, the interaction between interrupting sitting  
384 and habitual dietary patterns remains unclear. The controlled laboratory environment in  
385 which the conditions took place limits the ability to generalise the findings to free-living  
386 settings where habitual behaviours, such as workload and stress, may affect glucose and BP  
387 control. The total volume of walking in the interrupted sitting condition amounted to 2 h,  
388 which may be difficult for office workers to achieve who are unable to gain access to a  
389 treadmill workstation. Furthermore, the feasibility of treadmill desk workstations in the  
390 workplace remains to be determined. It is possible that short-term use of a treadmill desk  
391 may decrease work productivity and performance (Ojo, Bailey, Chater, & Hewson, 2018) and  
392 future research should thus establish the long term effects of these workstations in the  
393 workplace. Lastly, as the study sample were in good general health, it may not be  
394 appropriate to generalise the findings to clinical populations.

395

396 In conclusion, this study demonstrates that interrupting sitting with an accumulated 2 h of  
397 light-intensity walking acutely improves postprandial glucose, triglyceride, and BP responses  
398 in males and females compared with prolonged sitting. The findings have application to  
399 workplace settings in which treadmill desk walking may be an effective approach for  
400 reducing sedentary time and cardiometabolic disease risk in office workers.

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1 **Table 1** Descriptive participant characteristics (mean  $\pm$  SD)

	Males	Females
Age (years)	32.0 $\pm$ 10.5	39.5 $\pm$ 10.3
Height (cm)	176.7 $\pm$ 5.5	166.3 $\pm$ 5.1
Weight (kg)	83.4 $\pm$ 15.9	68.8 $\pm$ 16.2
Body mass index (kg/m <sup>2</sup> )	26.6 $\pm$ 4.5	24.8 $\pm$ 5.1
Body fat%	22.5 $\pm$ 5.0	29.8 $\pm$ 7.6
Sitting time (h/day)	9.4 $\pm$ 2.4	9.2 $\pm$ 2.4
Physical activity (MET-min/week)	1823 $\pm$ 1658	1618 $\pm$ 1182

2

**Table 2** Physical activity during the experimental conditions.

	Prolonged sitting		Interrupted sitting		P value for main effect of condition
Sitting (min)	377.8	(372.2, 383.3)	250.7	(238.8, 262.7)	<0.001
Standing (min)	11.0	(5.4, 16.5)	18.8	(7.6, 29.9)	0.247
Light-intensity stepping (min)	0.9	(0.6, 1.1)	35.3	(18, 52.6)	<0.001
Moderate-intensity stepping (min)	0.4	(0.3, 0.5)	85.2	(67.1, 103.2)	<0.001
Total stepping time (min)	1.3	(0.9, 1.6)	120.5	(117.7, 123.3)	<0.001
Light-intensity steps ( <i>n</i> )	17	(12, 22)	1045	(539, 1550)	<0.001
Moderate-intensity steps ( <i>n</i> )	19	(13, 25)	3734	(2920, 4549)	<0.001
Total steps ( <i>n</i> )	36	(26, 45)	4779	(4423, 5134)	<0.001

**Table 3** Biochemical values for each condition

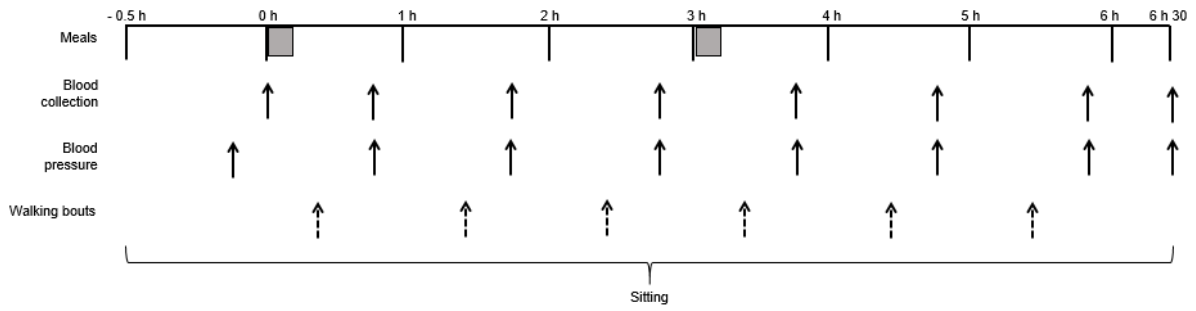
	Prolonged sitting		Interrupted sitting		P value for main effect of condition	P value for main effect of sex	P value for condition x sex interaction
	Males	Females	Males	Females			
Baseline blood glucose (mmol/L)	4.69 (4.45, 4.92)	4.09 (3.86, 4.33)	4.81 (4.57, 5.04)	4.10 (3.86, 4.33)	0.404	<b>0.001</b>	0.436
Baseline plasma insulin ( $\mu$ U/mL)	11.9 (9.2, 15.4)	7.2 (5.6, 9.3)	15.7 (12.2, 20.4)	9.7 (7.5, 12.6)	<b>0.002</b>	<b>0.009</b>	0.869
Baseline triglycerides (mmol/L)	1.23 (0.90, 1.55)	0.54 (0.22, 0.87)	1.49 (1.16, 1.81)	0.46 (0.14, 0.79)	0.479	<b>&lt;0.001</b>	0.187
Baseline systolic blood pressure (mmHg)	129 (123, 136)	108 (102, 115)	129 (122, 136)	110 (103, 117)	0.651	<b>&lt;0.001</b>	0.609
Baseline diastolic blood pressure (mmHg)	84 (79, 89)	71 (66, 76)	84 (79, 89)	71 (67, 76)	0.818	<b>0.001</b>	0.959
Blood glucose iAUC (mmol/L·6.5 h)	8.19 (6.51, 9.86)	5.14 (3.41, 6.87)	5.29 (3.50, 7.07)	3.75 (2.02, 5.47)	<b>0.001</b>	0.074	0.198
Plasma insulin iAUC ( $\mu$ U/mL·6.5 h)	266.7 (189.1, 375.4)	96.8 (67.5, 138.6)	221.3 (154.2, 317.6)	86.1 (61.1, 121.3)	0.110	<b>0.001</b>	0.665
Triglycerides iAUC (mmol/L·6.5 h)	5.66 (4.11, 7.21)	-0.25 (-1.82)	4.88 (3.27, 6.48)	-0.95 (-2.54, 0.63)	<b>0.022</b>	<b>&lt;0.001</b>	0.895
Mean systolic blood pressure (mmHg)	124 (121, 127)	119 (116, 122)	121 (118, 124)	115 (112, 117)	<b>0.010</b>	<b>0.003</b>	0.765
Mean diastolic blood pressure (mmHg)	79 (76, 81)	74 (72, 77)	76 (74, 79)	73 (70, 75)	<b>0.016</b>	<b>0.049</b>	0.636
Mean arterial pressure (mmHg)	94 (92, 97)	89 (86, 91)	92 (89, 94)	86 (83, 88)	<b>0.011</b>	<b>0.004</b>	0.768

Data presented as mean (95% CI)

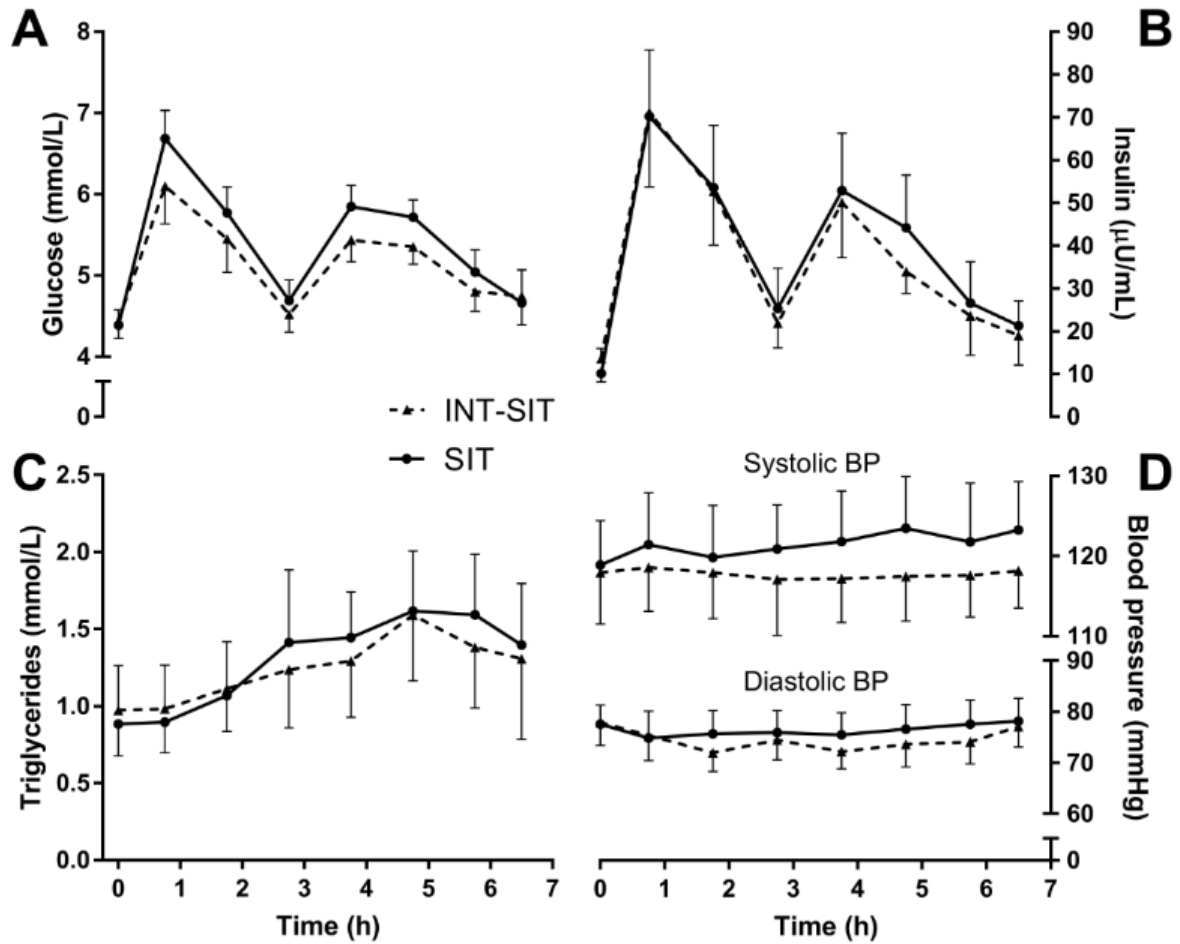
Statistically significant differences highlighted in bold

iAUC, incremental area under the curve





**Figure 1** Schematic of experimental protocol



**Figure 2** Changes in glucose (A), insulin (B), triglycerides (C), and blood pressure during the prolonged sitting (SIT) and interrupted sitting (INT-SIT) conditions. Data are mean and 95% confidence interval. Some error bars have been omitted for clarity.