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Effects of light-intensity physical activity on cardiometabolic parameters in young adults with overweight and obesity: The SED-ACT randomized controlled crossover trial

Sascha W. Hoffmann PhD[1] | Janis Schierbauer PhD[2] | Paul Zimmermann MD[2] | Thomas Voit MD[2] | Auguste Grothoff MSc[2] | Nadine Wachsmuth PhD[2] | Andreas Rössler PhD[3] | Helmut K. Lackner PhD[3] | Othmar Moser PhD[2,4]

[1]Division of Theory and Practice of Sports and Fields of Physical Activity, BaySpo-Bayreuth Center of Sport Science, University of Bayreuth, Bayreuth, Germany

[2]Division of Exercise Physiology and Metabolism, BaySpo-Bayreuth Center of Sport Science, University of Bayreuth, Bayreuth, Germany

[3]Department of Physiology and Pathophysiology, Medical University of Graz, Graz, Austria

[4]Interdisciplinary Metabolic Medicine Trials Unit, Department of Internal Medicine, Division of Endocrinology and Diabetology, Medical University of Graz, Graz, Austria

Correspondence
Sascha W. Hoffmann, Division of Theory and Practice of Sports and Fields of Physical Activity, BaySpo-Bayreuth Center of Sport Science, University of Bayreuth, 95440, Bayreuth, Germany.
Email: sascha.hoffmann@uni-bayreuth.de

Abstract

Aims: To investigate how a change in body position with light-intensity physical activity (PA) 'snacks' (LIPAS, alternate sitting and standing, walking or standing continuously) compared with uninterrupted prolonged sitting affects glucose metabolism and heart rate variability (HRV) parameters in young adults with overweight and obesity.

Materials and Methods: We conducted a four-arm randomized controlled crossover trial. The following conditions were tested during an 8-h simulated workday: uninterrupted prolonged sitting (SIT), alternate sitting and standing (SIT-STAND; 2.5 h total), continuous standing (STAND), and continuous walking (1.0 mph; WALK). The primary outcome was to investigate how a change in body position (alternate sitting and standing, walking or standing continuously) compared with uninterrupted sitting affects mean 8-h glucose metabolism. Secondary outcomes included the effects on 2-h postprandial glucose concentrations, as well as on 8-h/24-h heart rate and HRV parameters, in the respective study arms. Capillary blood samples were drawn from an hyperemised earlobe in the fasted state and once every hour during each trial intervention by puncturing the earlobe with a lancet and collecting 20 µL of blood (Biosen S-Line Lab+; EKF diagnostics, Barleben, Germany). HRV was assessed for 24 h including the 8-h intervention phase, and a home phase by means of a Holter

Trial Registration: German Clinical Trial Register DRKS00031425.

electrocardiogram. All participants received the same standardized non-relativised breakfast and lunch during the four trial visits.

Results: Seventeen individuals (eight women, mean age 23.4 ± 3.3 years, body mass index 29.7 ± 3.8 kg/m^2, glycated haemoglobin level 34.8 ± 3.1 mmol/mol [5.4 ± 0.3%], body fat 31.8 ± 8.2%) completed all four trial arms. Compared with SIT (89.4 ± 6.8 mg/dL), 8-h mean glucose was lower in all other conditions ($p < 0.05$) and this was statistically significant compared with WALK (86.3 ± 5.2 mg/dL; $p = 0.034$). Two-hour postprandial glucose after breakfast was approximately 7% lower for WALK compared with SIT ($p = 0.002$). Furthermore, significant time × condition effects on HRV parameters favouring light-intensity walking were observed ($p < 0.001$).

Conclusions: Replacement and interruption of prolonged sitting with light-intensity walking showed a significant blood glucose-lowering effect and improved HRV during an 8-h work environment in young adults with overweight and obesity.

KEYWORDS
glucose metabolism, heart rate variability, physical activity, sedentary behaviour, young adults

1 | INTRODUCTION

Sedentary behaviour, defined as any waking behaviour characterized by an energy expenditure ≤1.5 metabolic equivalents of task (METs), while in a sitting, lying or reclining posture,[1] and the absence of physical activity (PA) are behaviours that have increasingly shaped life in various environments.[2,3] Sedentary behaviour has steadily increased due to changes in physical, social and economic-environmental conditions, and has also been amplified by the COVID-19 pandemic.[4–6] Recently, studies have highlighted that young adults seem to be at high risk of uninterrupted, prolonged sitting times,[7,8] and regular prolonged sedentary behaviour has been identified as an independent risk factor for increased mortality in general and specifically for cardiovascular disease and cancer incidence, as well as type 2 diabetes (T2D) and obesity.[9–11]

Studies have demonstrated that prolonged sitting has detrimental effects on glucose metabolism, endogenous insulin, and vascular function.[12–14] Experimental trials have shown that breaking periods of prolonged sedentary behaviour with light-intensity PA 'snacks' (LIPAS) may attenuate adverse metabolic responses in physically inactive people and individuals with T2D.[15–23] Although interrupting sitting with bouts of PA in a wide variety of settings can improve glucose metabolism, studies do not issue entirely precise recommendations, which is mostly attributable to limitations and heterogeneity of study populations.[24]

Besides adverse glycaemic responses, cardiac-autonomic dysregulation is also linked to certain cardiovascular disease risk factors, such as hypertension and diabetes.[25] Autonomic cardiac modulation is commonly evaluated by measuring heart rate variability (HRV).[26] HRV analysis can be used to determine the autonomic regulatory capacity, and it is suitable as an integrative parameter for cardiovascular risk assessment and health prognosis. Reduced HRV leads to an increased risk of mortality,[27] and factors such as age, gender, posture, overweight and obesity, autonomic regulation due to PA, and diabetes may alter HRV parameters.[26,28] Though prolonged sitting exposure may increase the risk of various health outcomes, the involvement of cardiometabolic maladaptation is still not fully understood.

To the best of our knowledge, no study has investigated the interaction between sedentary behaviour, glucose metabolism, and cardiac-autonomic regulation in the high-risk population of young adults with overweight and obesity. Therefore, we aimed to investigate how a change in body position (alternate sitting and standing, walking or standing continuously) compared with uninterrupted prolonged sitting affects mean 8-h glucose metabolism, 2-h postprandial glucose concentration, and 8-h/24-h heart rate (HR) and HRV during an 8-h simulated working condition in young adults with overweight and obesity.

2 | MATERIALS AND METHODS

2.1 | Study design

The SED-ACT (Influence of SEDentary behaviour and physical ACTivity on inflammatory and physiological processes in the human body) study was a single-centre, prospective, randomized controlled four-arm crossover trial. The study protocol was approved by the local ethics committee of the University of Bayreuth (Bayreuth, Germany) with the processing number 22-037 and was registered at the German Clinical Trial Register (DRKS00031425). This trial was conducted in accordance with the principles of the declaration of Helsinki and

Good Clinical Practice. Before any trial-related examinations were performed, potential participants were informed about the study protocol and gave their written informed consent to participate in this trial.

2.2 | Eligibility criteria

The participants were recruited via notices (digital and paper form; also, in lectures), via the homepages of several organizational units of the University of Bayreuth, via face-to-face approach and via social networks. Positive ethics approval was received on 13 December 2022 and the recruitment process started on 13 February 2023 during the winter semester 2023/2024. After successful recruitment, the study participants were invited to a joint preparation meeting approximately 1 week prior to the initial screening examination, where an investigator assessed the following eligibility criteria: age range between 18 and 29 years (inclusive), and being overweight or obese according to the World Health Organization classification (body mass index [BMI] > 25.0 kg/m^2; the study team reserved the right to exclude individuals with a BMI >25 kg/m^2 whose classification was due to increased muscle mass and no apparent overweight; however, none of the participants were excluded for this reason). Individuals were excluded if they were already enrolled in a different study, had acute infection due to COVID-19, or had serious acute/chronic illnesses that precluded participation in the study in the judgement of the study medical team. The first patient visit took place on 20 March 2023.

2.3 | Study design

After enrolment in the study, participants were randomized (1:1:1:1) to the order of simulated work conditions by a researcher who was not further involved in the study, using Research Randomizer® 4.0 (Social Psychology Network, Lancaster, PA, USA).[29] Participants received ascending numbers, took part in an initial screening examination, and completed four 8-h simulated work and learning conditions in random order: (1) prolonged sitting (SIT); (2) sitting interrupted with standing (SIT-STAND); (3) continuous standing (STAND); and (4) continuous walking (WALK). After a 1-week washout, participants crossed over to the other trial arms. The initial screening visit and each trial intervention took place at our medical research laboratory at the Bayreuth Center of Sport Science (BaySpo) of the University of Bayreuth.

2.4 | Screening visit

The screening visit included a bioelectrical impedance analysis (Inbody 720, Inbody Co., Seoul, Republic of Korea), an overnight fasted oral glucose tolerance test (OGTT) and assessment of glycated haemoglobin (HbA1c) levels to verify whether the participants' glucose metabolism was impaired. HbA1c values below 39 mmol/mol (5.7%) were considered normal, while values of 39 to <48 mmol/mol (5.7 to <6.5%) were considered as borderline and values of ≥48 mmol/mol (≥6.5%) led to classification of T2D.[30]

2.5 | Trial visits

Prior to each trial visit, participants were required to fast for at least 12 h and refrain from any strenuous PA for at least 24 h. In addition, we informed the study participants that they were required to always eat the same meal the evening before each trial visit. To this end, we discussed appropriate examples of evening meals with the participants. The type of meal was left free, but participants were aiming to consume approximately 1 g/kg body weight of carbohydrates. At the beginning of each trial visit, participants were asked if they had consumed the same type of meal and amount as that consumed at the previous visits. All the participants confirmed that this was achieved. For all trial days, all participants received the same standardized non-relativised breakfast (421.9 ± 11.0 kcal, 9.1 ± 2.2 g fat, 2.4 ± 1.4 g saturated fatty acids, 68.9 ± 7.1 g carbohydrates, 25.3 ± 10.1 g sugars, 11.8 ± 4.1 g fibre, 11.4 ± 2.7 g protein, 0.40 ± 0.37 g salt) and lunch (550.7 ± 93.7 kcal, 21.6 ± 13.3 g fat, 7.5 ± 7.5 g saturated fatty acids, 65.9 ± 11.7 g carbohydrates, 13.1 ± 11.9 g sugars, 8.7 ± 3.3 g fibre, 19.8 ± 4.4 g protein, 3.28 ± 0.67 g salt). For breakfast, all the participants received the same standardized meal, however, for the lunch they were allowed to choose between two different meals. Each person then consumed the same meal at each trial visit. Breakfast and lunch were consumed between 8.30 and 9.00 AM and 12.00 and 12.30 PM, respectively. Both meals were brought and served directly to the participants, so that they were able to continue performing the respective activity type. Participants were asked to consume each meal within 15 min. Participants were allowed to drink water and sugar-free drinks during the intervention phase; however, during the trial visits, none of the participants consumed any sugar-free drinks. During the 8-h intervention period, participants might have been reading, watching movies, working, studying at their computer, or performing similar activities in the respective settings.

During SIT, participants remained seated for an 8-h period, but were allowed to use the toilet at the following times: before 08.30 AM, between 10.00 and 10.30 AM, during lunch time (12.00–12.30 PM) and between 15.00 and 16.00 PM, while no other PA was permitted.

During STAND, participants were required to stand continuously at a standing work desk (using a height-adjustable office desk; Aeris® Active Office, Germany). Toilet times were the same as those in the SIT condition. No other PA was permitted.

During SIT-STAND, participants were asked to change from sitting to standing at the same height-adjustable work desk (Aeris® Active Office) for a predetermined time each hour at progressively longer intervals throughout the day, as follows: for 10 min at 9:20 AM and 10:20 AM, for 15 min at 11:30 AM and during lunch time (12:00–12:30 PM), for 20 min at 1:40 and 2:20 PM, and for 30 min at 3.00 and 4.00 PM. This resulted in an accumulated standing time of 2.5 h per

day and was based on previous work on the effects of standing, alternating bouts of sitting and standing, and light-intensity walking on 24-h glucose, ambulatory blood pressure, and musculoskeletal discomfort.[17,31–33]

During WALK, participants were required to work at a normal treadmill with a special shelf for books, tablets, and computers (LifeFitness Platinum Series; Life Fitness Europe, Unterschleißheim, Germany) in a slow walking activity (1.0 mph). Exceptions to visit the toilet were made at the same times as in the SIT condition.

2.6 | Outcomes

The primary outcome was to investigate how a change in body position (alternate sitting and standing, walking or standing continuously) compared to uninterrupted sitting affects mean 8-h glucose metabolism. Secondary outcomes included the effects on 2-h postprandial glucose concentration. Capillary blood samples were drawn from a hyperemised earlobe in the fasted state (t0) and once every hour during each trial intervention (t1–t8) to analyse 8-h glucose profile. This was conducted by puncturing the earlobe with a lancet and collecting 20 µL of capillary blood. Glucose/lactate haemolysing solution (1 mL) was used immediately to dissolve blood samples (Sodium [Na+] heparinized) and blood glucose levels were measured within 2 h (Biosen S-Line Lab+; EKF diagnostics, Barleben, Germany).

Additional secondary outcomes included the effects on 8-h/24-h HR and HRV parameters in the respective study arms. The long-term recording of HR and HRV was performed over 24-h via a one-channel Holter electrocardiogram (ECG), with a 500-Hz sampling rate (Faros 180, Bittium, Oulu, Finland). In the time domain analysis, the following standard HRV measures were evaluated: standard deviation of R-R-intervals (SDNN), square root of the mean standard difference of successive R-R intervals (RMSSD) as well as analysis of low frequency (LF) and high frequency (HF) and their respective ratio (LF/HF).[34,35] Because of skewed distributions, a natural logarithmic transformation was applied for frequency domain variables. The continuously recorded HRV data were divided into three daytime periods to provide more clarity and to avoid artefacts during breakfast and lunch: the morning hours, between 9:00 and 11:00 AM; in the afternoon, between 1:00 and 3:00 PM; and in the night during the resting sleep phase of each participant. Data from the ECG, the three-dimensional acceleration sensor, and the activity log were analysed to assess sleep quality by determining a resting state index. A detailed description of the calculations for the restful sleep analysis has been published elsewhere.[36] HR and HRV were assessed according to the guidelines of the Task Force of the European Society of Cardiology and the recommendations of the North American Society of Pacing and Electrophysiology (NASPE).[37]

2.7 | Statistical analyses

Data were tested for normal distribution using the Shapiro–Wilk test. Data are presented according to their distribution type as arithmetic mean ± standard deviation, mean (95% confidence interval). For normally distributed outcomes, repeated-measures one-way analysis of variance or mixed models were conducted with Tukey's test for multiple comparisons between conditions. For data that were not normally distributed, a nonparametric test (Friedman test) with Dunn's multiple comparison test was applied. Analysis of the experimental 8-h blood glucose values and HRV data was performed by fitting a mixed-effects model to test for differences between the experimental conditions. As a single participant provided data for all four conditions, the two factors 'timepoint' and 'study condition' were defined as repeated measures. All data were calculated using a mixed-effects model with Greenhouse–Geisser correction. Data were analysed using GraphPad Prism Software version 8.0.2 (GraphPad, San Jose, CA, USA). Nonparametric tests were performed when necessary. For within-condition comparisons, statistical significance was accepted at $p < 0.05$ (two-tailed). Sample size estimation was conducted via G-power (3.1.9.7, HHU-Düsseldorf, Germany) for mean glucose from a comparable study by Crespo et al.,[17] which led to a power of 0.80 for $n = 14$ per trial arm.

3 | RESULTS

As shown in the CONSORT flow diagram[38] (Figure 1), of 47 people screened, 19 consented and were randomized, after 28 participants were withdrawn for not meeting the eligibility criteria. Among those randomized, two withdrew from the study during the first intervention because they were unwilling to participate further. A total of 17 young adults with overweight and obesity (eight women, age 23.4 ± 3.3 years, BMI 29.7 ± 3.8 kg/m^2, body fat 31.8 ± 8.2%, segmental lean mass 34.9 ± 8.7 kg, visceral fat area 119.2 ± 33.9 cm^2; Table 1) completed the initial examination and all four study arms.

3.1 | Glycaemia

Results of the OGTT show that the fasting blood glucose levels of all participants were below 5.6 mmol/L (100 mg/dL) and below 12.2 mmol/L (220 mg/dL) 2 h post-OGTT. No blood glucose levels exceeded 11.1 mmol/L (200 mg/dL) throughout the entire OGTT.[39] Participants had an average HbA1c value of 34.8 ± 3.2 mmol/mol (5.4 ± 0.3%). Based on the OGTT, none of the participants were classified as having a diagnosis of T2D.

3.2 | Glycaemia over the 8-h simulated working periods

The glucose profiles during the simulated working periods are given in Figure 2. The first initial increase in postprandial glucose response at timepoint 1 (t_1) after breakfast was 4% –12% higher for SIT (117.9 ± 13.2 mg/dL; 6.5 ± 0.7 mmol/L) compared with all other conditions, and reached statistical significance compared with WALK (5.7

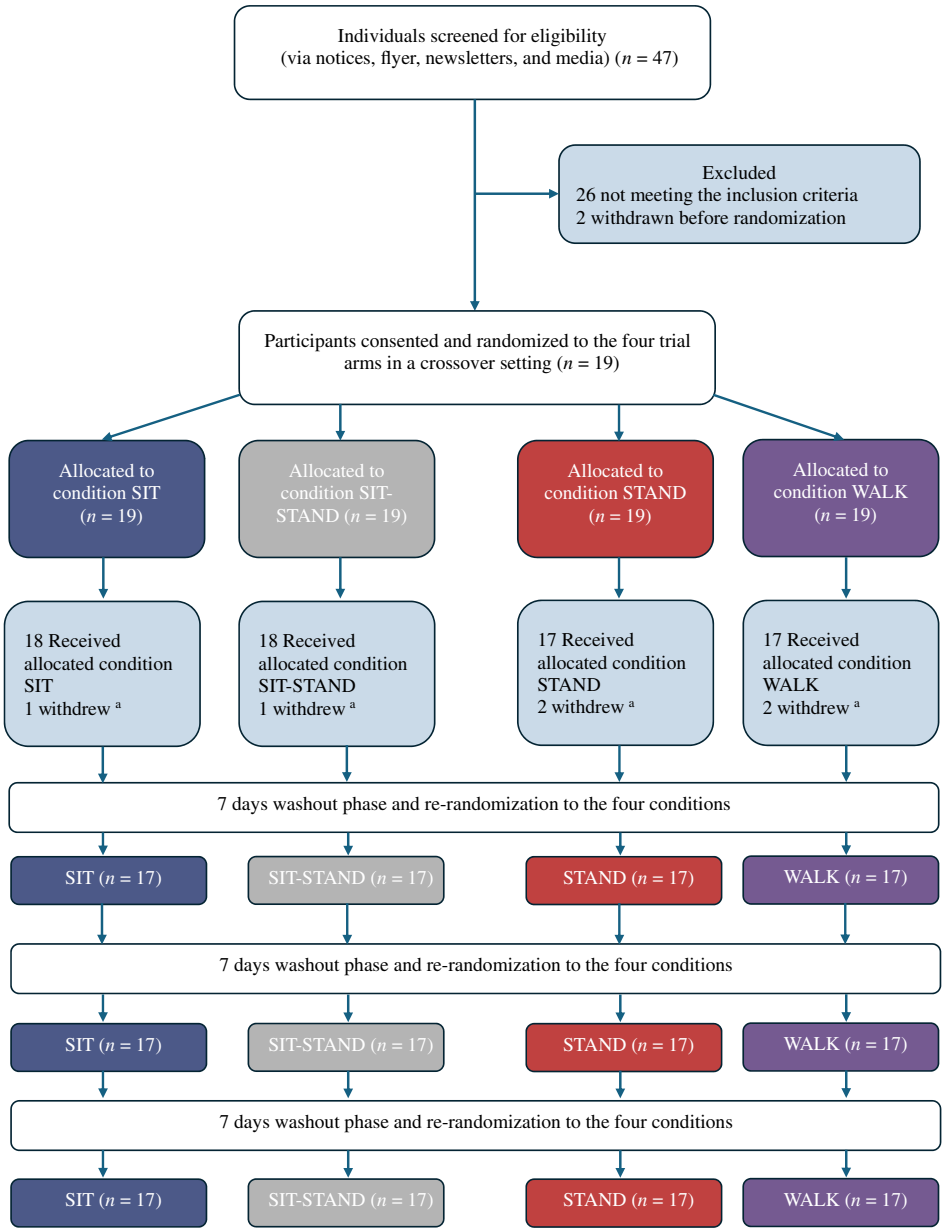

FIGURE 1 Participant flow chart. [a]Unwilling to participate: too busy, could not commit, did not want to participate. SIT, continuous sitting; SIT-STAND, sitting interrupted with standing; STAND, continuous standing WALK, continuous walking.

± 0.7 mmol/L [103.3 ± 13.2 mg/dL]; $p = 0.002$) but not with STAND (6.3 ± 0.7 mmol/L [113.2 ± 13.4 mg/dL]; $p = 0.606$) or SIT-STAND (6.0 ± 1.0 mmol/L [109.0 ± 17.8 mg/dL]; $p = 0.372$). However, there was also a significant difference between STAND (6.3 ± 0.7 mmol/L [113.2 ± 13.4 mg/dL]) and WALK (5.7 ± 0.7 mmol/L [103.3 ± 13.2 mg/dL]; $p = 0.021$).

There was a significant main effect for 8-h mean glucose ($p = 0.034$) and 2-h postprandial mean glucose for breakfast ($p = 0.019$), but not for the period after lunch ($p = 0.124$). The 8-h mean glucose was lower for STAND, SIT-STAND and WALK compared with SIT (Figure 3A–C and Table 2). The mean glucose level for WALK (4.8 ± 0.3 mmol/L [86.3 ± 5.2 mg/dL]) was significantly lower than for SIT (5.0 ± 0.4 mmol/L [89.4 ± 6.8 mg/dL]; $p = 0.033$). Two-hour postprandial mean glucose after breakfast was approximately 7% lower for WALK (4.9 ± 0.5 mmol/L [88.5 ± 8.6 mg/dL]) compared with SIT (5.3 ± 0.5 mmol/L [95.3 ± 9.2 mg/dL]; $p = 0.002$).

3.3 | HRV parameters

Significant time × condition effects ($F_{(6,84)} = 18.70$, $p < 0.001$) for the HR assessment were found across the four conditions (Table 3 and Figure 3D–F). Post hoc analyses showed significant differences in HR behaviour during the morning between the conditions SIT (69.4 ± 9.8 bpm) and STAND (80.6 ± 13.3 bpm; $p < 0.001$), between SIT and WALK (85.9 ± 13.0 bpm; $p < 0.001$) and between SIT-STAND (72.6 ± 11.4 bpm) and STAND (80.6 ± 13.3 bpm; $p = 0.005$) as well as between SIT-STAND and WALK (85.9 ± 13.0 bpm; $p < 0.001$). In the afternoon, significant differences between SIT (70.4 ± 8.2 bpm) and

TABLE 1 Participants' anthropometric characteristics.

Characteristic ($n = 17$)	
Females, *n* (%)	8 (47.1)
Age, years	23.4 ± 3.3
Height, cm	173.8 ± 12.1
Weight, kg	90.1 ± 18.3
BMI, kg/m^2	29.7 ± 3.8
Body fat mass, kg	29.2 ± 10.2
Body fat percentage, %	31.8 ± 8.2
Skeletal muscle mass, kg	34.9 ± 9.0
Skeletal muscle percentage, %	38.6 ± 4.9
Visceral fat area, cm^2	119.2 ± 33.9
HbA1c, mmol/mol	34.8 ± 3.2
HbA1c, %	5.4 ± 0.3

Note: Data are mean ± standard deviation, unless otherwise stated.
Abbreviations: BMI, body mass index; HbA1c, glycated haemoglobin.

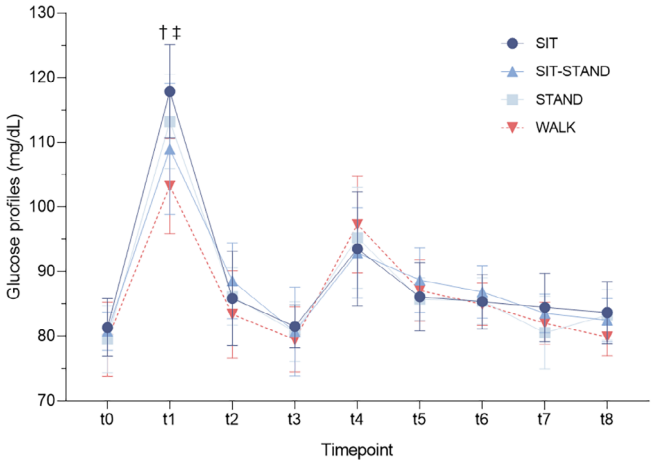

FIGURE 2 Glucose profiles during continuous sitting (SIT), sitting interrupted with standing (SIT-STAND), continuous standing (STAND) and continuous walking (WALK). Data are expressed as mean and standard deviation. Significant difference between STAND (t_1) and WALK (t_1; †, $p < 0.05$), and between SIT (t_1) and WALK (t_1, ‡, $p < 0.0001$) STAND, standing condition; WALK, walking condition; $t_{0\text{-}8}$, different timepoints measured glucose during the 8-h condition.

STAND (77.8 ± 15.1 bpm; $p = 0.039$), between SIT and WALK (87.2 ± 13.9 bpm; $p < 0.001$), between SIT-STAND and WALK (72.5 ± 10.4 bpm vs. 87.2 ± 13.9 bpm; $p < 0.001$), and between STAND and WALK (70.4 ± 8.2 bpm vs. 87.2 ± 13.9 bpm; $p = 0.001$) were observed, while no relevant differences during the night between conditions could be elucidated (Figure 3D).

For SDNN no significant time effects ($F_{(2,28)}$=0.13, $p = 0.793$) were provided, but for condition ($F_{(3,42)}$=26.41, $p < 0.001$), and for time × condition, significant effects were observed ($F_{(6,84)} = 12.16$, $p < 0.001$). In the morning SDNN was higher in the SIT condition (87.8 ± 33.9 ms) compared with WALK (47.5 ± 19.0 ms; $p < 0.001$) and significant differences between WALK (47.5 ± 19.0 ms) and SIT-STAND (85.6 ± 32.7 ms; $p < 0.001$), and STAND (71.7 ± 29.2 ms; $p < 0.001$) were observed. In the afternoon, we found the same behaviour compared to the morning hours referring to the relationship between the sympathetic and parasympathetic regulation (Figure 3E; Table 3). There were no significant differences in SDNN between conditions during the night. An overview of the overall results of the frequency domain as well as the ratio LF/HF is also presented in Table 3. Significant differences were found for HF in the morning between SIT (6.7 ± 1.1 ms^2) and STAND (5.6 ± 1.2 ms^2; $p = 0.007$) and WALK (5.0 ± 1.0 ms^2; $p < 0.001$) as well as between SIT-STAND (6.4 ± 1.1 ms^2) and STAND (5.6 ± 1.2 ms^2; $p = 0.019$) and WALK (5.0 ± 1.0 ms^2; $p < 0.001$). During the afternoon, significant differences were observed between WALK (4.9 ± 1.1 ms^2) and STAND (5.9 ± 1.3 ms^2; $p = 0.028$) and SIT-STAND (6.2 ± 0.8 ms^2; $p < 0.001$) and SIT (6.6 ± 0.9 ms^2; $p < 0.001$). During the nighttime, significant differences were found between the SIT (6.8 ± 0.7 ms^2) and STAND (7.1 ± 0.8 ms^2; $p < 0.001$) conditions (Figure 3F).

4 | DISCUSSION

To our knowledge, this is the first study to evaluate the effects of reducing uninterrupted prolonged sitting with a change in body position through different LIPAS (alternate sitting and standing, walking or standing continuously) during a simulated workday on 8-h mean glucose, first initial postprandial glucose response after breakfast, 2-h postprandial glucose, and HRV measurements in normoglycaemic young adults with overweight and obesity. Compared with SIT, results regarding the primary outcome show that 8-h mean glucose was reduced by approximately 1%–3% for the other conditions, and the first initial postprandial glucose response immediately at t_1 after breakfast was approximately 12% lower for WALK. Various studies,[16–21,31–33] and several systematic reviews or meta-analysis[12,24,40] have investigated the effects of different types of regular active breaks on certain glucose and cardiometabolic parameters compared with prolonged sitting.[41] Our study showed that even continuous light-intensity slow walking significantly reduces 8-h mean glucose. Other findings also suggest that light-intensity walking represents a superior PA break compared to standing breaks.[39] This might underpin our results that continuous standing for 8 h showed no significant effect on mean glucose compared with prolonged sitting, supposedly due to low muscle activity.[6]

Regarding our secondary outcome, 2-h postprandial glucose was reduced by approximately 2%–7% for SIT-STAND, STAND and WALK, respectively. These observed slight reductions may be clinically relevant, as it is reported that even small reductions in postprandial glucose levels from approximately 0.2 to 1.1 mmol/L are associated with less coronary stenosis in individuals with normal glucose tolerance,[42] and multiple postprandial glucose spikes have been identified to promote the development of atherosclerosis and cardiovascular disorders.[43]

Our results are in line with those of various studies,[12,16,20,21,33,40,44] showing that the first initial postprandial

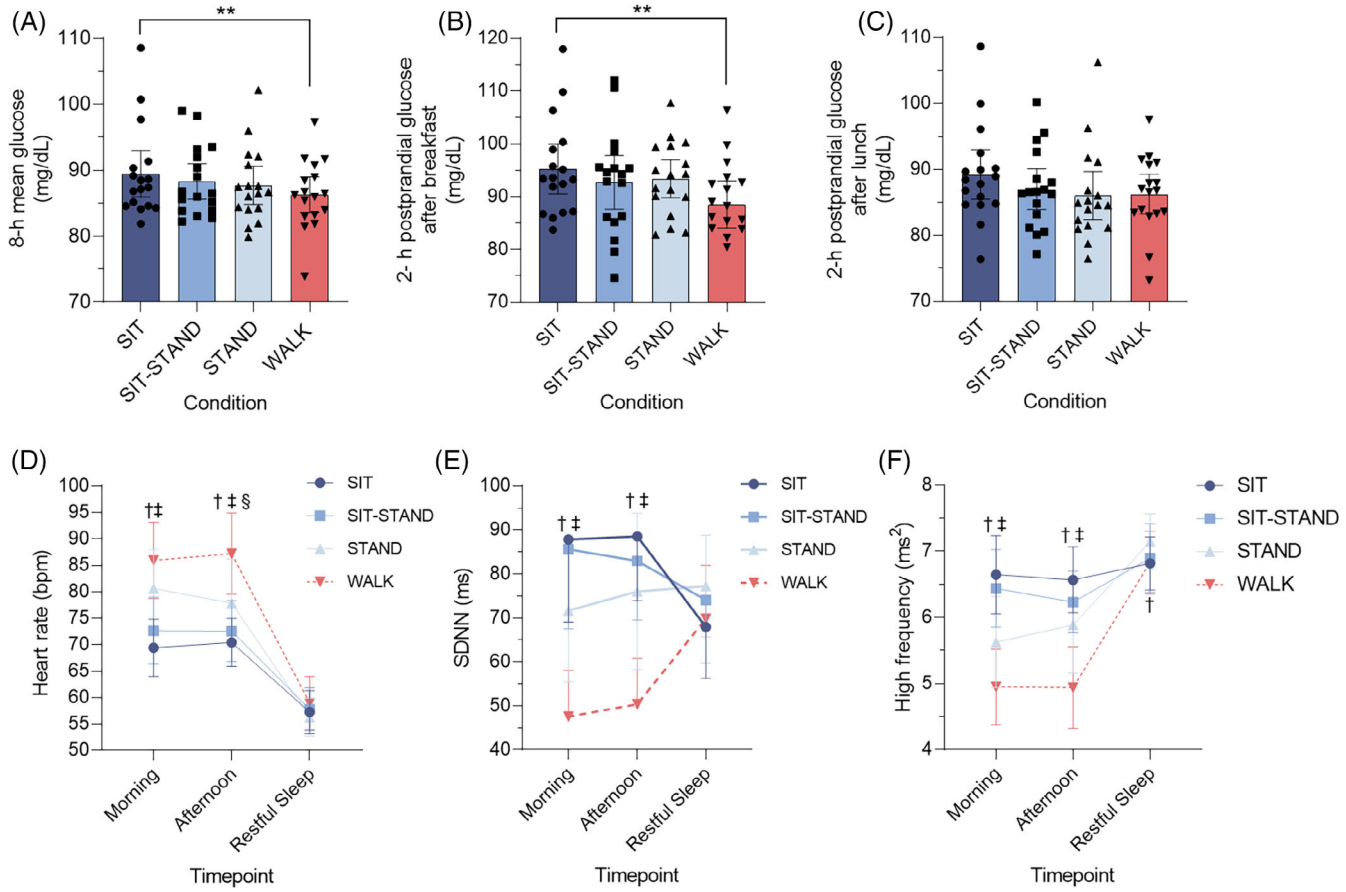

FIGURE 3 Differences in (A) 8-h mean glucose levels, (B) 2-h postprandial glucose levels after breakfast, (C) 2-h postprandial glucose levels after lunch, and (D) differences in heart rate (HR), (E) standard deviation of NN intervals (SDNN), (F) and high frequency for time × condition effects during continuous sitting (SIT), sitting interrupted with standing (SIT-STAND), continuous standing (STAND), and continuous walking (WALK). The time intervals for HR and HR variability measurements were 2 h each in the morning and afternoon, and during each individual restful sleep phase in the night. Error bars represent 95% confidence interval. Some error bars have been omitted for clarity (E). Stars indicate the level of significance (A–C). *Indicates $p < 0.05$, ** indicates $p < 0.01$. Significant differences between groups at different time points are indicated as follows (D-F): (D, morning) †between SIT and STAND, and WALK (both $p < 0.001$), ‡between SIT-STAND and STAND ($p = 0.005$), and WALK ($p < 0.001$), (D, afternoon) †between SIT and STAND ($p = 0.039$), and WALK ($p < 0.001$), ‡between SIT-STAND and WALK ($p < 0.001$), §between STAND and WALK ($p = 0.001$), (D, morning and afternoon) †between SIT and WALK ($p < 0.001$), ‡between WALK and SIT-STAND, and STAND (both $p < 0.001$), (F, morning) †between SIT and STAND ($p = 0.007$), and WALK ($p < 0.001$), ‡between SIT-STAND and STAND ($p = 0.019$), and WALK ($p < 0.001$), (F, afternoon) †between WALK and STAND ($p = 0.028$), and SIT-STAND ($p < 0.001$) as well as SIT ($p < 0.001$), (F, restful sleep) †between SIT and STAND ($p < 0.001$).

TABLE 2 Mean glucose concentration for each simulated condition during workday hours (8 h) and during postprandial periods (breakfast and lunch).

Phase	Measure	SIT	SIT-STAND	STAND	WALK
8-h	Glucose, mmol/L	5.0 (4.8, 5.2)	4.9 (4.7, 5.0)	4.9 (4.7, 5.0)	4.8 (4.6, 4.9)[a]
	Glucose, mg/dL	89.4 (85.9, 93.0)	88.3 (85.6, 90.9)	87.7 (84.7, 90.6)	86.3 (83.6, 89.0)[a]
2-h postprandial					
Breakfast	Glucose, mmol/L	5.3 (5.0, 5.5)	5.1 (4.9, 5.4)	5.2 (4.9, 5.4)	4.9 (4.7, 5.2)[b]
	Glucose, mg/dL	95.3 (90.5, 99.9)	92.7 (89.8, 97.0)	93.4 (87.6, 97.8)	88.5 (84.1, 92.9)[b]
Lunch	Glucose, mmol/L	5.0 (4.7, 5.2)	4.8 (4.7, 5.0)	4.8 (4.6, 4.9)	4.8 (4.6, 5.0)
	Glucose, mg/dL	89.2 (85.5, 93.0)	87.0 (83.9, 90.1)	86.0 (82.4, 89.7)	86.2 (83.3, 89.2)

Note: Data are presented as means (95% confidence interval).
Abbreviations: SIT-STAND, combined sitting and standing condition; SIT, sitting condition; STAND, standing condition; WALK, walking condition.
[a]Significant differences between SIT and WALK ($p = 0.033$).
[b]Significant differences between SIT and WALK ($p = 0.002$).

TABLE 3 Heart rate and heart rate variability measurements according to the study condition.

Parameter	Time	SIT (1)[a]	SIT-STAND (2)[a]	STAND (3)[a]	WALK (4)[a]	F-Statistics	*p* value
HR, bpm, mean (95% CI)	Morning	69.4 (64.0, 74.8)[3,4]	72.6 (66.3, 78.9)[3,4]	80.6 (73.3, 88.0)[1,2]	85.9 (78.7, 93.1)[1,2]	$F_{(3,42)} = 29.0$	$p < 0.001$***
	Afternoon	70.4 (65.9, 74.9)[3,4]	72.5 (66.8, 78.3)[4]	77.8 (69.5, 86.2) [1,4]	87.2 (79.5, 94.9)[1,2,3]	$F_{(3,42)} = 28.2$	$p < 0.001$***
	Restful sleep	57.2 (53.2, 61.3)	57.8 (53.7, 61.9)	56.2 (52.7, 59.8)	58.9 (53.9, 64.0)	$F_{(3,42)} = 2.8$	$p = 0.052$
SDNN, ms, mean (95% CI)	Morning	87.8 (69.0, 106.6)[4]	85.6 (67.5, 103.7)[4]	71.7 (55.5, 87.9)[4]	47.5 (37.0, 58.1)[1,2]	$F_{(3,42)} = 23.4$	$p < 0.001$***
	Afternoon	88.5 (73.9, 103.2)[4]	82.9 (69.5, 96.3)[4]	76.0 (58.3, 93.8)[4]	50.4 (39.9, 60.8)[1,2]	$F_{(3,42)} = 21.4$	$p < 0.001$***
	Restful sleep	67.9 (56.3, 79.6)	74.1 (59.7, 88.4)	77.2 (65.6, 88.8)	69.8 (57.7, 82.0)	$F_{(3,42)} = 2.9$	$p < 0.05$*
RMSSD, ms, mean (95% CI)	Morning	63.8 (45.9, 81.7)[3,4]	58.9 (39.3, 78.7)[4]	40.8 (28.7, 52.8)[1]	30.5 (21.5, 39.6)[1,2]	$F_{(3,42)} = 13.2$	$p < 0.001$***
	Afternoon	61.9 (46.7, 77.0)[4]	53.8 (38.9, 68.7)[4]	48.0 (33.0, 63.1)	31.0 (21.5, 40.5)[1,2]	$F_{(3,42)} = 12.6$	$p < 0.001$***
	Restful sleep	69.0 (54.0, 83.9)	74.8 (53.8, 95.8)	79.3 (63.0, 95.7)	70.6 (51.6, 89.6)	$F_{(3,42)} = 2.0$	$p = 0.148$
LF, ms^2, mean (95% CI)	Morning	7.6 (7.2, 8.0)[4]	7.6 (7.2, 8.0)[4]	7.4 (6.9, 7.9)[4]	6.6 (6.1, 7.1)[1,2,3]	$F_{(3,42)} = 21.6$	$p < 0.001$***
	Afternoon	7.6 (7.3, 8.0)[4]	7.5 (7.2, 7.9)[4]	7.5 (7.0, 7.9)[4]	6.6 (6.2, 7.1)[1,2,3]	$F_{(3,42)} = 15.8$	$p < 0.001$***
	Restful sleep	7.1 (6.7, 7.4)	7.2 (6.9, 7.6)	7.3 (7.0, 7.7)	7.1 (6.8, 7.4)	$F_{(3,42)} = 2.8$	$p = 0.053$
HF, ms^2, mean (95% CI)	Morning	6.7 (6.1, 7.2)[3,4]	6.4 (5.8, 7.0)[3,4]	5.6 (4.9, 6.3)[1,2]	5.0 (4.4, 5.5)[1,2]	$F_{(3,42)} = 20.8$	$p < 0.001$***
	Afternoon	6.6 (6.1, 7.1)[4]	6.2 (5.8, 6.7)[4]	5.9 (5.2, 6.6)[4]	4.9 (4.3, 5.6)[1,2,3]	$F_{(3,42)} = 18.8$	$p < 0.001$***
	Restful sleep	6.8 (6.4, 7.2)[3]	6.9 (6.3, 7.4)	7.1 (6.7, 7.6)[1]	6.8 (6.4, 7.3)	$F_{(3,42)} = 3.25$	$p < 0.05$*
LF/HF-ratio, −, mean (95% CI)	Morning	0.9 (0.6, 1.3)[3,4]	1.2 (0.8, 1.5)[3]	1.8 (1.4, 2.1)[1,2]	1.6 (1.4, 1.9)[1]	$F_{(3,42)} = 18.8$	$p < 0.001$***
	Afternoon	1.0 (0.8, 1.3)[3,4]	1.3 (1.0, 1.6)[4]	1.6 (1.2, 1.9)[1]	1.7 (1.4, 2.0)[1,2]	$F_{(3,42)} = 13.7$	$p < 0.001$***
	Restful sleep	0.3 (−0.1, 0.5)	0.3 (0.0, 0.7)	0.2 (−0.2, 0.5)	0.3 (−0.1, 0.6)	$F_{(3,42)} = 1.2$	$p = 0.305$

Note: Level of significance was calculated by comparing the different conditions with post hoc testing. Significant differences between the conditions (SIT, 1; SIT-STAND, 2; STAND, 3; WALK, 4) are displayed with superscript numbers (1–4).

Abbreviations: CI, confidence interval; HF, high frequency; HR, heart rate; LF, low frequency; RMSSD, root mean square of successive differences; SDNN, standard deviation of normal-to-normal beat; SIT-STAND, combined sitting and standing condition; SIT, sitting condition; STAND, standing condition; WALK, walking condition.

*Indicates $p < 0.05$.

***Indicates $p < 0.001$.

[a]$n = 15$; individuals with missing data were excluded from the analyses.

glucose response at t_1 as well as the 2-h postprandial glucose after breakfast is lower for SIT-STAND, STAND and WALK conditions, but only reached significant differences for WALK compared with SIT. New insights were provided by Engeroff et al.,[40] who found that exercise has a greater acute beneficial effect on postprandial hyperglycaemia when undertaken as soon as possible after a meal, and longer intervals between eating and exercising weaken the effectiveness with regard to glucose levels. Glycaemic spikes should be avoided not only for healthy individuals, but especially for patients with T2D as postprandial hyperglycaemia has the greatest detrimental effect on long-term blood glucose control.[40] Our results support this hypothesis since light-intensity walking immediately after breakfast showed a significant blood glucose-lowering effect compared with other conditions.

Regarding our additional secondary outcome, this research indicates that working in different conditions significantly altered HR and HRV parameters in young adults with overweight and obesity. Our results show significant time × condition effects for HR, SDNN and HF response during the morning and afternoon hours, as well as significant differences in HF between SIT and STAND during restful sleep. HR was increased during the day, with walking providing the highest HR, followed by continuous standing and sitting interrupted with standing. Previous research on changes in HR/HRV during interrupted prolonged sitting revealed moderate effects on HR only for healthy populations, and, additionally, walking as the interruption strategy resulted in the greatest increase in HR, as compared with other strategies.[45] For SDNN there are significant time × condition effects. During the day, SDNN is sympathetically controlled and highest when sitting, whereas post-condition sympathetic-parasympathetic answer during nighttime shows a sympathetically driven recovery situation, which is primarily evident for STAND, followed by SIT-STAND, WALK, and SIT. However, there was no significant difference in SDNN between conditions during nighttime, whereas the SDNN following STAND tends to be highest, but narrowly missing significance ($p = 0.054$). This is remarkable because HR in the STAND condition is significantly higher during the day, and still tends to be lower at night. There appears to be an obvious difference between sitting and standing regarding the sympathetic regulation. Standing seems to be more problematic as it requires more active night recovery compared with prolonged sitting and walking, which have the same need for rest during nighttime. This is supported by the parasympathetic activation level (i.e., RMSSD), which is only numerically higher in STAND compared with SIT ($p = 0.086$). The comparison of HF at night, as a marker for the parasympathetic regulation, between the conditions supports the hypothesis that standing requires the greatest recovery followed by SIT-STAND, WALK, and

SIT ($p < 0.001$), although WALK is the apparently higher daily load. Previous research indicates that PA increases vagus activity and thus leads to an improved cardiovascular prognosis, while obesity is associated with a reduction in parasympathetic activity.[27,46] Furthermore, a connection can be established between sympathicovagal balance, obesity, and insulin resistance.[47] This is in line with our findings, where we show that light-intensity walking positively affects both glucose metabolism and the overweight-induced HRV parameters in this cohort of young adults, and we hypothesize that long-term standing during the day may be a negatively perceived stressor for the human body.[48,49]

A strength of our study is its crossover design, which enhances internal validity and reliability of findings, enabling a control of within-subject factors across experimental exposures. Study limitations are as follows. Firstly, only acute effects on blood glucose metabolism were investigated, and 24-h long-term effects of the respective interventions cannot be extrapolated from the results of the present study. Secondly, the small number of included participants may limit the generalizability of our results. Additionally, some results of the HRV analysis narrowly missed significance. Thirdly, differences in sympathetic-parasympathetic balance of the participants, which we could not evaluate, might play a role. Sports, job strain, and other environmental conditions may affect the HRV profiles of each participant. Fourthly, the findings of the present study were not adjusted for covariates such as lifestyle habits during the intervention.

In conclusion, our trial showed that replacement and interruption of uninterrupted prolonged sedentary behaviour due to changes in body position with different LIPAS have positive effects on improving blood glucose levels and HRV parameters in young adults with overweight and obesity. Replacement of sedentary behaviour should best be carried out with light-intensity walking. We therefore recommend including LIPAS as often as possible throughout the day, and post-meal LIPAS, in particular, might be most beneficial to reduce postprandial glucose response. Further research is needed to determine implementable and effective strategies for preventing prolonged sitting in this subpopulation and promoting health-conscious behaviour towards LIPAS for the general population.

AUTHOR CONTRIBUTIONS

Conceptualization: Sascha W. Hoffmann, Othmar Moser; data curation: Sascha W. Hoffmann; formal analysis: Sascha W. Hoffmann, Othmar Moser; investigation: Sascha W. Hoffmann, Paul Zimmermann, Janis Schierbauer, Auguste Grothoff, Nadine Wachsmuth, Thomas Voit, Andreas Rössler, Helmut K. Lackner, Othmar Moser; methodology: Sascha W. Hoffmann, Helmut K. Lackner, Othmar Moser; project administration: Sascha W. Hoffmann, Othmar Moser; resources: Sascha W. Hoffmann, Othmar Moser, Andreas Rössler; supervision: Sascha W. Hoffmann, Othmar Moser; validation: Sascha W. Hoffmann, Helmut K. Lackner, Andreas Rössler, Othmar Moser; visualization: Sascha W. Hoffmann, Helmut K. Lackner; writing—original draft: Sascha W. Hoffmann, Helmut K. Lackner, Othmar Moser; writing—review and editing:Sascha W. Hoffmann, Paul Zimmermann, Janis Schierbauer, Auguste Grothoff, Nadine Wachsmuth, Thomas Voit, Andreas Rössler, Helmut K. Lackner, Othmar Moser All authors have read and agreed to the published version of the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest.

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DATA AVAILABILITY STATEMENT

Data are available from the authors on reasonable request.

ORCID

Sascha W. Hoffmann https://orcid.org/0009-0003-1458-2355
Othmar Moser https://orcid.org/0000-0002-1661-0685

REFERENCES

1. Tremblay MS, Aubert S, Barnes JD, et al. Sedentary behavior research network (SBRN)—terminology consensus project process and outcome. *Int J Behav Nutr Phys act*. 2017;14(1):75.
2. Bertuol C, Tozetto WR, Streb AR, Del Duca GF. Combined relationship of physical inactivity and sedentary behavior with the prevalence of noncommunicable chronic diseases: data from 52,675 Brazilian adults and elderly. *Eur J Sport Sci*. 2021;22:1-28.
3. Stamatakis E, Gale J, Bauman A, Ekelund U, Hamer M, Ding D. Sitting time, physical Activity, and risk of mortality in adults. *J Am Coll Cardiol*. 2019;73(16):2062-2072.
4. Hall G, Laddu DR, Phillips SA, Lavie CJ, Arena R. A tale of two pandemics: how will COVID-19 and global trends in physical inactivity and sedentary behavior affect one another? *Prog Cardiovasc Dis*. 2021;64:108-110.
5. Dunstan DW, Healy GN, Sugiyama T, Owen N. Too much sitting and metabolic risk—has modern technology caught up with us? *Eur Endocrinol*. 2010;6(1):19-23.
6. Dunstan DW, Dogra S, Carter SE, Owen N. Sit less and move more for cardiovascular health: emerging insights and opportunities. *Nat Rev Cardiol*. 2021;18(9):637-648.
7. Edelmann D, Pfirrmann D, Heller S, et al. Physical Activity and sedentary behavior in university students-the role of gender, age, field of study, targeted degree, and study semester. *Front Public Health*. 2022;10:821703.
8. Castro O, Bennie J, Vergeer I, Bosselut G, Biddle SJH. How sedentary are university students? A systematic review and meta-analysis. *Prev Sci*. 2020;21(3):332-343.
9. Biswas A, Oh PI, Faulkner GE, et al. Sedentary time and its association with risk for disease incidence, mortality, and hospitalization in adults: a systematic review and meta-analysis. *Ann Intern Med*. 2015;162(2):123-132.

10. Patterson R, McNamara E, Tainio M, et al. Sedentary behaviour and risk of all-cause, cardiovascular and cancer mortality, and incident type 2 diabetes: a systematic review and dose response meta-analysis. *Eur J Epidemiol*. 2018;33(9):811-829.
11. Saunders TJ, Larouche R, Colley RC, Tremblay MS. Acute sedentary behaviour and markers of cardiometabolic risk: a systematic review of intervention studies. *J Nutr Metab*. 2012;2012:712435.
12. Loh R, Stamatakis E, Folkerts D, Allgrove JE, Moir HJ. Effects of interrupting prolonged sitting with physical Activity breaks on blood glucose, insulin and triacylglycerol measures: a systematic review and meta-analysis. *Sports Med*. 2020;50(2):295-330.
13. Bellettiere J, Winkler EAH, Chastin SFM, et al. Associations of sitting accumulation patterns with cardio-metabolic risk biomarkers in Australian adults. *PLoS One*. 2017;12(6):e0180119.
14. Thosar SS, Bielko SL, Wiggins CC, Wallace JP. Differences in brachial and femoral artery responses to prolonged sitting. *Cardiovasc Ultrasound*. 2014;12(1):50.
15. Dempsey PC, Blankenship JM, Larsen RN, et al. Interrupting prolonged sitting in type 2 diabetes: nocturnal persistence of improved glycaemic control. *Diabetologia*. 2017;60(3):499-507.
16. Benatti FB, Larsen SA, Kofoed K, et al. Intermittent standing but not a moderate exercise bout reduces postprandial Glycemia. *Med Sci Sports Exerc*. 2017;49(11):2305-2314.
17. Crespo NC, Mullane SL, Zeigler ZS, Buman MP, Gaesser GA. Effects of standing and light-intensity walking and cycling on 24-h glucose. *Med Sci Sports Exerc*. 2016;48(12):2503-2511.
18. Dunstan DW, Kingwell BA, Larsen R, et al. Breaking up prolonged sitting reduces postprandial glucose and insulin responses. *Diabetes Care*. 2012;35(5):976-983.
19. Thorsen IK, Johansen MY, Pilmark NS, et al. The effect of frequency of activity interruptions in prolonged sitting on postprandial glucose metabolism: a randomized crossover trial. *Metabolism*. 2019;96:1-7.
20. Peddie MC, Bone JL, Rehrer NJ, Skeaff CM, Gray AR, Perry TL. Breaking prolonged sitting reduces postprandial glycemia in healthy, normal-weight adults: a randomized crossover trial. *Am J Clin Nutr*. 2013;98(2):358-366.
21. Henson J, Davies MJ, Bodicoat DH, et al. Breaking up prolonged sitting with standing or walking attenuates the postprandial metabolic response in postmenopausal women: a randomized acute study. *Diabetes Care*. 2016;39(1):130-138.
22. Gale JT, Wei DL, Haszard JJ, Brown RC, Taylor RW, Peddie MC. Breaking up evening sitting with resistance Activity improves postprandial glycemic response: a randomized crossover study. *Medicine and Science in Sports and Exercise*. Vol 55. Lippincott Williams and Wilkins; 2023:1471-1480.
23. Climie RE, Grace MS, Larsen RL, et al. Regular brief interruptions to sitting after a high-energy evening meal attenuate glycemic excursions in overweight/obese adults. *Nutr Metab Cardiovasc Dis*. 2018;28(9):909-916.
24. Benatti FB, Ried-Larsen M. The effects of breaking up prolonged sitting time: a review of experimental studies. *Med Sci Sports Exerc*. 2015;47(10):2053-2061.
25. Young HA, Benton D. Heart-rate variability: a biomarker to study the influence of nutrition on physiological and psychological health? *Behav Pharmacol*. 2018;29(2):140-151.
26. Zaffalon Júnior JR, Viana AO, de Melo GEL, De Angelis K. The impact of sedentarism on heart rate variability (HRV) at rest and in response to mental stress in young women. *Physiol Rep*. 2018;6(18):e13873.
27. Thayer JF, Lane RD. The role of vagal function in the risk for cardiovascular disease and mortality. *Biol Psychol*. 2007;74(2):224-242.
28. Eckstein ML, Moser O, Tripolt NJ, et al. Rapid glucose rise reduces heart rate variability in adults with type 1 diabetes: a prospective secondary outcome analysis. *Diabetes Obes Metab*. 2021;23(7):1681-1684.
29. Urbaniak G, Plous S. Research Randomizer (Version 4.0). Published online 2013.
30. Schleicher E, Gerdes C, Petersmann A, et al. Definition, classification and diagnosis of diabetes mellitus. *Exp Clin Endocrinol Diabetes*. 2022;130(S 01):S1-S8.
31. Zeigler ZS, Mullane SL, Crespo NC, Buman MP, Gaesser GA. Effects of standing and light-intensity activity on ambulatory blood pressure. *Med Sci Sports Exerc*. 2016;48(2):175-181.
32. Thorp AA, Kingwell BA, Owen N, Dunstan DW. Breaking up workplace sitting time with intermittent standing bouts improves fatigue and musculoskeletal discomfort in overweight/obese office workers. *Occup Environ Med*. 2014;71(11):765-771.
33. Thorp AA, Kingwell BA, Sethi P, Hammond L, Owen N, Dunstan DW. Alternating bouts of sitting and standing attenuate postprandial glucose responses. *Med Sci Sports Exerc*. 2014;46(11):2053-2061.
34. Zimmermann P, Herz D, Karl S, et al. Effects of different fasting interventions on cardiac autonomic modulation in healthy individuals: a secondary outcome analysis of the EDIF trial. *Biology*. 2023;12(3):372-384.
35. Eckstein ML, Brockfeld A, Haupt S, et al. Acute changes in heart rate variability to glucose and fructose supplementation in healthy individuals: a double-blind randomized crossover placebo-controlled trial. *Biology*. 2022;11(2):338-349.
36. Hackl-Wimmer S, Eglmaier MTW, Eichen L, et al. Effects of touchscreen media use on toddlers' sleep: insights from longtime ECG monitoring. *Sensors*. 2021;21(22):7515-7528.
37. Electrophysiology TF of the ES of C the NA. Heart rate variability. *Circulation*. 1996;93(5):1043-1065.
38. Dwan K, Li T, Altman DG, Elbourne D. CONSORT 2010 statement: extension to randomised crossover trials. *BMJ*. 2019;366:l4378.
39. Buffey AJ, Herring MP, Langley CK, Donnelly AE, Carson BP. The acute effects of interrupting prolonged sitting time in adults with standing and light-intensity walking on biomarkers of Cardiometabolic health in adults: a systematic review and meta-analysis. *Sports Med*. 2022;52(8):1765-1787.
40. Engeroff T, Groneberg DA, Wilke J. After dinner rest a while, after supper walk a mile? A systematic review with meta-analysis on the acute postprandial glycemic response to exercise before and after meal ingestion in healthy subjects and patients with impaired glucose tolerance. *Sports Med*. 2023;53(4):849-869.
41. Gao Y, Li Q, Pesola AJ. Acute physiological effects of breaking up prolonged sitting on overweight/obese male. *Med Sci Sports Exerc*. 2022;54(9S):508.
42. Sasso FC. Glucose metabolism and coronary heart disease in patients with Normal glucose tolerance. *JAMA*. 2004;291(15):1857.
43. O'Keefe JH, Bell DSH. Postprandial hyperglycemia/hyperlipidemia (postprandial Dysmetabolism) is a cardiovascular risk factor. *Am J Cardiol*. 2007;100(5):899-904.
44. Maylor BD, Zakrzewski-Fruer JK, Orton CJ, Bailey DP. Beneficial postprandial lipaemic effects of interrupting sedentary time with high-intensity physical activity versus a continuous moderate-intensity physical activity bout: a randomised crossover trial. *J Sci Med Sport*. 2018;21(12):1250-1255.
45. Bates LC, Alansare A, Gibbs BB, Hanson ED, Stoner L. Effects of acute prolonged sitting and interrupting prolonged sitting on heart rate variability and heart rate in adults: a meta-analysis. *Front Physiol*. 2021;12:12.
46. Thayer JF, Yamamoto SS, Brosschot JF. The relationship of autonomic imbalance, heart rate variability and cardiovascular disease risk factors. *Int J Cardiol*. 2010;141(2):122-131.

47. Lindmark S, Lönn L, Wiklund U, Tufvesson M, Olsson T, Eriksson JW. Dysregulation of the autonomic nervous system can Be a link between visceral adiposity and insulin resistance. *Obes Res*. 2005; 13(4):717-728.
48. Koch FS, Sepa A, Ludvigsson J. Psychological stress and obesity. *J Pediatr*. 2008;153(6):839-844.e3.
49. Hoffmann SW, Ulrich R, Simon P. Refined analysis of the critical age ranges of childhood overweight: implications for primary prevention. *Obesity*. 2012;20(10):2151-2154.

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