

REVIEW OPEN ACCESS

The Acute Effects of Interrupting Prolonged Sitting With Regular Activity Breaks on Postprandial Glucose and Insulin in Adults: A Systematic Review and Meta-Analysis

Jennifer T. Gale^{1,2} | Hannah Martin¹ | Jillian J. Haszard^{3,4} | Meredith C. Peddie¹

¹Department of Human Nutrition, University of Otago, Dunedin, New Zealand | ²Human Potential Research Institute, School of Sport, Exercise and Health, Auckland University of Technology, Auckland, New Zealand | ³Haszard Biostatistics, Auckland, New Zealand | ⁴Department of Nutrition, University of Auckland, Auckland, New Zealand

Correspondence: Jennifer T. Gale (jen.gale@aut.ac.nz)

Received: 24 April 2025 | **Revised:** 15 December 2025 | **Accepted:** 17 April 2026

Keywords: cardiometabolic health | metabolism | physical activity | public health | sedentary behavior

ABSTRACT

Background: Regular activity breaks improve postprandial glycemia, but the effects across different population groups and modes of breaks remain unclear. This systematic review and meta-analysis examined the impact of activity breaks on postprandial glucose and insulin response in adult populations.

Methods: Studies were identified from five databases until October 9, 2024. Eligible studies were acute (<24-h duration) laboratory-based randomized crossover trials comparing postprandial glucose and/or insulin response between prolonged sitting and activity breaks (<10 min, ≥3 breaks over 3 h). Risk of bias was assessed using the Downs and Black quality assessment tool. Random-effects meta-analysis was conducted including subgroup analyses by activity mode, frequency, and participant health/weight status.

Results: Overall 53 studies met the eligibility criteria; 39 were included in the meta-analysis. Compared with prolonged sitting, activity breaks lowered postprandial glucose incremental area under the curve (iAUC) (SMD -0.30, 95% CI -0.43 to -0.13) and insulin iAUC (SMD -0.30, 95% CI -0.46 to -0.14). Walking breaks had the greatest effect on glucose iAUC (SMD -0.33, 95% CI -0.48 to -0.17) and insulin iAUC (SMD -0.44, 95% CI -0.62 to -0.27), compared with other modes. Interrupting sitting every 15–20 min produced the largest reductions in glucose (SMD -0.51, 95% CI -0.83 to -0.19) and insulin iAUC (SMD -0.41, 95% CI -0.77 to -0.06). The largest reduction in glucose iAUC was observed in those living with obesity (SMD -0.52, 95% CI -1.07 to 0.03).

Conclusion: Frequent short walking breaks, performed every 20 min, provide the most improvement in postprandial glucose and insulin response in adults.

1 | Introduction

1.1 | Rationale

It is well established that sitting, particularly when accumulated in longer, uninterrupted bouts, is associated with poorer cardiometabolic risk profiles [1, 2] and increased risk of disease

incidence [3, 4] and mortality [5, 6]. A proposed mechanism to explain these associations is that frequently interrupting prolonged periods of sitting improves postprandial metabolism [7] due to activity-induced attenuations in postprandial hyperglycemia [8] and stimulation of glucose uptake via both insulin-dependent and insulin-independent pathways [9]. Postprandial hyperglycaemia itself is an independent risk factor for cardiometabolic

This is an open access article under the terms of the [Creative Commons Attribution-NonCommercial-NoDerivs](https://creativecommons.org/licenses/by-nc-nd/4.0/) License, which permits use and distribution in any medium, provided the original work is properly cited, the use is non-commercial and no modifications or adaptations are made.

© 2026 The Author(s). *Obesity Reviews* published by John Wiley & Sons Ltd on behalf of World Obesity Federation.

disease [10–12] and is sensitive to acute changes in response to meals and physical activity [13, 14]. Indeed, over the past 13 years, there has been exponential growth in the experimental evidence assessing the impact of interrupting prolonged sitting, with regular activity breaks, on postprandial metabolism. However, the lack of a consensus for the optimal frequency, duration, and mode of interruptions to sedentary time has been acknowledged by the World Health Organization [15], indicating a need for a comprehensive review of the evidence.

In this context, a ‘regular activity break’ refers to frequent interruptions to prolonged sitting (approximately every 20–60 min) with short bouts (< 10 min) of standing or physical activity. Several previous systematic reviews have pooled the evidence from such experimental studies with early reviews providing seminal evidence for the benefits of interrupted prolonged sitting time with activity [16, 17]. However, these reviews were limited due to the small number of experimental studies published prior to 2015. More recent reviews have extended our understanding of the collective impact of regularly interrupting sitting time but have been limited by inclusion criteria. For example, studies have included breaks longer than 10 min in duration [18], did not include standing breaks [19], only included standing or light intensity walking activity breaks [20] or only included studies in healthy [18] or overweight/obese participants [21]. A comprehensive review is, therefore, needed to provide the overall picture of the effects of activity breaks that may vary by mode and frequency across a variety of population groups. This understanding is vital to help inform the development of longer intervention studies and public health guidelines about the optimal frequency, duration, and mode of interruptions to prolonged sitting time.

1.2 | Objective

Our aim was to conduct a systematic review and meta-analysis of the results of experimentally controlled studies to determine the overall effect of performing regular activity breaks, when compared with prolonged sitting on postprandial glucose and insulin response. An additional aim was to investigate whether the effects of regular activity breaks vary based on the mode or intensity of the activity or whether the effect differs across participants of differing weight or health status using subgroup analysis.

2 | Methods

We followed the approach outlined in the Cochrane Handbook for Systematic Reviews of Interventions in conducting this systematic review and meta-analysis [22] and were guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement in preparing this manuscript [23, 24]. This review was not registered with a database such as PROSPERO and no protocol was prepared.

2.1 | Data Sources and Search Strategy

A systematic literature search was conducted using Medline OVID, Scopus, Web of Science, Embase OVID, and PubMed, prior to December 20, 2022, and updated on October 9, 2024. The

search strategy was developed to include peer-reviewed articles containing research relevant to “sedentary behavior,” “physical activity,” “activity break,” and “postprandial metabolism.” The full search strategy is outlined in Table S1. Searches were also restricted to only include articles published in the English language and in adults at least 18 years of age.

2.2 | Eligibility Criteria

Eligible studies were randomized crossover trials.

2.2.1 | Population

Study populations include adults at least 18 years of age who were healthy, living with overweight or obesity, or those with pre-existing conditions such as T2DM.

2.2.2 | Intervention

Eligible studies included interventions commencing at any time of the day, that were of at least 3 h but less than 24 h in duration, and were conducted in a laboratory (i.e., not free-living studies). Interventions had to involve the utilization of regular interruptions (at least one per hour, on average) of sitting with activity breaks lasting no longer than 10 min in duration. The activity breaks could be performed using any mode or intensity of activity (including standing). The 10-min threshold for an activity break was used to align with the general consensus of what an “activity break” is within the literature, as bouts of 10 min or longer are considered continuous exercise [25].

2.2.3 | Comparison

A prolonged sitting control of the same duration as the regular activity breaks intervention.

2.2.4 | Outcome

Serial measures of postprandial glucose and/or insulin concentrations taken at baseline and over at least 3 h, measured in plasma, serum, interstitial fluid, or whole blood, and used to calculate average, AUC, or iAUC as summary measures.

2.2.5 | Exclusions

Studies were excluded if (1) they did not involve the crossover of all participants across all intervention and control conditions; (2) they were conducted in a free-living setting; (3) the intervention was 24 h or longer; (4) each activity break was longer than 10 min in duration; (5) there was no prolonged sitting control; and (6) no serial measures of postprandial glucose or insulin response were reported.

Using Rayyan software (Rayyan.ai, Massachusetts, USA), at least two reviewers (Gale, J.T., Martin, H., and Peddie, M.C.)

independently screened each title and abstract, decided the eligibility of full-text papers for inclusion and extracted data from all papers included in this review. Conflicts regarding study selection or data extraction between the two reviewers that screened or extracted data from each paper were resolved via consensus. The flow of information through the review is presented in Figure 1.

2.3 | Data Extraction

We extracted data on author, year of publication, characteristics of participants, mode, duration, frequency, and intensity of activity breaks, duration of prolonged sitting, duration of the measurement period, and sample collection. We also extracted

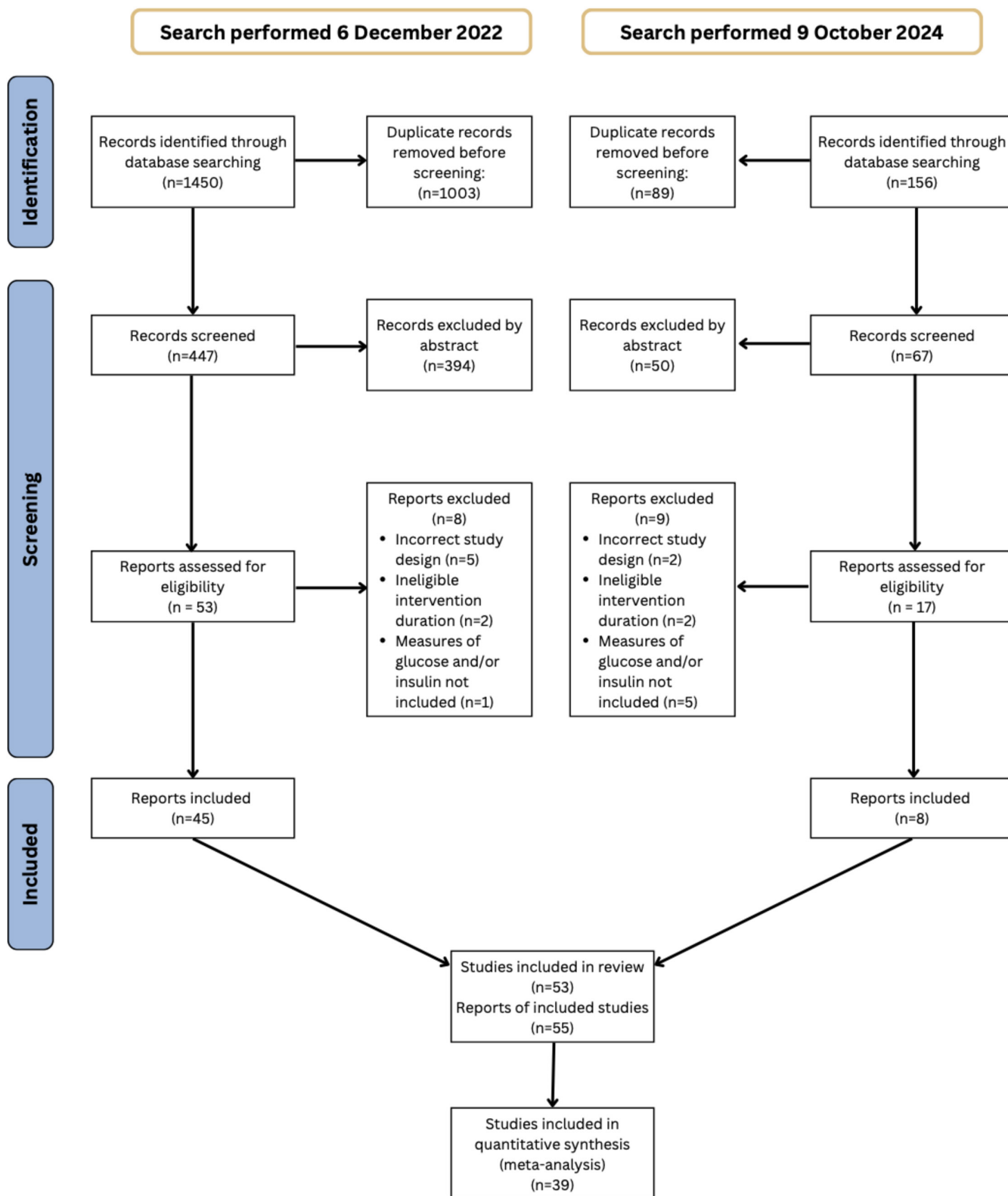


FIGURE 1 | PRISMA flow diagram.

whether insulin or glucose was measured in whole blood, serum, plasma, or interstitial fluid. Postprandial responses were reported in a variety of ways in the different studies so all available data on outcomes were extracted. Effect sizes (i.e., mean differences between conditions) and 95% confidence intervals (CI) were prioritized as the main outcome from each study as they should have been estimated using appropriate methods for the cross-over design. In addition, a standard deviation (SD) of the effect was required to standardize all results. However, if these statistics were not reported, they were calculated from available data (e.g., effect SD calculated from 95% CI of the effect, or effect SE estimated from a reported *p* value and then used to calculate CI and effect SD). If results were only reported by condition, then the effect was estimated as the difference of the means of the two outcomes, and the effect SD was estimated as the mean of the SD from both conditions. It was suspected that one study reported SE as SD, and this was amended [26]. Some studies reported 95% CI for each condition, and these statistics were used to calculate the SD for each condition and then treated as outlined previously. The main outcomes included in the meta-analyses were the mean difference and 95% CI between conditions. These were all standardized by the effect SD.

2.4 | Risk of Bias Assessment

Study bias was assessed using a modified version of Downs and Black Checklist [20, 27] by at least two reviewers (Gale, J.T., Martin, H., and Peddie, M.C.) independently. Question 27, which involves scoring studies based on whether they are sufficiently powered, was modified for the context of this review. Based on the subject knowledge of the authors (which includes a biostatistician), we chose to assign the scoring as follows: $n \geq 30 = 5$; $n = 25$ to $29 = 4$; $n = 20$ to $24 = 3$; $n = 15$ to $19 = 2$; $n = 10$ to $14 = 1$; $n \leq 10 = 0$. This assumed, considering the possible variation of postprandial responses in different populations, that it was unlikely that a sample size of 30 or greater would result in a study being underpowered, whereas a study with a sample size of 9 or less was a high risk of being underpowered. Thus, the maximum score of the modified version of Downs and Black was 31, where a score of 27–31 was considered excellent, 22 to 26 good, 17 to 21 fair, and a score < 17 poor.

2.5 | Statistical Analysis

All statistical analysis was undertaken in Stata 18.5 (StataCorp). Restricted maximum likelihood random-effects meta-analyses were undertaken for each outcome using the standardized mean effects from each study and the “meta” suite of commands in Stata. Forest plots were generated for all glucose and insulin outcomes, including all eligible studies or arms of studies. Standardized mean differences and 95% CI between regular activity breaks and prolonged sitting were plotted for each study arm and heterogeneity statistics, I^2 , τ^2 , and H^2 were calculated and reported on the forest plots. The overall effect and 95% CI were determined using a multilevel meta-analysis (“meta multilevel” command in Stata) with random intercepts for same-study clusters. Heterogeneity was

further explored with a series of subgroup analyses. Subgroup analyses were only conducted for the two main outcomes of glucose and insulin iAUC. Subgroups were split by mode of activity (standing, walking, etc.), frequency of activity breaks (every 15–20 min, every 30 min, or every 45–60 min), health status (healthy, type 2 diabetes, impaired glucose tolerance/increased cardiometabolic risk, or other), and body mass index (healthy weight, overweight, obese, or mixed). Forest plots were generated by each subgroup, including all eligible study arms. Overall effects and 95% CI and I^2 were also estimated for each subgroup using a multilevel meta-analysis with random effects of same-study clusters and reported in a table.

2.6 | Equity, Diversity, and Inclusion Statement

Our research and author team consist of female, junior, mid-career and senior researchers from different disciplines (Human Nutrition & Dietetics, Biostatistics Sleep and Exercise Sciences); however, all members are based at one University. Our inclusion criteria did not purposefully include or exclude marginalized communities or organizations; rather, we aimed to identify all of the studies available regardless of the populations studied.

3 | Results

3.1 | Study Selection

A total of 1606 records were identified through database searches. Fifty-five reports from 53 studies met the inclusion criteria (Figure 1). Four of the included reports were separate publications of the same study samples [28–31]. For the meta-analysis, the venous blood glucose [29, 31] and continuous glucose monitoring results [28, 30] from these studies were reported separately. Twenty studies included more than one activity breaks condition compared with the prolonged sitting control condition. Three of these compared activity breaks of different durations [26, 32, 33], six compared different durations and frequencies [28, 29, 32, 34–36], two compared different intensities [37, 38], one compared different intensities and frequencies [39], and eight compared different modes of activity breaks [30, 31, 40–45]. Two studies included comparisons of different diet compositions within the same study [46, 47], a further two studies compared different BMI groups [48, 49], and one study included two separate samples of differing nationality [45]. For the meta-analysis, each of these comparisons were plotted separately in the forest plots but not treated as individual comparisons in the estimation of overall effect. A total of 39 studies had sufficient data to be included in the meta-analysis.

3.2 | Study Characteristics

Descriptions of the 53 included studies are summarized in Table S2. The included studies were conducted across five continents with most studies being conducted in Europe ($n = 24$), followed by Oceania ($n = 11$ [Australia and New Zealand]), North

America ($n=8$), Asia ($n=8$), and South America ($n=2$). Most studies included a combination of male and female participants ($n=39$), seven studies included only female participants, while seven studies included only male participants. Most studies recruited samples of generally healthy adults ($n=44$), whereas smaller numbers of studies recruited participants with impaired glucose tolerance ($n=3$), type 2 diabetes ($n=2$), type 1 diabetes ($n=1$), rheumatoid arthritis ($n=1$), previous stroke ($n=1$), and mid- to low-level paraplegia ($n=1$). Samples sizes ranged from 8 to 70 participants; however, the median sample size was 14 participants. The minimum mean age was 19.2 years (SD 0.2), and the maximum mean age was 76.2 years (SD 5.6). Application of the Downs and Black checklist resulted in all but one study (which was categorized as excellent), being categorized as good ($n=33$) or fair ($n=22$). The mean score was 22 out of 31, with a range of 18 to 27.

3.2.1 | Study Protocols

By design, all included studies were randomized crossover trials, which included a prolonged sitting control arm and at least one activity breaks arm. The activity breaks protocols differed in terms of (1) frequency, ranging from every 15 to 60 min (median 30 min); (2) duration, ranging from 0.5 to 10 min (median 2.5 min); (3) mode of activity break: standing ($n=6$), walking ($n=35$), cycling ($n=4$), resistance exercises ($n=13$), stair climbing ($n=2$), and arm ergometry ($n=2$); and (4) the duration of the intervention, ranging from 3 to 12 h (median 6.5 h). Some studies prescribed activity breaks so that all participants did the same amount of work, whereas others prescribed or described intensity using a variety of methods including Borg Ratings of Perceived Exertion scale (RPE), heart rate, and percent of VO_{2max} . Of the 53 studies included, 32 collected venous blood samples, 9 collected capillary blood samples, and 10 measured postprandial response in interstitial fluid using a continuous glucose monitor. The remaining two studies used a combination of venous and interstitial samples.

3.3 | Activity Breaks Versus Sitting

Overall, when compared with sitting, interrupting sitting with activity breaks resulted in a small, but statistically significant reduction in glucose iAUC (SMD -0.30 , 95% CI -0.43 to -0.16) and insulin iAUC (SMD -0.30 , 95% CI -0.46 to -0.14) (Figures 2 and 3). Effects were similar when glucose AUC or mean glucose was used as the outcome (SMD -0.32 , 95% CI -0.50 to -0.15 and SMD -0.29 , 95% CI -0.54 to -0.04 , respectively [Figures S1 and 3]), but smaller when insulin AUC or mean insulin was the outcome (SMD -0.21 , 95% CI -0.39 to -0.03 and SMD -0.13 , 95% CI -0.31 to 0.05 , respectively [Figures S2 and S4]). There was evidence of high heterogeneity ($I^2 > 75\%$) across all these estimates (except for mean insulin).

3.4 | Subgroup Analysis

A summary of the standardized mean differences for all subgroup analyses, accounting for study clusters, is described in Table 1.

3.4.1 | Mode of Activity Breaks

Compared with prolonged sitting, the effect of regular activity breaks on glucose iAUC appeared to differ by mode, with standing resulting in smaller reductions than walking (standing SMD -0.08 , 95% CI -0.48 to 0.32 , I^2 5.5; walking SMD -0.33 , 95% CI -0.48 to -0.17 , I^2 61.7), resistance (SMD -0.28 , 95% CI -0.65 to 0.09 , I^2 81.8), and other activities (SMD -0.36 , 95% CI -0.83 to 0.11 , I^2 63.1 [Figure S5]). Similarly, for insulin, the largest effect was seen with walking breaks (SMD -0.44 , 95% CI -0.62 to -0.27 , I^2 43.6), while standing, resistance, and other activities resulted in reductions of a similar magnitude (Figure S6).

3.4.2 | Frequency of Activity Breaks

For both glucose and insulin iAUC, more frequent breaks appeared to result in larger reductions in postprandial response (Figures S7 and S8). Interrupting sitting every 15–20 min resulted in a moderate improvement in glucose iAUC (SMD -0.51 , 95% CI -0.83 to -0.19 , I^2 75.0) and a small mean improvement in insulin iAUC (SMD -0.41 , 95% CI -0.77 to -0.06 , I^2 56.9), compared with sitting. Smaller improvements were observed for glucose iAUC (SMD -0.30 , 95% CI -0.47 to -0.14 , I^2 80.0) and insulin iAUC (SMD -0.28 , 95% CI -0.49 to -0.07 , I^2 91.4) for studies on interrupting prolonged sitting every 30 min, and improvements were smaller again (and not statistically significant) when breaks were performed every 45–60 min.

3.4.3 | Health Status

The largest activity-breaks-induced reductions in both glucose and insulin responses were observed in participants with type 2 diabetes, where moderate reductions were observed for both glucose (SMD -0.45 , 95% CI -1.46 to 0.56 , I^2 89.9) and insulin (SMD -0.66 , 95% CI -1.63 to 0.31 , I^2 75.5); although in both cases there was a large amount of variation associated with these estimates, which were not statistically significant (Figures S9 and S10). A small, but more consistent reduction was observed in healthy participants, with smaller, non-significant reductions observed in both those with impaired glucose tolerance and other health conditions. Heterogeneity remained high among the healthy subgroup ($I^2 > 78\%$ for both glucose and insulin iAUC).

3.4.4 | Body Mass Index

Activity-breaks-induced reductions in glucose appear to increase in magnitude across the weight categories, with a moderate reduction observed in those with obesity (SMD -0.52 , 95% CI -1.07 to 0.03 , I^2 41.0), with the effect of decreasing in magnitude as you move down the weight categories (Figure S11). However, the observed reductions were only statistically significant in the overweight and mixed groups. There was less variation in insulin response with small reductions observed across all weight classes, with only the estimate in the mixed category reaching statistical significance (SMD -0.32 , 95% CI -0.46 to -0.18 , I^2 31.2 [Figure S12]).



FIGURE 2 | Legend on next page.

FIGURE 2 | Forest plot for the effect of regular activity breaks (RAB) on glucose iAUC in the full sample (58 projects from $n=38$ studies); SIT = prolonged sitting.

4 | Discussion

This systematic review and meta-analysis provides important insights into the effects of performing regular activity breaks on postprandial metabolism. The results reinforce the positive impact that interrupting sedentary time with regular, short bouts of activity can have on postprandial glucose and insulin response. Overall, regular activity breaks produce small to moderate reductions in postprandial glucose and insulin response. However, there is high heterogeneity associated with these estimates, most of which remains unexplained by the individual subgroup analysis that was performed.

This is the largest systematic review and meta-analysis performed to date to assess the effects of different frequencies of activities breaks on postprandial glucose and insulin response. Overall, there appears to be more consistent reductions in postprandial glucose with more frequent (every 20 to 30 min) regular activity breaks. A recent meta-analysis of nine studies indicated a significantly greater reduction in glucose response (SMD of -0.30 95% CI -0.57 to -0.03) when prolonged sitting is interrupted at least every 30 min, compared with less frequently [50]. Our findings extend these results by indicating a greater magnitude reduction in postprandial glucose, but also for insulin response when sitting is interrupted even more frequently (i.e., every 15–20 min). Data from a large observational study indicated a reduced risk of all-cause mortality when a larger percentage of objectively measured sedentary time was accumulated in bouts of less than 30 min [5]. Furthermore, Bellettiere et al. [51] indicated an increased risk of CVD with sedentary bouts exceeding 8.5 min (HR 1.53, 95% CI 1.09 to 2.14). Taken together, these results build an argument to suggest that interrupting sitting time at least every 30 min (if not more frequently) may provide the most benefit, which should be considered by the World Health Organization guidelines at the next review of current sedentary behavior guidelines [15].

Regarding the mode of activity break, standing breaks appear to result in much smaller reductions in postprandial glucose and insulin iAUC than walking or resistance exercise, which is consistent with previous meta-analyses [18–20]. Several mechanisms have been proposed to explain the regular activity-breaks-induced reductions in postprandial glucose and insulin responses. Compared with sitting, continuous standing has been shown to increase energy expenditure by 0.07 kcal/min [52]. Although Buffey et al. [20] indicated a small, statistically significant improvement in postprandial glucose response when sitting was interrupted with standing, this finding was likely driven by a single study [53] that was excluded from the current analysis as it did not involve a complete crossover of participants between interventions. Finds from the current review and others affirm that standing regular activity breaks fail to produce meaningful reductions in postprandial glucose and insulin, indicating that standing is not a sufficient stimulus. Jódice et al. [52] also found that sit to stand (and returning to sit) transitions increase energy expenditure (EE) by 0.32 kcal/

min. This is supported by findings from a pooled analysis of three studies (matched for meal standardization, population, and activity breaks duration and frequency), which found that EE increased in a dose–response manner with increasing intensity of activity breaks from standing, through light-intensity walking, to moderate-intensity walking [54]. Fenemor et al. [55] reported that compared with 7 h of prolonged sitting, EE was 863 kJ greater when sitting was interrupted every 28 min, with 2 min of walking activity breaks and that the increase in EE was driven in part, by the fact that energy utilization remained elevated for up to 4 min following each activity break. This suggests that total EE may play a role in activity break induced reductions in glucose and insulin concentration and that repeated skeletal muscle contraction (initiated in sit-to-stand and stand-to-sit transitions) may be part of the equation. Another potential pathway is increased glucose uptake via contraction stimulated pathways independent of insulin [56, 57]. Indeed, experimental evidence has indicated that interrupting prolonged sitting every 20 min with 2 min of physical activity, stimulated glucose uptake via the contraction-mediated pathway, in preference to the insulin-mediated pathway in skeletal muscle, collected via muscle biopsy [58]. This proposed mechanism is strengthened by the fact that in some studies there was an activity break induced reduction in insulin, without a reduction in glucose (i.e., the same amount of glucose is being cleared with less insulin present) [45, 49, 59–62]. This process occurs in addition to insulin-mediated glucose uptake induced by acute activity. Both mechanisms increase GLUT4 translocation and expression, increasing glucose uptake, thereby reducing blood glucose level [57]. Regular activity breaks are likely to increase energy expenditure if displacing sedentary time with additional activity, but this increase alone does not explain the benefits. Our current understanding suggests that the primary mechanisms that explain the beneficial effect of interrupting sitting on glucose metabolism is a result of glucose uptake by skeletal muscle via both insulin- and contraction-mediated pathways.

Most studies to date, have investigated activity breaks that require equipment (e.g., treadmill, standing bike, or arm ergometer) or necessitate relocation (e.g., walking or stair climbing), which may limit feasibility in real-world settings. Resistance exercises, that can be performed on the spot without equipment may represent a more practical and effective alternative to walking activity breaks. Although the estimates generated here indicate that the effect of resistance activity breaks on postprandial glucose and insulin response not statistically significant, the magnitude of the estimates should not be ignored, particularly given the small number of studies ($n=7$) compared with walking ($n=23$). Furthermore, postprandial glucose results from English et al. [40] may have been influenced by changes in muscle physiology that can occur after a stroke [63, 64]. Future research may be needed to assess the efficacy of regular activity breaks in clinical populations.

Previous research has suggested that individuals who are less metabolically healthy (i.e., with impaired glucose tolerance or overweight/obesity) may experience greater benefits from

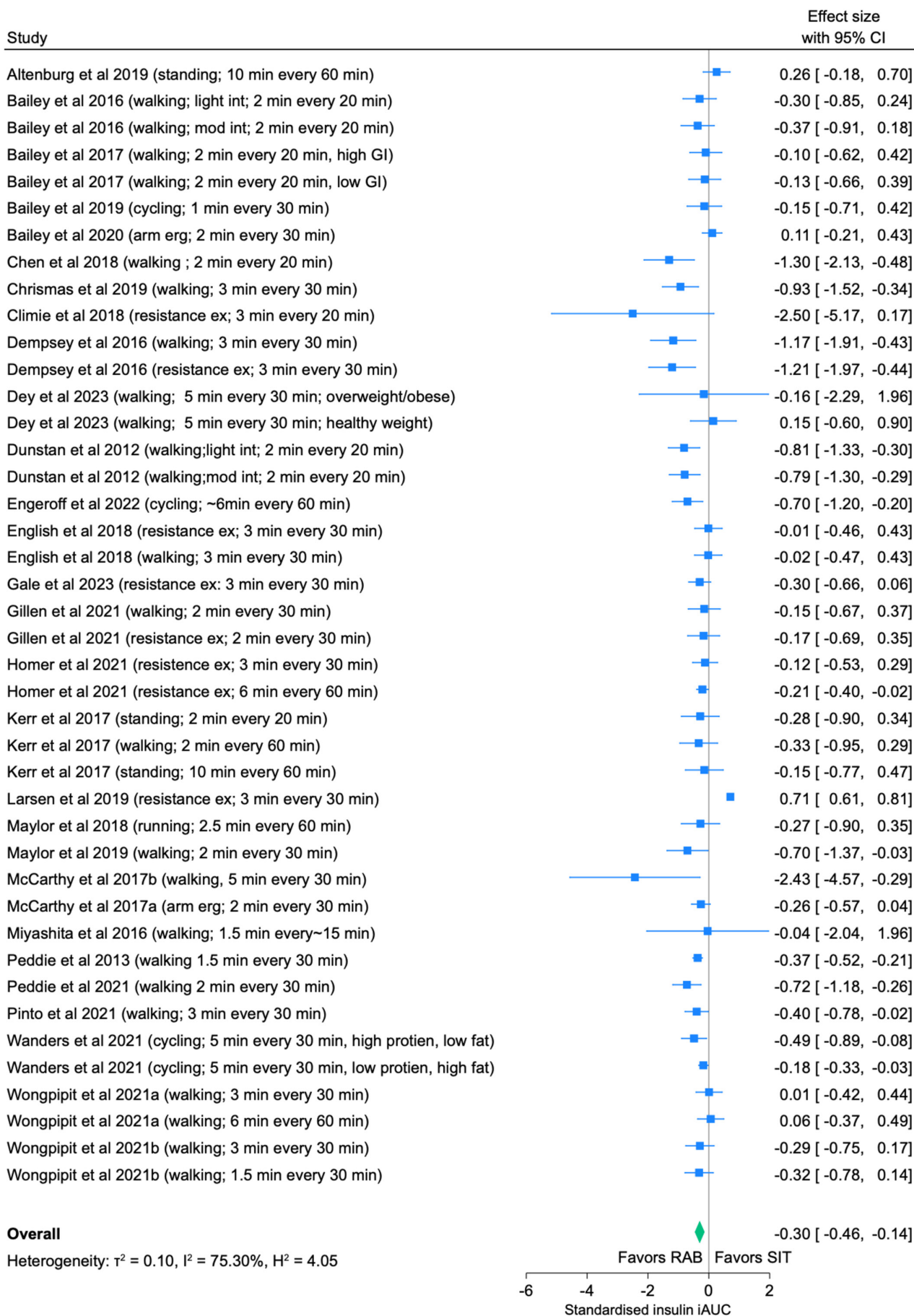


FIGURE 3 | Legend on next page.

FIGURE 3 | Forest plot for the effect of regular activity breaks (RAB) on insulin iAUC in the full sample (42 projects from $n = 29$ studies); SIT = prolonged sitting.**TABLE 1** | Overall results for meta-analyses of subgroups accounting for study clusters.

	Glucose iAUC			Insulin iAUC		
	Number of projects (number of studies)	I^2	Standardized mean difference (95% CI)	Number of projects (number of studies)	I^2	Standardized mean difference (95% CI)
Full sample	58 (38)	80.1	-0.30 (-0.43, -0.16)	42 (29)	87.2	-0.30 (-0.46, -0.14)
Health status						
Healthy	43 (29)	78.8	-0.32 (-0.48, -0.17)	34 (24)	88.7	-0.30 (-0.49, -0.12)
Type 2 diabetes	4 (2)	89.9	-0.45 (-1.46, 0.56)	4 (2)	75.5	-0.66 (-1.63, 0.31)
Impaired glucose tolerance/ increased cardiometabolic risk	2 (2)	—	-0.25 (-0.67, 0.17)	0	—	—
Other	4 (3)	0	-0.06 (-0.29, 0.17)	4 (3)	41.1	-0.10 (-0.40, 0.20)
Mode of activity						
Standing	3 (2)	5.5	-0.08 (-0.48, 0.32)	2 (1)	—	-0.21 (-3.94, 3.51)
Walking	32 (23)	61.5	-0.33 (-0.48, -0.17)	22 (17)	43.6	-0.44 (-0.62, -0.27)
Resistance	8 (7)	81.8	-0.28 (-0.65, 0.09)	8 (7)	94.3	-0.21 (-0.68, 0.27)
Other	7 (6)	63.1	-0.36 (-0.83, 0.11)	7 (6)	38.0	-0.21 (-0.38, -0.04)
Break frequency						
15–20 min	15 (12)	75.0	-0.51 (-0.83, -0.19)	11 (8)	56.9	-0.41 (-0.77, -0.06)
30 min	30 (21)	80.0	-0.30 (-0.47, -0.14)	24 (18)	91.4	-0.28 (-0.49, -0.07)
45–60 min	12 (10)	65.1	-0.20 (-0.41, 0.02)	7 (6)	37.9	-0.17 (-0.40, 0.06)
Weight status						
Mixed	26 (19)	65.9	-0.29 (-0.47, -0.11)	20 (16)	31.2	-0.32 (-0.46, -0.18)
Healthy weight	2 (2)	—	0.12 (-0.25, 0.49)	2 (2)	—	0.23 (-0.15, 0.61)
Overweight	21 (13)	78.5	-0.34 (-0.59, -0.09)	19 (11)	92.2	-0.37 (-0.75, 0.01)
Obese	4 (3)	41.0	-0.52 (-1.07, 0.03)	1 (1)	—	-0.26 (-0.57, 0.04)

Note: Study clusters included as random intercepts in a multilevel meta-analysis for each subgroup. Heterogeneity statistics with less than 2° of freedom were not calculated.

regular activity breaks [19, 20]. Regarding weight status, the findings of this review align with this hypothesis, with greater reductions in postprandial glucose observed with increasing weight status. Statistically significant effects were limited to the mixed-weight group and postprandial glucose response in overweight samples, results which may be influenced by the small number of studies targeting individuals with normal weight or obesity. Furthermore, the categorization of weight status, which does not account for factors such as insulin sensitivity or habitual physical activity levels, limits the ability to determine who may benefit the most from activity breaks. Additionally, the

mean BMI from different studies in the mixed-weight subgroup ranged from 21.5 to 30.9 kg/m² (median 25 kg/m²), and for many of these studies, the participant inclusion criteria was based around participants not having obesity (i.e., a BMI of <30), emphasizing the need for further research with well-defined metabolic subgroups. Although subgroup analysis by health status indicated statistically significant improvements for the healthy group only, the magnitude of the regular activity-breaks-induced reductions in glucose and insulin observed in those with type 2 diabetes were larger, and likely to be more clinically meaningful. It is possible that the smaller number of studies and

higher variability in responses in these populations groups has precluded us from detecting an effect that is both statistically and clinically meaningful.

4.1 | Unexplained Heterogeneity

Despite the strict inclusion criteria applied to this review, many of the generated estimates still had high levels of heterogeneity associated with them, even after subgroup analysis was performed. There are a number of variables including nationality, sample age and sex, intervention duration, intervention meal standardization, timing of sample collection relative to meals and activity, and pre-intervention standardization protocols (such as avoidance of exercise or caffeine), which differ between studies and may have contributed to the high levels of heterogeneity observed. Differences in venous versus interstitial glucose responses (venous sampling may miss peaks and nadirs in blood glucose response, while interstitial glucose responses lag behind venous responses) may have also contributed to heterogeneity. Future studies should consider following more standardized protocols in terms of preintervention standardization, intervention duration, meal provision, and sample timing to hopefully allow for more consistent results to be generated across studies (and thus improve the confidence of estimates generated by future meta-analyses).

4.2 | Risk of Bias

Overall, the vast majority of studies scored good or fair. As a field, studies in this area are limited in the ability to score in the excellent range as blinding of participants is not possible, and recruitment of samples that are truly representative of the populations from which they are drawn is unlikely. Most of the variation between studies included in this review was due to a lack of clarity in the reporting around participants lost to follow up and whether or not the researchers who were assessing outcomes were blinded. Additionally, the range in sample sizes also contributed to the variability in bias scores. All future studies in this area are encouraged to carefully consider the CONSORT statement when designing and reporting the results of their studies and to consider conducting sample size calculations using variances in outcomes from similar populations and careful consideration of differences that might be considered clinically meaningful.

4.3 | Strengths and Limitations

All studies included in this review were randomized crossover trials which provide causal evidence of the relationship between interruptions to prolonged sitting and postprandial glucose and insulin response in a range of adult populations. The results indicate that performing regular activity breaks can reduce postprandial glucose and insulin responses, and that the magnitude of these responses is likely small to moderate in terms of their clinical effect [65]. However, this review has some limitations that should be considered. By limiting the review to studies published in English and in peer-reviewed journals, the possibility that some studies may have been missed cannot be excluded. Regarding the included studies, the prolonged sitting

interventions, particularly in longer duration studies, are unlikely to reflect habitual sitting behavior. Furthermore, given the acute nature of these studies, results cannot be extrapolated to suggest longer term benefits of interrupting sitting with regular activity breaks. Two studies that interrupted sitting with regular activity breaks, that were not true randomized crossover trials, were excluded [53, 66]; however, their inclusion would not have altered the key results.

5 | Conclusion

Interrupting prolonged sitting with regular activity breaks consistently improves acute postprandial glucose and insulin response, particularly with walking activity breaks and those performed frequently (every 20–30 min). Furthermore, while the largest magnitude reductions are observed for those living with obesity, regular activity breaks appear to produce meaningful reductions in postprandial metabolism in a range of population groups, suggesting a large portion of the adult population could benefit from this behavior. Future studies could benefit from utilizing standardized study protocols and sample sizes to improve the confidence of estimates generated by future meta-analyses.

Author Contributions

Conceptualization: J.T.G., M.C.P., and J.J.H.; methodology: J.T.G., M.C.P., and J.J.H.; formal analysis: J.T.G., H.M., and J.J.H.; investigation: J.T.G., H.M., M.C.P., and J.J.H.; resources: M.C.P.; data curation: J.J.H.; writing the original draft preparation: J.T.G.; writing review and editing: J.T.G., H.M., M.C.P., and J.J.H.; supervision: J.J.H. and M.C.P.; project administration: J.T.G. All authors have read and agreed to the published version of the manuscript.

Acknowledgements

Jennifer T. Gale was supported by a University of Otago Doctoral Publishing Bursary. Open access publishing facilitated by University of Otago, as part of the Wiley - University of Otago agreement via the Council of Australasian University Librarians

Funding

The authors received no specific funding for this study.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data described in the manuscript will be made available upon reasonable request to the corresponding author.

References

1. G. N. Healy, D. W. Dunstan, and J. Salmon, "Breaks in Sedentary Time," *Diabetes Care* 31, no. 4 (2008): 661–666, <https://doi.org/10.2337/dc07-2046>.
2. G. N. Healy, C. E. Matthews, D. W. Dunstan, E. A. H. Winkler, and N. Owen, "Sedentary Time and Cardio-Metabolic Biomarkers in US Adults: NHANES 2003–06," *European Heart Journal* 32, no. 5 (2011): 590–597, <https://doi.org/10.1093/eurheartj/ehq451>.

3. D. P. Bailey, D. J. Hewson, R. B. Champion, and S. M. Sayegh, "Sitting Time and Risk of Cardiovascular Disease and Diabetes: A Systematic Review and Meta-Analysis," *American Journal of Preventive Medicine* 57, no. 3 (2019): 408–416, <https://doi.org/10.1016/j.amepre.2019.04.015>.
4. S. Nguyen, J. Belletiere, B. Anuskiewicz, et al., "Prospective Associations of Accelerometer-Measured Machine-Learned Sedentary Behavior with Death Among Older Women: The Opach Study," *Journal of the American Heart Association* 13, no. 5 (2024): e031156, <https://doi.org/10.1161/JAHA.123.031156>.
5. K. M. Diaz, V. J. Howard, B. Hutto, et al., "Patterns of Sedentary Behavior and Mortality in U.S. Middle-Aged and Older Adults," *Annals of Internal Medicine* 167, no. 7 (2017): 465–475, <https://doi.org/10.7326/M17-0212>.
6. M. S. Yerramalla, V. T. van Hees, M. Chen, A. Fayosse, S. F. M. Chastin, and S. Sabia, "Objectively Measured Total Sedentary Time and Pattern of Sedentary Accumulation in Older Adults: Associations With Incident Cardiovascular Disease and All-Cause Mortality," *Journals of Gerontology, Series A: Biological Sciences and Medical Sciences* 77, no. 4 (2022): 842–850, <https://doi.org/10.1093/geronol/glac023>.
7. A. C. Bell, J. Richards, J. K. Zakrzewski-Fruer, L. R. Smith, and D. P. Bailey, "Sedentary Behaviour—A Target for the Prevention and Management of Cardiovascular Disease," *International Journal of Environmental Research and Public Health* 20, no. 1 (2022): 532, <https://doi.org/10.3390/ijerph20010532>.
8. S. R. Colberg, R. J. Sigal, J. E. Yardley, et al., "Physical Activity/Exercise and Diabetes: A Position Statement of the American Diabetes Association," *Diabetes Care* 39, no. 11 (2016): 2065–2079, <https://doi.org/10.2337/dc16-1728>.
9. A. Moreno-Cabañas and J. T. Gonzalez, "Role of Prior Feeding Status in Mediating the Effects of Exercise on Blood Glucose Kinetics," *Journal of Physiology-Cell Physiology* 325, no. 4 (2023): C823–C832, <https://doi.org/10.1152/ajpcell.00271.2023>.
10. Q. Qiao, S. Larsen, K. Borch-Johnsen, et al., "Glucose Tolerance and Cardiovascular Mortality. Comparison of Fasting and 2-Hour Diagnostic Criteria," *Archives of Internal Medicine* 161, no. 3 (2001): 397–405, <https://doi.org/10.1001/archinte.161.3.397>.
11. J. D. Sorkin, D. C. Muller, J. L. Fleg, and R. Andres, "The Relation of Fasting and 2-H Postchallenge Plasma Glucose Concentrations to Mortality: Data From the Baltimore Longitudinal Study of Aging With a Critical Review of the Literature," *Diabetes Care* 28, no. 11 (2005): 2626–2632, <https://doi.org/10.2337/diacare.28.11.2626>.
12. E. B. Levitan, Y. Song, E. S. Ford, and S. Liu, "Is Nondiabetic Hyperglycemia a Risk Factor for Cardiovascular Disease? A Meta-Analysis of Prospective Studies," *Archives of Internal Medicine* 164, no. 19 (2004): 2147–2155, <https://doi.org/10.1001/archinte.164.19.2147>.
13. E. E. Blaak, J.-M. Antoine, D. Benton, et al., "Impact of Postprandial Glycaemia on Health and Prevention of Disease," *Obesity Reviews* 13, no. 10 (2012): 923–984, <https://doi.org/10.1111/j.1467-789X.2012.01011.x>.
14. J. B. Gillen, S. Estafanos, and A. Govette, "Exercise-Nutrient Interactions for Improved Postprandial Glycemic Control and Insulin Sensitivity," *Applied Physiology, Nutrition, and Metabolism* 46, no. 8 (2021): 856–865, <https://doi.org/10.1139/apnm-2021-0168>.
15. World Health Organization, "WHO Guidelines on Physical Activity and Sedentary Behaviour," 2020, <https://www.who.int/publications/item/9789240015128>.
16. S. F. M. Chastin, T. Egerton, C. Leask, and E. Stamatakis, "Meta-Analysis of the Relationship Between Breaks in Sedentary Behavior and Cardiometabolic Health," *Obesity* 23, no. 9 (2015): 1800–1810, <https://doi.org/10.1002/oby.21180>.
17. F. B. Benatti and M. Ried-Larsen, "The Effects of Breaking Up Prolonged Sitting Time," *Medicine and Science in Sports and Exercise* 47, no. 10 (2015): 2053–2061, <https://doi.org/10.1249/MSS.0000000000000654>.
18. T. J. Saunders, H. F. Atkinson, J. Burr, B. MacEwen, C. M. Skeaff, and M. C. Peddie, "The Acute Metabolic and Vascular Impact of Interrupting Prolonged Sitting: A Systematic Review and Meta-Analysis," *Sports Medicine* 48, no. 10 (2018): 2347–2366, <https://doi.org/10.1007/s40279-018-0963-8>.
19. R. Loh, E. Stamatakis, D. Folkerts, J. E. Allgrove, and H. J. Moir, "Effects of Interrupting Prolonged Sitting With Physical Activity Breaks on Blood Glucose, Insulin and Triacylglycerol Measures: A Systematic Review and Meta-Analysis," *Sports Medicine* 50, no. 2 (2020): 295–330, <https://doi.org/10.1007/s40279-019-01183-w>.
20. A. J. Buffey, M. P. Herring, C. K. Langley, A. E. Donnelly, and B. P. Carson, "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 Medicine* 52, no. 8 (2022): 1765–1787, <https://doi.org/10.1007/s40279-022-01649-4>.
21. M. Yin, Q. Liu, K. Xu, B. Zhang, and S. Deng, "久坐间断对超重与肥胖成人糖脂代谢急性改善效果的Meta分析 Acute Effects of Interrupted Prolonged Sitting on Glucose and Lipid Metabolism in Overweight and Obese Adults: A Meta-Analysis," 32 (2024): 768–777, <https://doi.org/10.16386/j.cjpcd.issn.1004-6194.2024.10.009>.
22. J. P. T. Higgins, J. Thomas, J. Chandler, et al., *Cochrane Handbook for Systematic Reviews of Interventions* (Wiley, 2019), <https://doi.org/10.1002/9781119536604>.
23. L. Shamseer, D. Moher, M. Clarke, et al., "Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P) 2015: Elaboration and Explanation," *BMJ (Clinical Research Ed.)* 349, no. jan02 1 (2015): g7647-g7647, <https://doi.org/10.1136/bmj.g7647>.
24. A. Liberati, D. G. Altman, J. Tetzlaff, et al., "The PRISMA Statement for Reporting Systematic Reviews and Meta-Analyses of Studies That Evaluate Healthcare Interventions: Explanation and Elaboration," *BMJ (Clinical Research Ed.)* 339, no. jul21 1 (2009): b2700-b2700, <https://doi.org/10.1136/bmj.b2700>.
25. M. Yin, Y. Li, A. R. Aziz, et al., "Short Bouts of Accumulated Exercise: Review and Consensus Statement on Definition, Efficacy, Feasibility, Practical Applications, and Future Directions," *Journal of Sport and Health Science* 15 (2025): 101088, <https://doi.org/10.1016/j.jshs.2025.101088>.
26. W. Wongpipit, W. Y. Huang, M. Miyashita, X. Y. Tian, and S. H. S. Wong, "Frequency of Interruptions to Prolonged Sitting and Postprandial Metabolic Responses in Young, Obese, Chinese Men," *Journal of Sports Sciences* 39, no. 12 (2021): 1376–1385, <https://doi.org/10.1080/02640414.2021.1874170>.
27. S. H. Downs and N. Black, "The Feasibility of Creating a Checklist for the Assessment of the Methodological Quality Both of Randomised and Non-Randomised Studies of Health Care Interventions," *Journal of Epidemiology and Community Health* 52, no. 6 (1998): 377–384, <https://doi.org/10.1136/jech.52.6.377>.
28. A. R. Homer, F. C. Taylor, P. C. Dempsey, et al., "Different Frequencies of Active Interruptions to Sitting Have Distinct Effects on 22 H Glycemic Control in Type 2 Diabetes," *Nutrition, Metabolism, and Cardiovascular Diseases* 31, no. 10 (2021): 2969–2978, <https://doi.org/10.1016/j.numecd.2021.07.001>.
29. A. R. Homer, F. C. Taylor, P. C. Dempsey, et al., "Frequency of Interruptions to Sitting Time: Benefits for Postprandial Metabolism in Type 2 Diabetes," *Diabetes Care* 44, no. 6 (2021): 1254–1263, <https://doi.org/10.2337/dc20-1410>.
30. P. C. Dempsey, J. M. Blankenship, R. N. Larsen, et al., "Interrupting Prolonged Sitting in Type 2 Diabetes: Nocturnal Persistence of

- Improved Glycaemic Control,” *Diabetologia* 60, no. 3 (2017): 499–507, <https://doi.org/10.1007/s00125-016-4169-z>.
31. P. C. Dempsey, R. N. Larsen, P. Sethi, et al., “Benefits for Type 2 Diabetes of Interrupting Prolonged Sitting With Brief Bouts of Light Walking or Simple Resistance Activities,” *Diabetes Care* 39, no. 6 (2016): 964–972, <https://doi.org/10.2337/dc15-2336>.
32. M. Rodriguez-Hernandez, J. S. Martin, D. D. Pascoe, M. D. Roberts, and D. W. Wadsworth, “Multiple Short Bouts of Walking Activity Attenuate Glucose Response in Obese Women,” *Journal of Physical Activity and Health* 15, no. 4 (2018): 279–286, <https://doi.org/10.1123/jpah.2017-0251>.
33. W. Wongpipit, X. Zhang, M. Miyashita, and S. H. S. Wong, “Interrupting Prolonged Sitting Reduces Postprandial Glucose Concentration in Young Men With Central Obesity,” *Journal of Clinical Endocrinology and Metabolism* 106, no. 2 (2021): E791–E802, <https://doi.org/10.1210/clinem/dgaa834>.
34. A. T. Duran, C. P. Friel, M. A. Serafini, I. Ensari, Y. K. Cheung, and K. M. Diaz, “Breaking Up Prolonged Sitting to Improve Cardiometabolic Risk: Dose–Response Analysis of a Randomized Crossover Trial,” *Medicine and Science in Sports and Exercise* 55, no. 5 (2023): 847–855, <https://doi.org/10.1249/MSS.0000000000003109>.
35. S. X. Ma, Z. Zhu, L. I. N. Zhang, X. M. Liu, Y. Y. Lin, and Z. B. Cao, “Metabolic Effects of Three Different Activity Bouts During Sitting in Inactive Adults,” *Medicine and Science in Sports and Exercise* 52, no. 4 (2020): 851–858, <https://doi.org/10.1249/MSS.0000000000002212>.
36. I. K. Thorsen, M. Y. Johansen, N. S. Pilmark, et al., “The Effect of Frequency of Activity Interruptions in Prolonged Sitting on Postprandial Glucose Metabolism: A Randomized Crossover Trial,” *Metabolism* 96 (2019): 1–7, <https://doi.org/10.1016/j.metabol.2019.04.003>.
37. D. P. Bailey, D. R. Broom, B. C. R. Christmas, L. Taylor, E. Flynn, and J. Hough, “Breaking Up Prolonged Sitting Time With Walking Does Not Affect Appetite or Gut Hormone Concentrations but Does Induce An Energy Deficit and Suppresses Postprandial Glycaemia in Sedentary Adults,” *Applied Physiology, Nutrition, and Metabolism* 41, no. 3 (2016): 324–331, <https://doi.org/10.1139/apnm-2015-0462>.
38. D. W. Dunstan, B. A. Kingwell, R. Larsen, et al., “Breaking Up Prolonged Sitting Reduces Postprandial Glucose and Insulin Responses,” *Diabetes Care* 35, no. 5 (2012): 976–983, <https://doi.org/10.2337/dc11-1931>.
39. D. M. Bhammar, B. J. Sawyer, W. J. Tucker, and G. A. Gaesser, “Breaks in Sitting Time,” *Medicine and Science in Sports and Exercise* 49, no. 10 (2017): 2119–2130, <https://doi.org/10.1249/MSS.0000000000001315>.
40. C. English, H. Janssen, G. Crowfoot, et al., “Breaking Up Sitting Time After Stroke (BUST-Stroke),” *International Journal of Stroke* 13, no. 9 (2018): 921–931, <https://doi.org/10.1177/1747493018801222>.
41. J. B. Gillen, S. Estafanos, E. Williamson, et al., “Interrupting Prolonged Sitting With Repeated Chair Stands or Short Walks Reduces Postprandial Insulinemia in Healthy Adults,” *Journal of Applied Physiology (1985)* 130, no. 1 (2021): 104–113, <https://doi.org/10.1152/jappphysiol.00796.2020>.
42. E. G. Heiland, O. Tarassova, M. Fernström, C. English, Ö. Ekblom, and M. M. Ekblom, “Frequent, Short Physical Activity Breaks Reduce Prefrontal Cortex Activation but Preserve Working Memory in Middle-Aged Adults: ABaH Study,” *Frontiers in Human Neuroscience* 15 (2021): e719509, <https://doi.org/10.3389/fnhum.2021.719509>.
43. J. Kerr, K. Crist, D. G. Vital, et al., “Acute Glucoregulatory and Vascular Outcomes of Three Strategies for Interrupting Prolonged Sitting Time in Postmenopausal Women: A Pilot, Laboratory-Based, Randomized, Controlled, 4-Condition, 4-Period Crossover Trial,” *PLoS ONE* 12, no. 11 (2017): e0188544, <https://doi.org/10.1371/journal.pone.0188544>.
44. R. M. Pulsford, J. Blackwell, M. Hillsdon, and K. Kos, “Intermittent Walking, but Not Standing, Improves Postprandial Insulin and Glucose Relative to Sustained Sitting: A Randomised Cross-Over Study in Inactive Middle-Aged Men,” *Journal of Science and Medicine in Sport* 20, no. 3 (2017): 278–283, <https://doi.org/10.1016/j.jsams.2016.08.012>.
45. T. Yates, C. L. Edwardson, C. Celis-Morales, et al., “Metabolic Effects of Breaking Prolonged Sitting With Standing or Light Walking in Older South Asians and White Europeans A Randomized Acute Study,” *Journals of Gerontology Series A* 75, no. 1 (2020): 139–146, <https://doi.org/10.1093/gerona/gly252>.
46. D. P. Bailey, B. D. Maylor, C. J. Orton, and J. K. Zakrzewski-Fruer, “Effects of Breaking Up Prolonged Sitting Following Low and High Glycaemic Index Breakfast Consumption on Glucose and Insulin Concentrations,” *European Journal of Applied Physiology* 117, no. 7 (2017): 1299–1307, <https://doi.org/10.1007/s00421-017-3610-4>.
47. L. Wanders, I. Cuijpers, R. P. C. Kessels, O. van de Rest, M. T. E. Hopman, and D. H. J. Thijsen, “Impact of Prolonged Sitting and Physical Activity Breaks on Cognitive Performance, Perceivable Benefits, and Cardiometabolic Health in Overweight/Obese Adults: The Role of Meal Composition,” *Clinical Nutrition* 40, no. 4 (2021): 2259–2269, <https://doi.org/10.1016/j.clnu.2020.10.006>.
48. K. C. Dey, J. K. Zakrzewski-Fruer, L. R. Smith, R. L. Jones, and D. P. Bailey, “Interrupting Sitting Acutely Attenuates Cardiometabolic Risk Markers in South Asian Adults Living With Overweight and Obesity,” *European Journal of Applied Physiology* 124, no. 4 (2024): 1163–1174, <https://doi.org/10.1007/s00421-023-05345-7>.
49. H. Rafiei, K. Omidian, É. Myette-Cote, and J. P. Little, “Metabolic Effect of Breaking Up Prolonged Sitting With Stair Climbing Exercise Snacks,” *Medicine and Science in Sports and Exercise* 53, no. 1 (2021): 150–158, <https://doi.org/10.1249/MSS.0000000000002431>.
50. M. Yin, K. Xu, J. Deng, et al., “Optimal Frequency of Interrupting Prolonged Sitting for Cardiometabolic Health: A Systematic Review and Meta-Analysis of Randomized Crossover Trials,” *Scandinavian Journal of Medicine & Science in Sports* 34, no. 12 (2024): e14769, <https://doi.org/10.1111/sms.14769>.
51. J. Belletiere, M. J. LaMonte, K. R. Evenson, et al., “Sedentary Behavior and Cardiovascular Disease in Older Women,” *Circulation* 139, no. 8 (2019): 1036–1046, <https://doi.org/10.1161/CIRCULATIONAHA.118.035312>.
52. P. B. Júdice, M. T. Hamilton, L. B. Sardinha, T. W. Zderic, and A. M. Silva, “What is the Metabolic and Energy Cost of Sitting, Standing and Sit/Stand Transitions?,” *European Journal of Applied Physiology* 116, no. 2 (2016): 263–273, <https://doi.org/10.1007/s00421-015-3279-5>.
53. J. Henson, M. J. Davies, D. H. Bodicoat, et al., “Breaking Up Prolonged Sitting With Standing or Walking Attenuates the Postprandial Metabolic Response in Postmenopausal Women: A Randomized Acute Study,” *Diabetes Care* 39, no. 1 (2016): 130–138, <https://doi.org/10.2337/dc15-1240>.
54. R. N. Larsen, P. C. Dempsey, F. Dillon, et al., “Does the type of activity “break” from prolonged sitting differentially impact on postprandial blood glucose reductions? An exploratory analysis,” *Applied Physiology, Nutrition, and Metabolism* 42, no. 8 (2017): 897–900, <https://doi.org/10.1139/apnm-2016-0642>.
55. S. P. Fenemor, A. R. Homer, T. L. Perry, C. M. Skeaff, M. C. Peddie, and N. J. Rehrer, “Energy Utilization Associated With Regular Activity Breaks and Continuous Physical Activity: A Randomized Crossover Trial,” *Nutrition, Metabolism, and Cardiovascular Diseases* 28, no. 6 (2018): 557–564, <https://doi.org/10.1016/j.numecd.2018.02.003>.
56. E. A. Richter and M. Hargreaves, “Exercise, GLUT4, and Skeletal Muscle Glucose Uptake,” *Physiological Reviews* 93, no. 3 (2013): 993–1017, <https://doi.org/10.1152/physrev.00038.2012>.
57. V. T. Samuel and G. I. Shulman, “The Pathogenesis of Insulin Resistance: Integrating Signaling Pathways and Substrate Flux,” *Journal of Clinical Investigation* 126, no. 1 (2016): 12–22, <https://doi.org/10.1172/JCI77812>.

58. A. Bergouignan, C. Latouche, S. Heywood, et al., "Frequent Interruptions of Sedentary Time Modulates Contraction- and Insulin-Stimulated Glucose Uptake Pathways in Muscle: Ancillary Analysis From Randomized Clinical Trials," *Scientific Reports* 6, no. 1 (2016): 32044, <https://doi.org/10.1038/srep32044>.
59. B. C. R. Christmas, L. Taylor, A. Cherif, et al., "Postprandial Insulin and Triglyceride Concentrations Are Suppressed in Response to Breaking Up Prolonged Sitting in Qatari Females," *Frontiers in Physiology* 10, no. JUN (2019): 706, <https://doi.org/10.3389/fphys.2019.00706>.
60. R. N. Larsen, H. Ali, P. C. Dempsey, et al., "Interrupting Sitting Time With Simple Resistance Activities Lowers Postprandial Insulinemia in Adults With Overweight or Obesity," *Obesity* 27, no. 9 (2019): 1428–1433, <https://doi.org/10.1002/oby.22554>.
61. B. D. Maylor, J. K. Zakrzewski-Fruer, D. J. Stensel, C. J. Orton, and D. P. Bailey, "Effects of Frequency and Duration of Interrupting Sitting on Cardiometabolic Risk Markers," *International Journal of Sports Medicine* 40, no. 13 (2019): 818–824, <https://doi.org/10.1055/a-0997-6650>.
62. M. C. Peddie, C. Kessell, T. Bergen, et al., "The Effects of Prolonged Sitting, Prolonged Standing, and Activity Breaks on Vascular Function, and Postprandial Glucose and Insulin Responses: A Randomised Crossover Trial," *PLoS ONE* 16, no. 1 (2021): e0244841, <https://doi.org/10.1371/journal.pone.0244841>.
63. C. E. Hafer-Macko, A. S. Ryan, F. M. Ivey, and R. F. Macko, "Skeletal Muscle Changes After Hemiparetic Stroke and Potential Beneficial Effects of Exercise Intervention Strategies," *Journal of Rehabilitation Research and Development* 45, no. 2 (2008): 261–272, <https://doi.org/10.1682/JRRD.2007.02.0040>.
64. C. English, H. McLennan, K. Thoirs, A. Coates, and J. Bernhardt, "Loss of Skeletal Muscle Mass After Stroke: A Systematic Review," *International Journal of Stroke* 5, no. 5 (2010): 395–402, <https://doi.org/10.1111/j.1747-4949.2010.00467.x>.
65. J. Cohen, "A Power Primer," *Psychological Bulletin* 112, no. 1 (1992): 155–159, <https://doi.org/10.1037/0033-2909.112.1.155>.
66. A. Colvin, L. Murray, J. Noble, and S. Chastin, "Effects of Breaking Up Sedentary Behavior With Short Bouts of Yoga and Tai-Chi on Glycemia, Concentration, and Well-Being," *Journal of Physical Activity & Health* 21, no. 2 (2024): 181–188, <https://doi.org/10.1123/jpah.2023-0308>.
67. T. M. Altenburg, J. Rotteveel, D. W. Dunstan, J. Salmon, and M. J. M. Chinapaw, "The Effect of Interrupting Prolonged Sitting Time With Short, Hourly, Moderate-Intensity Cycling Bouts on Cardiometabolic Risk Factors in Healthy, Young Adults," *Journal of Applied Physiology* 115, no. 12 (2013): 1751–1756, <https://doi.org/10.1152/jappphysiol.00662.2013>.
68. T. M. Altenburg, J. Rotteveel, E. H. Serné, and M. J. M. Chinapaw, "Standing Is Not Enough: A Randomized Crossover Study on the Acute Cardiometabolic Effects of Variations in Sitting in Healthy Young Men," *Journal of Science and Medicine in Sport* 22, no. 7 (2019): 790–796, <https://doi.org/10.1016/j.jsams.2018.12.016>.
69. D. P. Bailey and C. D. Locke, "Breaking Up Prolonged Sitting With Light-Intensity Walking Improves Postprandial Glycemia, but Breaking Up Sitting With Standing Does Not," *Journal of Science and Medicine in Sport* 18, no. 3 (2015): 294–298, <https://doi.org/10.1016/j.jsams.2014.03.008>.
70. D. P. Bailey, C. J. Orton, B. D. Maylor, and J. K. Zakrzewski-Fruer, "Cardiometabolic Response to a Single High-Intensity Interval Exercise Session Versus Breaking Up Sedentary Time With Fragmented High-Intensity Interval Exercise," *International Journal of Sports Medicine* 40, no. 3 (2019): 165–170, <https://doi.org/10.1055/a-0828-8217>.
71. D. P. Bailey, T. M. Withers, V. L. Goosey-Tolfrey, et al., "Acute Effects of Breaking Up Prolonged Sedentary Time on Cardiovascular Disease Risk Markers in Adults With Paraplegia," *Scandinavian Journal of Medicine & Science in Sports* 30, no. 8 (2020): 1398–1408, <https://doi.org/10.1111/sms.13671>.
72. M. D. Campbell, A. M. Alobaid, M. Hopkins, et al., "Interrupting Prolonged Sitting With Frequent Short Bouts of Light-Intensity Activity in People With Type 1 Diabetes Improves Glycaemic Control Without Increasing Hypoglycaemia: The SIT-LESS Randomised Controlled Trial," *Diabetes, Obesity & Metabolism* 25, no. 12 (2023): 3589–3598, <https://doi.org/10.1111/dom.15254>.
73. O. P. Charlett, V. Morari, and D. P. Bailey, "Impaired Postprandial Glucose and No Improvement in Other Cardiometabolic Responses or Cognitive Function by Breaking Up Sitting With Bodyweight Resistance Exercises: A Randomised Crossover Trial," *Journal of Sports Sciences* 39, no. 7 (2021): 792–800, <https://doi.org/10.1080/02640414.2020.1847478>.
74. Y. C. Chen, J. A. Betts, J. P. Walhin, and D. Thompson, "Adipose Tissue Responses to Breaking Sitting in Men and Women With Central Adiposity," *Medicine and Science in Sports and Exercise* 50, no. 10 (2018): 2049–2057, <https://doi.org/10.1249/MSS.0000000000001654>.
75. M. Cho, K. Bunsawat, H. Kim, E. Yoon, and S. Jae, "The Acute Effects of Interrupting Prolonged Sitting With Stair Climbing on Vascular and Metabolic Function After a High-Fat Meal," *European Journal of Applied Physiology* 120, no. 3 (2020): 829–839, <https://doi.org/10.1007/s00421-020-04321-9>.
76. R. E. Climie, M. S. Grace, R. L. Larsen, et al., "Regular Brief Interruptions to Sitting After a High-Energy Evening Meal Attenuate Glycemic Excursions in Overweight/Obese Adults," *Nutrition, Metabolism, and Cardiovascular Diseases* 28, no. 9 (2018): 909–916, <https://doi.org/10.1016/j.numecd.2018.05.009>.
77. I. R. Correia, J. P. Magalhães, P. B. Júdice, et al., "Breaking-Up Sedentary Behavior and Detraining Effects on Glycemic Control: A Randomized Crossover Trial in Trained Older Adults," *Journal of Aging and Physical Activity* 31, no. 3 (2023): 391–399, <https://doi.org/10.1123/japa.2022-0124>.
78. T. Engeroff, E. Füzeki, L. Vogt, and W. Banzer, "The Acute Effects of Single or Repeated Bouts of Vigorous-Intensity Exercise on Insulin and Glucose Metabolism During Postprandial Sedentary Behavior," *International Journal of Environmental Research and Public Health* 19, no. 8 (2022): 4422, <https://doi.org/10.3390/ijerph19084422>.
79. Y. A. Freire, G. d. A. D. de Macêdo, R. A. V. Browne, et al., "Effect of Breaks in Prolonged Sitting or Low-Volume High-Intensity Interval Exercise on Markers of Metabolic Syndrome in Adults With Excess Body Fat: A Crossover Trial," *Journal of Physical Activity & Health* 16, no. 9 (2019): 727–735, <https://doi.org/10.1123/jpah.2018-0492>.
80. J. T. Gale, D. L. Wei, J. J. Haszard, R. C. Brown, R. W. Taylor, and M. C. Peddie, "Breaking Up Evening Sitting With Resistance Activity Improves Postprandial Glycemic Response: A Randomized Crossover Study," *Medicine and Science in Sports and Exercise* 55, no. 8 (2023): 1471–1480, <https://doi.org/10.1249/MSS.0000000000003166>.
81. Y. Gao, Q. Li, T. Finni, and A. J. Pesola, "Enhanced Muscle Activity During Interrupted Sitting Improves Glycemic Control in Overweight and Obese Men," *Scandinavian Journal of Medicine & Science in Sports* 34, no. 4 (2024): e14628, <https://doi.org/10.1111/sms.14628>.
82. N. S. A. Hawari, J. Wilson, and J. M. R. Gill, "Effects of Breaking Up Sedentary Time With "Chair Squats" on Postprandial Metabolism," *Journal of Sports Sciences* 37, no. 3 (2019): 331–338, <https://doi.org/10.1080/02640414.2018.1500856>.
83. M. Holmstrup, T. Fairchild, S. Keslacy, R. Weinstock, and J. Kanaley, "Multiple Short Bouts of Exercise Over 12-H Period Reduce Glucose Excursions More Than an Energy-Matched Single Bout of Exercise," *Metabolism* 63, no. 4 (2014): 510–519, <https://doi.org/10.1016/j.metabol.2013.12.006>.
84. R. J. Kowalsky, J. M. Jakicic, A. Hergenroeder, R. J. Rogers, and B. B. Gibbs, "Acute Cardiometabolic Effects of Interrupting Sitting

- With Resistance Exercise Breaks,” *Applied Physiology, Nutrition, and Metabolism* 44, no. 10 (2019): 1025–1032, <https://doi.org/10.1139/apnm-2018-0633>.
85. F. C. Kuo, Y. T. Lin, T. Y. Chueh, Y. K. Chang, T. M. Hung, and Y. C. Chen, “Breaking Prolonged Sitting Increases 24-H Physical Activity and Self-perceived Energy Levels But Does Not Acutely Affect Cognition in Healthy Adults,” *European Journal of Applied Physiology* 124, no. 2 (2024): 445–455, <https://doi.org/10.1007/s00421-023-05278-1>.
86. R. N. Larsen, B. A. Kingwell, C. Robinson, et al., “Breaking Up of Prolonged Sitting Over Three Days Sustains, but Does Not Enhance, Lowering of Postprandial Plasma Glucose and Insulin in Overweight and Obese Adults,” *Clinical Science* 129, no. 2 (2015): 117–127, <https://doi.org/10.1042/CS20140790>.
87. B. D. Maylor, J. K. Zakrzewski-Fruer, C. J. Orton, and D. P. Bailey, “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,” *Journal of Science and Medicine in Sport* 21, no. 12 (2018): 1250–1255, <https://doi.org/10.1016/j.jsams.2018.05.022>.
88. M. McCarthy, C. L. Edwardson, M. J. Davies, et al., “Fitness Moderates Glycemic Responses to Sitting and Light Activity Breaks,” *Medicine and Science in Sports and Exercise* 49, no. 11 (2017): 2216–2222, <https://doi.org/10.1249/MSS.0000000000001338>.
89. M. McCarthy, C. L. Edwardson, M. J. Davies, et al., “Breaking Up Sedentary Time With Seated Upper Body Activity Can Regulate Metabolic Health in Obese High-Risk Adults: A Randomized Crossover Trial,” *Diabetes, Obesity and Metabolism* 19, no. 12 (2017): 1732–1739, <https://doi.org/10.1111/dom.13016>.
90. M. Miyashita, K. Edamoto, T. Kidokoro, et al., “Interrupting Sitting Time With Regular Walks Attenuates Postprandial Triglycerides,” *International Journal of Sports Medicine* 37, no. 02 (2015): 97–103, <https://doi.org/10.1055/s-0035-1559791>.
91. M. C. Peddie, J. L. Bone, N. J. Rehrer, C. M. Skeaff, A. R. Gray, and T. L. Perry, “Breaking Prolonged Sitting Reduces Postprandial Glycemia in Healthy, Normal-Weight Adults: A Randomized Crossover Trial,” *American Journal of Clinical Nutrition* 98, no. 2 (2013): 358–366, <https://doi.org/10.3945/ajcn.112.051763>.
92. A. J. Pinto, K. Meireles, T. Peçanha, et al., “Acute Cardiometabolic Effects of Brief Active Breaks in Sitting for Patients With Rheumatoid Arthritis,” *American Journal of Physiology. Endocrinology and Metabolism* 321, no. 6 (2021): E782–E794, <https://doi.org/10.1152/ajpendo.00259.2021>.
93. M. J. L. Toledo, B. E. Ainsworth, G. A. Gaesser, S. P. Hooker, M. A. Pereira, and M. P. Buman, “Does Frequency or Duration of Standing Breaks Drive Changes in Glycemic Response? A Randomized Crossover Trial,” *Scandinavian Journal of Medicine & Science in Sports* 33, no. 7 (2023): 1135–1145, <https://doi.org/10.1111/sms.14344>.
94. P. Wennberg, C. J. Boraxbekk, M. Wheeler, et al., “Acute Effects of Breaking Up Prolonged Sitting on Fatigue and Cognition: A Pilot Study,” *BMJ Open* 6, no. 2 (2016): e009630, <https://doi.org/10.1136/bmjopen-2015-009630>.

Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Table S1:** Ovid MEDLINE search strategy (searched on 6 December 2022 and updated 9 October 2024). **Table S2:** Acute laboratory randomized crossover trials ($n = 53$) which investigate the effect of interrupting prolonged sitting with different exercise types on postprandial glycemia and insulinemia as measured by total (AUC) and incremental area under the curve (iAUC) following an overnight fast. **Figure S1:** Forest plot for the effect of regular activity breaks on glucose AUC. **Figure S2:** Forest plot for the effect of regular activity breaks on insulin AUC. **Figure S3:** Forest plot for the effect of regular activity breaks on mean glucose concentration. **Figure S4:**

Forest plot for the effect of regular activity breaks on mean insulin concentration. **Figure S5:** Forest plot for the effect of regular activity breaks on glucose iAUC by mode of activity. **Figure S6:** Forest plot for the effect of regular activity breaks on insulin iAUC by mode of activity. **Figure S7:** Forest plot for the effect of regular activity breaks on glucose iAUC by frequency of activity breaks. **Figure S8:** Forest plot for the effect of regular activity breaks on insulin iAUC by frequency of activity breaks. **Figure S9:** Forest plot for the effect of regular activity breaks on glucose iAUC by health status. **Figure S10:** Forest plot for the effect of regular activity breaks on insulin iAUC by health status. **Figure S11:** Forest plot for the effect of regular activity breaks on glucose iAUC by sample weight status. **Figure S12:** Forest plot for the effect of regular activity breaks on insulin iAUC by sample weight status.