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An Evening Activity Breaks Intervention for Improvement of Glucose, Blood Pressure, and Sleep: A Pilot Study in Free-Living Adults

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ABSTRACT

Aims: Interrupting evening sedentary time with activity breaks in a laboratory setting improves postprandial metabolism and sleep duration. This pilot study aimed to assess if a theory-informed intervention was able to increase the number of activity breaks performed in the evening at home, and to describe changes in movement patterns, glycaemic response and blood pressure.

Methods: Twenty participants (mean age 34 ± 12 years, female $n = 18$) completed a 2-week intervention which supported them to perform 2–3 min activity breaks every 30 min during periods of prolonged sitting in the evening. The intervention utilised behaviour change techniques and a mobile application. The number of activity breaks performed was assessed via self-report, mobile app data, and accelerometer data. Other outcomes included: glycaemic control; 24-h movement patterns; blood pressure; self-reported sleep and capability, opportunity and motivation to interrupt evening sitting. Data was collected at baseline, 2-weeks (immediately post-intervention) and 4-weeks (following a 2-week follow-up period).

Results: On average, participants self-reported completing 3.6 activity breaks per evening during the intervention. There was little change in objective measures of sedentary time, sleep, physical activity, and glycaemic outcomes. A reduction in sleep disturbances (−0.35, 95% CI −0.6 to −0.1), as measured by the PSQI, was observed. Participants reported improved automatic motivation to interrupt evening sitting, but capability, opportunity and reflective motivation were unchanged.

Conclusion: Increases in the number of activity breaks performed in the evening can be achieved and were accompanied by small improvements in sleep quality. A full-scale effectiveness RCT based on this intervention is warranted.

1 | Introduction

Experimental evidence indicates that interrupting sedentary time with short (2–3 min), regularly performed (every 20–30 min) bouts of physical activity (often termed 'activity breaks') in controlled laboratory settings improves postprandial metabolism [1–5], sleep duration [6] and blood flow [7, 8]. To date, translation of experimental findings in free-living studies has produced little to no benefit in cardiometabolic outcomes [9–11]. Indeed, in a small single-arm free-living study ($n = 16$), an activity breaks intervention induced small increases in daily steps and walking time compared to baseline; however, changes in daily sitting time and glycaemic control and tolerance were negligible [12]. A single

randomised controlled trial (RCT) performed in 283 older adults in which sitting time was interrupted with standing, resulted in 3.48 mmHg reductions in systolic blood pressure after 6 months (95% CI −6.68 to −0.28 mmHg); however, sedentary time was interrupted with standing, not activity; the participants were older, and no significant differences were observed for any other cardiometabolic markers [13].

The evening is often the time when the longest period of prolonged sitting is accumulated [14–16], when we consume the greatest percentage of daily energy intake [17] and is also accompanied by lower insulin sensitivity [18]. Therefore, this is a time of the day when interventions to interrupt prolonged sitting may have the greatest impact to reduce the risk of cardiometabolic disease. There have been two small laboratory-based studies that have focused specifically on interrupting evening sitting time, with resistance exercise activity breaks, in healthy adults ($n = 30$) [19] and adults living with overweight or obesity ($n = 9$) [20]. These studies found that interrupting evening sitting with regular activity breaks induced some of the largest reductions in postprandial glucose concentrations (standardised mean difference [SMD] of −0.74 to −1.70) compared to activity breaks intervention conducted during daytime (SMD −0.30, 95% CI −0.43 to −0.16) [21]. However, to date, no free-living intervention studies, that specifically target the evening period have been conducted.

As the evening has been an underexplored period for behavioural intervention, our understanding of how to encourage evening activity breaks, or their feasibility in free-living settings, is limited and the use of behaviour change theory and techniques is recommended [22]. Before an intervention can be tested for effectiveness, it must first be shown to be feasible to support people to do activity breaks. Therefore, the aim of this pilot study was to assess if an activity breaks intervention, informed by behaviour change theory, could increase the number of activity breaks undertaken in the evening in a free-living setting. In addition, changes in 24-h movement patterns, glycaemic response and blood pressure over the intervention period and 2-weeks after will be described.

2 | Materials and Methods

The methodology for this study has been described in detail elsewhere [23]. In brief, this single group intervention pilot study, consisting of a 1-week baseline assessment period, 2-week intervention period, and a 2-week follow up which was conducted at the University of Otago, Dunedin New Zealand between May and October 2024. The trial was approved by the University of Otago Human Ethics Committee (H23/105; October 2023) and was registered prospectively with the Australian New Zealand Clinical Trials Registry (ANZCTR 12624000371594). Participants were recruited through the distribution of print and electronic flyers and advertisements on social media. Participants were eligible to participate if they were over the age of 18 years, self-reported habitually accumulating more than 3-h of sitting in the evening, had a smart phone compatible with the Moova application (previously called StretchMinder; Better Primate Labs Limited, Hong Kong) and were able to ambulate unaided (i.e., not using a wheelchair, crutches or other assistive device). The Physical Activity Readiness Questionnaire (PAR-Q) was completed at screening to check whether participation might not be medically appropriate.

2.1 | Study Procedures

After contacting the research team via email, participants were sent a link to an online survey (REDCap software Research Electronic Data Capture, production server version 13.10.0, Vanderbilt University. Nashville, TN, USA) where they viewed an information sheet about the study, provided electronic consent, and completed a screening questionnaire. If participants met the inclusion criteria, they were then scheduled to attend an introductory session for baseline assessment.

2.2 | Baseline Assessment

The 1-week baseline assessment period began with participants attending an introductory session in the laboratory. At this session height, weight and blood pressure were measured. Participants discussed their usual evening eating and activity patterns to identify the 3-h period when they were generally the most sedentary. To assess baseline 24-h movement patterns participants were fitted with three accelerometers; two ActiGraph GT3+ (ActiGraph, Pensacola, FL, USA) accelerometers worn on the non-dominant wrist and hip, and an ActivPAL3 accelerometer (PAL Technologies Limited, Glasgow, Scotland) worn on the midpoint of right thigh. Accelerometers were worn 24-h a day, for 3 days during, which time participants completed a wear time diary where they recorded attempted sleep and wake times (to constrain the sleep detection algorithm), when accelerometers were removed (e.g., for swimming or playing contact sport) and when they performed activities that may not have been accurately identified in the accelerometer output (e.g., biking on a stationary bike). To measure glycaemic response, participants were fitted with a Freestyle Libre Pro iQ CGM which was worn on the posterior upper arm and measured interstitial glucose concentrations, every 15 min for 7-days. Participants completed the Pittsburgh Sleep Quality Index (PSQI) as a measure of self-reported sleep quality [24], and a questionnaire to assess their capability, opportunity and motivation to perform regular activity breaks [25].

2.3 | Activity Breaks Intervention

A detailed overview of the activity breaks intervention design and development is provided elsewhere [23]. In brief, the design of the intervention was informed by findings from previous experimental research [19, 26] along with previously conducted successful behaviour change interventions [27, 28]. Furthermore, as recommended by The Medical Research Foundation [22], the design was informed by behaviour change theory, specifically the COM-B (capability, opportunity and motivation) model of behaviour [29, 30], and the use of other behaviour change techniques that have been found to successfully support reductions in sedentary time. The activity breaks intervention involved a one-on-one session with an activity breaks coach, the provision of the Moova mobile phone application, and two follow-up phone consultation sessions

with the activity breaks coach on days three and seven of the first week of the intervention. The Moova app is a tool to help people interrupt their daily sitting time with activity breaks. Key features of the app include a repository of activity videos, reminder and scheduling functionality, and self-monitoring of completion of activity breaks. For the intervention, the app was primarily used as a prompt to remind participants to take activity breaks using the pre-schedule alerts function, but also to provide videos of different activity break options participants could complete and self-monitoring. During this period participants were fitted with the same three accelerometers as at baseline, which they were instructed to wear for the first 3 days and last 3 days of the two-week intervention period, and to complete the sleep and wear time diary. Participants were also fitted with a new Freestyle Libre Pro iQ CGM, which they were instructed to wear for the full 2-week intervention period.

2.4 | Activity Breaks Coach Consultation

This one–one–one consultation lasted approximately 30 min and comprised discussion of the following: (1) The health benefits associated with interrupting bouts of prolonged sitting with regular activity breaks; (2) Downloading and setting up the Moova application on the participant's mobile device so that it prompted the participant to perform an activity break every 30 min during the participant's per identified period of prolonged sitting in the evening. The self-monitoring feature of the app was also demonstrated to participants; (3) Development of an individualised action and contingency plan; (4) Discussion around how participants could obtain support from those in their household, friends and family to perform activity breaks; and (5) Encouragement for participants to reflect on the experienced positive consequences and factors that may have helped and/or hindered them from performing activity breaks before each follow-up session.

2.5 | Follow Up Phone Call

Participants received two follow-up phone calls on day three and seven in the first week of the 2-week intervention. During these phone calls, the activity breaks coach discussed with the participant how they were finding the intervention and modified the action and contingency plan if necessary.

2.6 | Pilot Study Outcomes

2.6.1 | Activity Breaks Undertaken in the Evening

The number of activity breaks performed during the evenings in the intervention period was assessed in three ways: self-report; the Moova app; and an algorithm (developed by the authors) applied to accelerometry data. Participants self-reported when they undertook an activity break in an activity breaks diary (including a description of the type of activity, time started, time ended and intensity). An average increase of at least four activity breaks per evening in at least 50% of the sample is the threshold at which we consider this intervention to be feasible. Four activity breaks were selected because this represents two-thirds of the six possible activity breaks during the minimum 3-h evening period [23]. This threshold is also consistent with definitions of a 'regular activity break' in the literature, which typically describe an interruption to prolonged sitting at least once per hour, if not more frequently [21, 31, 32]. Participants only recorded activity breaks during the 2-week measurement period and during the 2-week follow-up period since they did not yet understand what an activity break was at baseline. Participants were encouraged to initiate activity breaks using the Moova app, and app use data for the entire 2-week intervention period and the 2-week follow up period for each participant was accessible to the research team. Activity breaks were also identified using an algorithm specifically designed for this purpose by the authors, utilising data from all three accelerometers, where an activity break was defined as a period of activity that was more than 90 s but no more than 10 min, and should break up two periods of interrupted sedentary time of at least 5 min each. Although participants were not completing activity breaks at baseline, applying the algorithm to the baseline accelerometery allowed for estimation of habitual breaks in evening sedentary time.

2.6.2 | 24 h Activity Patterns

For all three periods of 24-h activity assessment (baseline period, and the first and last 3 days of the 2-week intervention period) time-stamped activity data were downloaded using Actilife software (Actilife Version 6.14.4), for the Actigraph accelerometers and ActivPAL software for the ActivPAL accelerometers, saved in 15 s epochs and imported into Stata (Version 17, Statacorp, College Station, TX, USA). For a day to be considered valid, total wear time had to be greater than 10 h per day. Self-reported attempted sleep and wake times were entered manually into Actilife to constrain the Cole-Kripke algorithm [33], which was applied to the wrist derived data to determine sleep period (time between self-reported attempted sleep and wake time), wake after sleep onset (WASO; minutes spent awake between sleep onset and sleep offset, determined by the algorithm), total sleep time (amount of time spent sleeping during sleep period time, for example sleep period, minus the time between attempted sleep and sleep onset and WASO), number of awakening, and sleep efficiency (how consolidated the sleep was). The intensity and duration of activity performed during self-reported non-wear time (e.g., swimming) were identified from the wear time diaries and manually overwritten in Stata for all three accelerometers. Time spent sedentary, in light and in moderate-to-vigorous physical activity was calculated using validated cut points of the wrist [34] and hip [35] derived accelerometer data. The ActivPAL data was used to identify time spent sitting, standing and stepping.

2.6.3 | Changes in Interstitial Glucose Concentrations and Variability

Time stamped interstitial glucose concentrations from the Freestyle Libre Pro iQ CGMs were downloaded using the FreeStyle Libre Pro software (Version 1.0, Abbott Diabetes Care Limited, Oxcon, UK) and exported into Stata. Mean (mmol/L), standard deviation (as a measure of glycaemic variability), total

and incremental area under the curve (mmol.h/L) of the interstitial glucose concentrations were calculated for the entire day and the predetermined individualised 'evening period' for the baseline and intervention periods.

2.6.4 | Changes in Blood Pressure

Systolic and diastolic blood pressure were measured using an automated sphygmomanometer (OMRON-HEM907) at baseline, end of the 2-week intervention and at the end of the 2-week follow up. Measurements were taken in triplicate, 3 min apart, and the mean of the three measurements was used to represent blood pressure at that timepoint.

2.6.5 | Changes in Perceived Sleep Quality

Perceived sleep quality was assessed using the Pittsburgh Sleep Quality Index [24] adapted to assess the previous 2-weeks rather than the standard 4-week period. Participants completed this questionnaire at the end of the baseline assessment period and the end of the 2-week intervention.

2.6.6 | Changes in Capability, Opportunity and Motivation to Perform Activity Breaks in the Evening

Capability, opportunity and motivation to perform activity breaks in the evening at home was assessed using an adapted COM-B questionnaire [25] at the end of baseline assessment period, and at the end of the 2-week intervention. This questionnaire asked participants to 'please rate your ability and willingness to reduce the time you spent sitting in the evening, at home', on an 11-point scale (0 = strongly disagree, 10 = strongly agree), related to the six components of the COM-B model (Physical Opportunity, Social Opportunity, Automative Motivation, Reflective Motivation, Physical Capability and Psychological Capability) plus an additional question related specifically to knowledge.

2.7 | Sample Size

Because this was predominantly a pilot study, a formal sample size calculation was not performed. Instead, we chose a target sample size of 20 participants based on the need to balance the need for information about the feasibility of the intervention, budget and time constraints, and the reliability of the estimates of variance that would be provided with a sample of this size.

2.8 | Statistical Analysis

All statistical analysis was undertaken in Stata 18.0 (StataCorp, Texas). The mean number of activity breaks each evening was calculated for each participant across the intervention period. The mean of these means was then calculated for the whole sample, along with standard deviations and ranges. Because the accelerometry data could be used to estimate the number of activity breaks at baseline, the mean change from baseline to post-intervention was estimated using a mixed effects regression analysis, using all days of data and participant as a random effect. A 95% confidence interval was also calculated. These same methods were used to describe changes in 24-h movement patterns, sleep patterns, and blood glucose measures. Residuals of models were plotted and visually assessed for homoskedasticity and normality. Changes in blood glucose measures were reported as standardised mean differences, using the pooled SD, and plotted as box plots. As this is a pilot study, no statistical testing was undertaken and confidence intervals are provided, not as a proxy for determining 'statistical significance', but as precision intervals for the estimates of change.

Accelerometer results are presented for the baseline period and the intervention period, where the intervention period is defined as the combined data collected from the first and last 3 days of the intervention. Separate data are provided in Tables S1–S3.

3 | Results

Figure 1 presents information of the flow of participants through the study. The intervention was delivered to 20 participants, the majority of which were women, of New Zealand European ethnicity, who had at least some tertiary education and obesity (Table 1).

3.1 | Pilot Outcomes

3.1.1 | Activity Breaks

On average, participants self-reported intentionally performing 3.6 activity breaks per evening during the intervention (where performing 6 activity breaks was considered 100% compliance) (Table 2). Self-reported activity breaks per evening were slightly higher in the first half of the intervention (mean 3.8 SD 1.8) compared to the second half of the intervention period (mean 3.4 SD 2.3). A total of 13 participants reported performing at least four activity breaks (on average) across the intervention. However, self-reported average compliance across the 2-week intervention did range from less than 1 to 6.5 activity breaks per evening. The accelerometer algorithm detected an average of 2.1 activity breaks per evening at baseline; this increased by 0.9 (95% CI 0.1–1.7) activity breaks between baseline and the intervention (Table 2). Data from the Moova app indicated that slightly fewer breaks were being recorded in the app than being self-reported (Table 2). App data from the 2-week follow-up period showed, on average, 1.2 (1.3) breaks per day were recorded in the app, with a range of 0 (reported by 7 users) to 4.7 breaks per day.

3.1.2 | 24 h Activity Patterns

There was very little change in accelerometry measured sedentary time, light, moderate or vigorous activity, sitting, standing and stepping time, or sleep duration between baseline and the

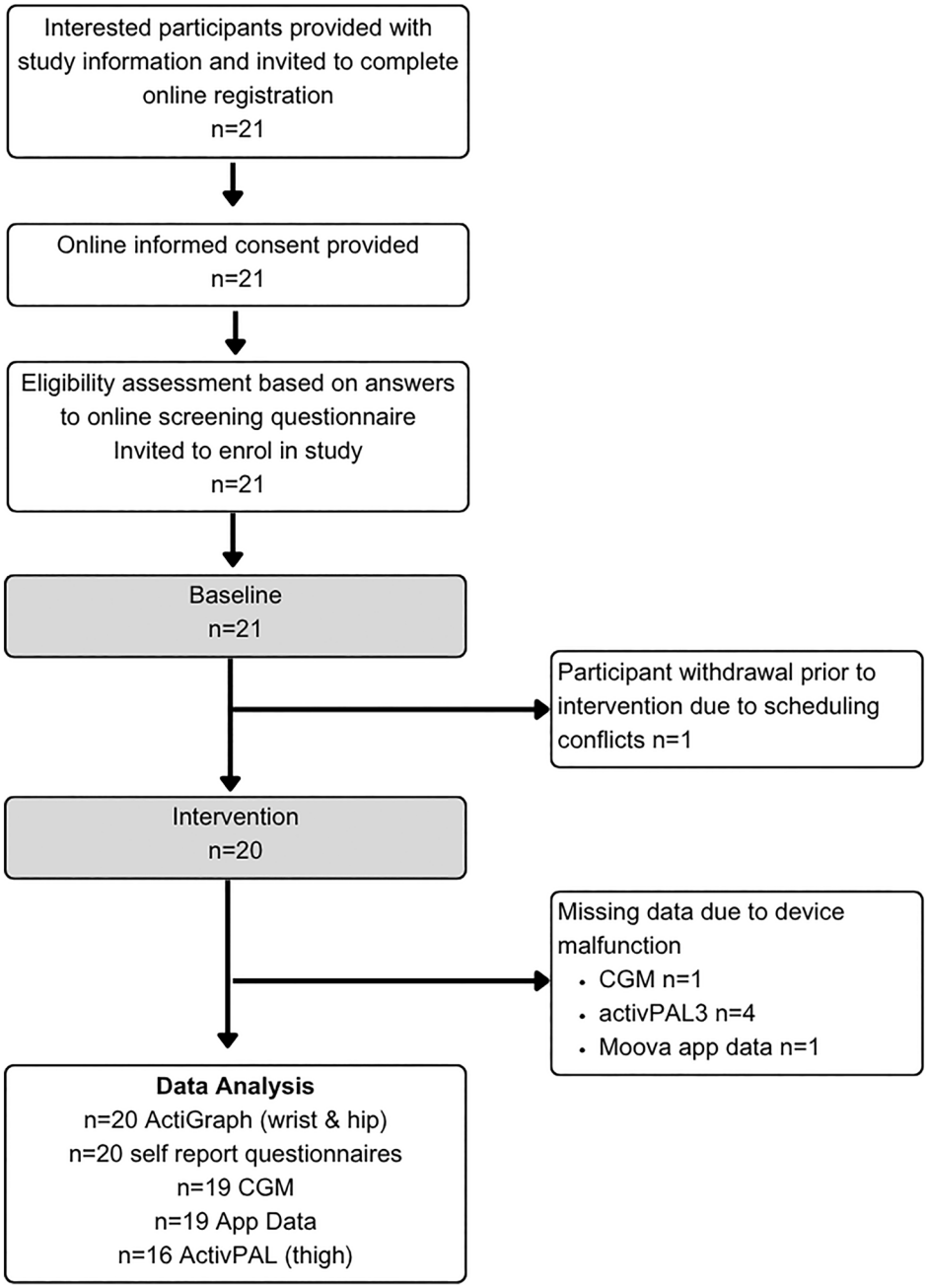

FIGURE 1 | Pilot study flow diagram.

intervention (Table 3). Sedentary time during the evening did not decrease substantially, although the variance was high. Sleep period time was, on average, 22 min less (95% CI −56.9 to 13.6 min) during the intervention compared to baseline and sleep quality was largely unchanged, with small improvements in WASO and fewer awakenings (Table 4).

At both timepoints (baseline and immediately post-intervention) 90% of participants self-reported their sleep quality to be 'Very Good' or 'Fairly Good'. The Global PSQI score improved by 1.0 point (95% CI −2.1 to 1.4) on average. The largest improvement was observed in the sleep disturbance component score, which indicated fewer sleep disturbances were being reported (0.35-point reduction (95% CI −0.6 to −0.1)) immediately following the 2-week intervention (Table 4).

3.1.3 | CGM Data

There were no meaningful changes in mean glucose, glycaemic variability or AUC from baseline to immediately post-intervention (standardised mean difference: −0.1, 0.02 and 0.04 respectively). However, small reductions in medians and interquartile ranges across a variety of metrics were observed (Table S4, Figure S1).

3.1.4 | Blood Pressure

Mean (SD) systolic blood pressure was 119 (10) mmHg at baseline, 116 (12) mmHg at 2-Weeks (mean difference −3 mmHg 95% CI −8 to 2) and 118 (9) mmHg at 4-weeks (mean difference from

baseline −2 mmHg 95% CI −6 to 3). Mean (SD) diastolic blood pressure was 80 (10) mmHg at baseline, 77 (8) mmHg immediately post-intervention (mean difference −4 mmHg 95% CI −7 to 0) and 78 (8) mmHg at the end of the 2-week follow-up (mean difference from baseline −1 mmHg 95% CI −5 to 2).

TABLE 1 | Participant characteristics ($n = 20$).

	All
Age, y	34 (12)
Gender, *n* (%)	
Male	2 (10)
Female	18 (90)
Ethnicity, *n* (%)	
New Zealand European	14 (70)
Māori	2 (10)
Other	4 (20)
Blood pressure, mmHg	
Systolic	119 (10)
Diastolic	80 (10)
Weight status	
Height, cm	159 (38)
Weight, kg	89 (27)
BMI, kg/m^2	33 (10)
Education status, *n* (%)	
Less than high school	1 (5)
High school graduate	2 (10)
Some Tertiary Study	13 (65)
Postgraduate Degree	4 (20)

Note: Values reported as mean (standard deviation), unless otherwise stated.

3.1.5 | Change in Self-Perceived Capability, Opportunity and Motivation to Perform Activity Breaks in the Evening

Self-perceived capability (psychological and physical), opportunity (physical and social) and self-perceived knowledge to reduce evening sitting time at home showed negligible changes between baseline and immediately post-intervention (Table S5) with the exception of automatic motivation to reduce evening sitting time, which improved by 1.4 points (95% CI 0.0–2.9).

4 | Discussion

To our knowledge, this is the first study to pilot an activity breaks intervention that supports people to perform regular activity breaks in the evening in a free-living setting. Our results indicate that this intervention is feasible, as 65% of participants reported performing an average of four or more breaks per evening during the intervention period, meeting our predefined feasibility threshold [23]. However, large variability was observed within the sample. Three participants (10%) reported fewer than one activity break per day, on average, over the intervention period, whilst the most adherent 10% of participants reported performing an average of at least six activity breaks per day. In the entire sample, a small decrease in the average number of activity breaks performed was observed between the first and second week of the intervention. These findings are consistent with that of Smith and Colleagues [12] who examined adherence to a free-living activity breaks intervention that targeted performance of activity breaks during the day. Adherence, measured as any increase in hourly steps and/or postural transitions, was high during the first week, but dissipated over the intervention timeline, with data from one participant indicating no improvement in activity breaks at all.

In our study, data from the Moova app indicated slightly lower activity break rates than self-report, which may be due to variability in mobile app interaction. These discrepancies also raise important considerations regarding measurement validity. Self-reported

TABLE 2 | Activity breaks performed during the evening during baseline and intervention ($n = 20$).

	Baseline		Intervention		Change from baseline to intervention
	Mean (SD)	Range	Mean (SD)	Range	Mean (95% CI)[a]
Mean self reported, *n* per evening	—	—	3.6 (1.9)		—
Mean self reported using algorithm requirements[b], *n* per evening	—	—	2.9 (1.8)		—
Accelerometer algorithm identified, *n* per evening	2.1 (1.5)		3.0 (1.4)		0.9 (0.1, 1.7)
Average length of activity break, min	2.4 (1.5)		2.8 (0.7)	—	0.4 (−0.2, 1.0)
Number of breaks completed in the Moova app[c], *n* per evening	—	—	3.0 (1.3)	0 to 4.7	—

[a]Estimated using a mixed effects regression analysis with all days of data and participant as a random effect.
[b]Algorithm requirements were: Activity break needed to be between 1.5 and 10 min long and occur between sedentary bouts of at least 5 min.
[c]$n = 19$ due to missing data for $n = 1$.

TABLE 3 | Accelerometer measured 24 h movement patterns during baseline and intervention.

	Baseline mean (SD)	Intervention mean (SD)	Change from baseline to intervention mean (95% CI)[a]
All Day (hip derived)			
n	20	20	20
Non-wear time, min	43 (57)	65 (103)	22 (−12, 57)
Sedentary time, min	504 (111)	519 (120)	15 (−32, 62)
Light activity, min	300 (79)	281 (80)	−19 (−37, −0.2)
Moderate physical activity, min	89 (47)	84 (47)	−5 (−17, 7)
Vigorous physical activity, min	2.6 (4.3)	3.7 (4.6)	1.1 (0.7, 4.5)
Evening (hip derived)			
n	19	19	19
Average period, min	224 (57)	235 (85)	1 (−41, 43)
Sedentary time, min	143 (45)	137 (35)	−5 (−27, 16)
Sedentary time as % of evening period	62.0 (14.2)	59.4 (10.3)	−2.5 (−7.6, 2.5)
Light activity, min	63 (30)	65 (36)	2 (−12, 17)
Moderate physical activity, min	15 (12)	15 (9)	1 (−4, 6)
Vigorous physical activity, min	0.4 (1.2)	0.8 (1.1)	0.3 (−0.3, 1.0)
Total PA, min	78 (37)	82 (41)	4 (−15, 22)
Total activity as % of evening period	32.2 (11.2)	34.9 (22.7)	2.7 (−1.3, 6.7)
All Day (wrist derived)			
n	20	20	20
Non-wear time, min	43 (57)	44 (64)	1 (−19, 21)
Sedentary time, min	618 (107)	631 (112)	13 (−30, 56)
Total physical activity, min	278 (89)	257 (87)	−21 (−42, −0.3)
Sleep, min	501 (76)	509 (90)	7 (−28, 43)
Evening (wrist derived)			
n	19	19	17
Average period, min	234 (57)	235 (85)	1 (−41, 43)
Sedentary time, min	165 (50)	162 (47)	−3 (−29, 22)
Sedentary time as % of evening period	70.9 (12.5)	69.7 (9.2)	−1.2 (−5.4, 3.1)
Total activity, min	55 (26)	57 (26)	2 (−11, 14)
Total activity as % of evening period	23.3 (9.4)	24.7 (7.6)	1.4 (−1.8, 4.6)
All Day (thigh derived)			
n	20	20	20
Sedentary time, min	1152 (106)	1100 (209)	−52 (−153, 48)
Standing time, min	206 (88)	301 (203)	95 (2, 188)

(Continues)

TABLE 3 | (Continued)

	Baseline mean (SD)	Intervention mean (SD)	Change from baseline to intervention mean (95% CI)[a]
Stepping time, min	82 (45)	39 (28)	−43 (−61, −24)
Evening (thigh derived)			
n	18	18	18
Total time, min	184 (49)	190 (66)	7 (−25, 38)
Sedentary time, min	141 (46)	149 (53)	8 (−17, 32)
Standing time, min	32 (21)	31 (22)	−1 (−10, 8)
Stepping time, min	11 (8)	11 (8)	0 (−5, 4)

[a]Estimated using a mixed effects regression analysis with participant as a random effect.

breaks may be influenced by recall or social desirability bias [36], whereas app-recorded breaks depend on participants consistently logging or interacting with the app. Accelerometer-derived estimates provide an objective measure, but may not capture whether these movements were intentional activity breaks performed in response to the intervention. As such, each measure may have captured a different component of the target behaviour, limiting precision in estimating adherence and the true intervention dose achieved in the free-living setting. Furthermore, objective data showed that baseline activity patterns, assessed using the activity breaks algorithm already included activity that would be defined as 'activity breaks'. Therefore, changes in the number of objectively identified breaks were very small (0.9 breaks). This small change in objectively identified breaks, alongside the variability in adherence, may also suggest that the achieved intervention dose was too low or inconsistent to meaningfully influence glycaemic or blood pressure outcomes. In addition, because the intervention was delivered in a free-living setting, the intensity and duration of activity breaks were likely more variable than in controlled experimental studies where cardiometabolic benefits have been demonstrated [21].

Although this pilot study was not designed to detect changes in biological measures, exploratory analysis indicated some small improvements in interstitial glucose, blood pressure, and both self-reported and objectively measured sleep quality. Accordingly, these secondary findings should be interpreted cautiously and may reflect both the feasibility-focused design and the limited dose and intensity achieved during the intervention period. Capability and opportunity did not meaningfully change, but a small improvement was seen in automatic motivation. It is worthwhile to note that the baseline scores related to participant capability and opportunity to interrupt evening sitting were already high (>8 out of 10), which may partially explain the absence of large changes in these domains. This pattern suggests that the intervention does support participants to strengthen their habits, desires and impulses to take activity breaks in the evening, again highlighting the feasibility of this intervention in a free-living setting. Taken together, these findings suggest that this intervention may work to improve habit formation related to performing activity breaks in the evening, and although a modest and inconsistent increase in activity breaks was reported, some positive changes in cardiometabolic outcomes were observed.

As with most behaviour change, in this context the ultimate goal is for individuals to perform activity breaks in the evening as a habitual break in sedentary time. Results from the current study and Smith and colleagues [12] highlight the challenge of sustaining behaviour change, evidenced by dissipation in adherence over a relatively short period. Although the intervention appeared feasible and acceptable over the short term, the observed decline in activity-break adherence between the first and second week raises important questions about longer-term sustainability. This pattern suggests that initial engagement with evening activity breaks may be achievable, but that maintaining the behaviour over time may require additional support. For example, future interventions could incorporate personalised feedback, habit-based prompts, environmental restructuring, or integration with commonly used evening technologies such as streaming platforms, television, or gaming systems. Longer follow-up periods will also be needed to determine whether activity breaks can become habitual and sustained in free-living settings. This type of intervention may also be particularly beneficial for people living with obesity or inactive adults, especially when interruptions are performed more frequently, as this has been shown to have the largest positive effects on postprandial metabolism [21] and cardiometabolic health [37] in experimental trials. Therefore, while the present findings support the feasibility of initiating evening activity breaks, and although there is sufficient experimental evidence for the benefit of regularly interrupting prolonged sedentary time in a range of population groups [21, 37], further work is needed to translate these findings into real world improvements. A unique aspect of this study is the focus on the evening period, in particular. Future research may consider exploring environmental factors that could be altered to promote the target behaviour. For example, the integration of regular activity breaks reminders into streaming services, network television or gaming platforms.

This pilot study was completed with no drop-outs and no reported adverse effects, demonstrating strong feasibility and acceptability of the study. Conducting the study in a free-living environment has also highlighted the larger variability in individual responses, providing valuable insight for refining both the intervention and study procedures before progressing to a full RCT. In addition, objective measurement of participants' baseline behaviours already included elements of the target

TABLE 4 | Sleep quality during baseline and intervention ($n = 20$).

	Baseline mean (SD)	Intervention mean (SD)	Change from baseline to intervention mean (95% CI)[c]
Accelomerometer measured			
Sleep period time, min	521.4 (56.1)	499.8 (54.2)	−21.6 (−56.9, 13.6)
Sleep efficiency, %	87.6 (6.5)	87.7 (7.1)	0.1 (−4.3, 4.4)
Wake after sleep onset, min	60.6 (36.0)	59.0 (37.0)	−1.5 (−24.9, 21.8)
Number of awakenings, n	20.1 (9.6)	17.4 (6.8)	−2.6 (−7.9, 2.7)
Total Sleep time, min	456.1 (53.6)	437.8 (57.4)	−18.2 (−53.8, 17.3)
PSQI measured			
Global score[a]	6.7 (2.73)	5.7 (2.9)	−1.0 (−2.1, 1.4)
Subjective Sleep quality[b]	1.1 (0.4)	1.1 (0.6)	0 (−0.3, 0.3)
Sleep latency	1.2 (1.0)	0.9 (1.1)	−0.3 (−0.6, 0.0)
Sleep duration	0.4 (0.5)	0.6 (0.7)	0.2 (−0.1, 0.5)
Habitual sleep efficiency	0.7 (0.9)	0.5 (0.7)	−0.2 (−0.6, 0.2)
Sleep disturbances	1.5 (0.5)	1.15 (0.5)	−0.35 (−0.6, −0.1)
Use of medication	0.75 (1.2)	0.5 (1.1)	−0.25 (−0.6, 0.1)
Daytime dysfunction	1.1 (0.6)	1.0 (0.8)	−0.1 (−0.5, 0.3)

[a]Global score out of 21 points, with '0' indicating no difficulty and '21' indicating severe difficulties in all areas.
[b]Component scores are out of a total of 3 points, with '0' indicting no difficulty and '3' indicating severe difficulty.
[c]Estimated using a mixed effects regression analysis with all days of data and participant as a random effect.

behaviour (habitual interruptions to evening sitting time), which likely constrained the magnitude of observable change.

Changing behaviour in a free-living setting is challenging, and as with many interventions it seems very unlikely that the magnitude of effects observed in experimental trials will be maintained in a free-living setting. Nevertheless, performing activity breaks as a means to interrupt evening sedentary time was feasible in the sample of adults, but performance of this behaviour dissipated over time. Furthermore, interrupting evening sitting produced small improvement in self-rated sleep quality and did not negatively impact 24-h movement patterns, glycaemic control or blood pressure. This intervention should be tested in a fully powered effectiveness randomised controlled trial with a longer follow-up to evaluate real-world scalability and impact.

Author Contributions

Jennifer T. Gale, **Elaine A. Hargreaves**, **Jillian J. Haszard**, and **Meredith C. Peddie:** conceptualization. **Jennifer T. Gale**, **Elaine A. Hargreaves**, **Jillian J. Haszard**, and **Meredith C. Peddie:** methodology. **Jennifer T. Gale**, **Jillian J. Haszard**, and **Meredith C. Peddie:** formal analysis. **Jennifer T. Gale**, **Meredith C. Peddie**, and **Jillian J. Haszard:** investigation. **Jennifer T. Gale:** resources. **Jennifer T. Gale:** data curation. **Jennifer T. Gale**, and **Meredith C. Peddie:** writing – original draft preparation. **Jennifer T. Gale**, **Elaine A. Hargreaves**, **Jillian J. Haszard**, and **Meredith C. Peddie:** writing – review and editing. **Jennifer T. Gale** and **Meredith C. Peddie:** supervision. **Jennifer T. Gale:** project administration. All authors have read and agreed to the published version of the manuscript.

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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.

Peer Review

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Figure S1:** Boxplots of mean glucose, glucose variability (SD), and AUC for all-day and evening periods at baseline and during the intervention. **Table S1:** Activity breaks performed during the first and last 3 days of the intervention. **Table S2:** Accelerometer measured 24 h movement patterns during the first and last 3 days of the intervention. **Table S3:** Accelerometer measured sleep during the first and last 3 days of the intervention. **Table S4:** Glucose outcomes on days and evenings during baseline and intervention ($n = 18$). **Table S5:** Mean self-perceived capability, opportunity and motivation to change evening sitting behaviour scores at baseline and end of 2-week intervention.