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Application of N-of-1 Experiments to Test the Efficacy of Inactivity Alert Features in Fitness Trackers to Increase Breaks from Sitting in Older Adults

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Summary

Background—Frequent breaks from sitting could improve health. Many commercially available fitness trackers deliver vibration alerts that could be used to cue sitting breaks. As a potentially pragmatic approach to promote frequent breaks from sitting, we tested the efficacy of inactivity alerts among obese older adults, a highly sedentary population.

Methods—We conducted 10 sequential N-of-1 (single-case) experimental ABA trials. Participants (mean age = 68, mean BMI = 35) were monitored for a baseline phase (“A1”) followed by an intervention phase (“B”). The intervention was then removed and participants were monitored to test an experimental effect (reversal “A2” phase). Total time in the study was limited to 25 days. During the intervention phase (“B”), participants used fitness trackers to stand up or move every time they received an alert (every 15 or 20 minutes of inactivity). Participants wore activPAL devices to measure breaks from sitting each day. Randomization tests were used to determine whether the number of breaks was significantly higher during the “B” phase than the two “A” phases.

Results—Breaks were higher by 7.2 breaks per day during the “B” phase compared to the mean of the “A” phases. Seven out of 10 participants had more sitting breaks during the intervention phase which subsequently decreased during the reversal “A2” phase (combined p-value < .05).

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Ethical Statement

This study was reviewed and approved by Group Health Research Institute’s Institutional Review Board.

Conflict of Interest

The authors declare that they have no conflicts of interest.

Conclusion—Inactivity alert features within commercially available devices are efficacious for promoting modest improvements in breaks from sitting among older adults with obesity and could be a simple health-promoting strategy in this population.

Keywords

Physical activity; sedentary behavior; aging; chronic conditions; sensors

1. Introduction

One in 10 adults owns a wearable fitness tracking device and only 20% of users are over age 55 [1]. Yet as the older adult population grows, such devices could support improvements in physical activity, particularly for those with chronic conditions that physical activity can help treat or control [2]. Several studies now report using interventions that include fitness trackers in populations with chronic health conditions including women at-risk for breast cancer, people with chronic obstructive pulmonary disorder, and people with back pain [3, 4, 5, 6]. While several studies have demonstrated the reliability, validity, and acceptability of these devices [6, 7, 8, 9], few studies have isolated the specific features of fitness trackers that are efficacious.

Given that sedentary behaviors are ubiquitous and that research now shows such behaviors to be detrimentally related to various health outcomes, there is a need for approaches that could reduce population levels of sedentary time. The Sedentary Behavior Research Network defines sedentary behavior as “any waking behavior characterized by an energy expenditure < 1.5 [metabolic equivalents] while in a sitting or reclining posture” [10]. This is distinguished from the term “inactivity” which refers to doing less than recommended moderate-to-vigorous intensity physical activity [10]. There is increasing evidence specifically linking sedentary behavior to health risks including obesity, type 2 diabetes, and cardiovascular disease [11]. Recent laboratory studies suggest that breaking up 30-minute bouts of sitting with standing for 5 minutes can improve insulin levels, glucose, and non-esterified fatty acids [12]. Older adults are highly sedentary spending about 9.4 hours per day in sedentary time [13]. Interventions to reduce older adult sedentary time are beginning to proliferate and show promising results though effects have been modest with decreases in sitting time of about 30 minutes per day with very little impact on breaks from sitting [13, 14, 15, 16].

One possible solution exists within a common feature of many commercially available fitness trackers (e.g. Jawbone Up band) called inactivity alerts. Inactivity alerts allow users to set the tracker to subtly vibrate at various time periods (e.g. every 15, 30, or 45 minutes) when the user is inactive; alerts do not happen when the user is being physically active. However, the alerts could be easily repurposed as a cue to take breaks from sitting or lying down. There is currently no data from randomized studies demonstrating the specific efficacy of these devices for increasing breaks from sitting. Yet there is a need to determine whether these alert features are acceptable to users and effective for increasing breaks from sitting in free-living settings.

The prompts provided by commercially available fitness trackers may be particularly important for bringing more awareness to the inherent automaticity of sitting behaviors, particularly according to theories of habit formation [17, 18]. Without specific behavior change strategies designed to continually remind individuals to be more conscious of their sitting habits, frequent disruptions in sitting are unlikely to occur. Furthermore, according to operant conditioning principles, the Jawbone Up band alerts serve as a cue in the environment which elicits breaks from sitting [19]. Such cues have been an efficacious behavior change strategy for improving physical activity in older adults [20, 21]. Interestingly, the majority of prior studies in older populations did not provide specific cues and prompts to help individuals form new habits that promote more conscious decision-making around whether to take a break from sitting. Indeed, these prior studies did not find significant improvements in breaks from sitting [14, 15, 16]. One exception is a recent study that provided health education and goals to take breaks from sitting using a choice of tools to prompt breaks from sitting (e.g. phone or computer apps, vibrating watch, timers) among working and retired middle aged and older adults[22]. Results showed a significant increase in breaks from sitting (13 additional breaks per day) [22]. Despite the promise of this prior study, there is a need for theory-based studies that evaluate the efficacy of single simple strategies that are more scalable and could improve public health by helping individuals form new habits around their sitting behaviors.

N-of-1 (single-case) designs allow rapid completion of an experimental study. This nimble approach is appropriate for evaluating technology interventions in part because randomized controlled trials are slow and costly with technologies often becoming obsolete by the time results are available [23, 24, 25, 26]. In an N-of-1 design, each participant is their own control and experimenters systematically introduce and withdraw control and intervention conditions to see the impact on behaviors across replications of different participants [26]. N-of-1 designs are not quasi-experimental designs; rather they are fully experimental and include controls and replications which meet criteria for establishing causality [26]. We leveraged this methodology to experimentally determine whether inactivity alerts embedded in commercially available fitness tracking devices increase breaks from sitting. Furthermore, we sought to understand the acceptability of using inactivity alerts as one concern has been that frequent alerts could be too annoying or disruptive. Our target study population was adults over 60 with obesity as this group reflects a growing population that could benefit from increased breaks from sitting [27, 28, 29]. In addition, this group has substantial barriers to engaging in physical activity (e.g. health difficulties, fatigue, pain) [30, 31, 32]. If inactivity alerts promote increased breaks from sitting, encouraging greater uptake among populations with chronic conditions could be a highly practical and low cost health-promoting strategy.

2. Methods

The study occurred from May 2015–December 2015 in Seattle, WA. Ethics approval was obtained from the Group Health Research Institute’s institutional review board.

2.1 Recruitment

Participants were recruited from a health care system located in Washington State. Electronic health record data were used to select a recruitment sampling frame consisting of randomly selected adults over age 60 with a BMI ≥ 30 kg/m² that lived in Seattle, WA. Letters explaining the study and requesting that interested individuals call a study phone line were mailed in waves until the study was filled. A research assistant screened individuals for eligibility over the phone. Inclusion criteria obtained during the phone call included self-reported ability to: stand up from a seated position, walk one block without assistance, and read and speak English. Exclusion criteria included self-report of having fallen in the past three months and already taking breaks from sitting 5 or more times per hour. After giving oral consent to participate, participants were scheduled for an in-person baseline visit.

2.2 Study Design

We conducted 10 sequential N-of-1 experimental study designs (i.e. ABA design).

For the current study, participants completed a baseline monitoring-only phase (i.e. “A1”), an intervention phase (i.e. B), and a reversal monitoring-only phase (i.e. “A2”). The lengths of each A and B phase were randomly assigned such that the minimum number of days for each phase was 5 days and the total number of days in the study was constrained to 25 days. Five days was selected as the minimum because in activity monitoring studies this is considered the amount of data needed to estimate habitual behaviors [33]. By randomizing the length of study phases, we controlled for known and unknown time-related variables that could threaten the internal validity of our study and allowed for a statistical test based on the randomization of the moments of phase change as it was implemented in the study design [34, 35, 36].

2.3 Procedures

Participants were met at their local health care clinic by a study staff member for an in-person measurement visit. At the visit, participants had their height and weight, waist circumference, and blood pressure measured and completed a self-reported survey to collect information on demographics and current health status. Participants were fitted with a thigh-worn activPAL device (described in more detail in the measures section below). They were provided with daily monitoring logs to record their sleep time and activPAL wear time for all days, plus fitness tracker wear time during the intervention phase only. Each participant was also provided with a tailored schedule detailing the date ranges for each phase of the study.

2.4 Baseline Monitoring-only (“A1”) Phase

During the first (baseline) “A1” phase, participants wore the activPAL on their thigh and completed their daily wear logs. They were instructed to go about their normal routine.

2.5 Intervention (“B”) Phase

For the intervention phase of the study, participants were provided with a Jawbone Up band or Pivotal Living band on their wrist that was set to vibrate after either 15 minutes or 20

minutes of inactivity respectively. The two devices were used interchangeably as they had identical functionality but we wanted to test whether a very affordable device (Pivotal Living band) was as acceptable as a more expensive device (Jawbone Up band) to support more cost-effective studies in the future.

On the last day of participants' "A1" phase, they received a package containing either a Jawbone Up or Pivotal Living band with instructions on how to wear and charge the device. The package was received by courier with clear instructions to open it upon waking up the following morning. Participants were also given written instructions to stand up and walk around for 1–2 minutes whenever they felt the device vibrate if they were sitting. If they were unable to walk around when they felt the prompt, they were asked to stand up and sit right back down. Based on the available settings, the Pivotal Living band was set to vibrate every 20 minutes and the Jawbone Up band vibrated every 15 minutes of inactivity. Participants were provided with an envelope to mail the device back to study researchers the morning after the last day of their "B" phase. They were also given a midpoint survey to complete on the last day of their "B" phase which they mailed back with the device.

2.6 Reversal "A2" Phase

Following removal of the device, participants continued wearing the activPAL for a reversal monitoring-only period to assess the impact of our experimental manipulation. The morning following their last day in the reversal phase, participants mailed their activPAL back to study researchers. After all materials had been received by the research team, participants were sent feedback charts with summaries of their average daily step count, number of breaks from sitting, and hours spent standing, sitting, and stepping for each study phase. They were then scheduled for a phone-based exit interview.

2.7 Measurement

Throughout the duration of the study (up to 25 days), participants wore an activPAL micro (PAL Technologies Ltd, Glasgow, UK). The activPAL is unobtrusive, very light (10 grams), and small (5 mm thick). The activPAL is considered the most valid device for measuring free-living sedentary behaviors. It assesses time spent sitting/lying, standing, and stepping and the number of sit-to-stand transitions [37, 38]. This device has been used with older adults [39]; it is more sensitive to change [40] and has higher validity in comparison to direct observations than accelerometers [37].

The activPAL was adhered to the front, center thigh using a medical waterproof dressing so that it could be worn 24 hours a day for the entire study period. Some individuals preferred to take the device off while sleeping and this was allowed. All participants kept sleep logs to determine non-wear time. Participants were shown how to apply the device and were given written instructions with photographs to ensure it was properly reapplied throughout the study.

Devices were initialized to count any sit-to-stand transitions lasting 1 second or more. The outcome measurement of interest was the number of sit-to-stand transitions per day. The battery life of the activPAL is approximately 14 days. Halfway through the 25-day study period, participants were couriered a newly charged replacement device. The activPAL data

were processed using proprietary activPAL software. Crude data files were downloaded from the activPAL device in 15-second epochs, and non-wear and sleep time were removed using Stata 13 (Version 13.1, StataCorp, College Station, Texas). Day-level data were dropped from analysis if the activPAL was not worn or did not record data for more than 7 waking hours.

2.8 Exit Interview

After completion of the study, participants underwent a 30-minute semi-structured interview with a trained research assistant. Interviews were audio-recorded and transcribed. The key purpose was to collect feedback on participants' perceptions of the acceptability, wearability, and usefulness of the prompting devices as an intervention to encourage people to take more breaks from sitting throughout the day.

2.9 Sample Size and Study Design Calculations

N-of-1 designs are standalone experiments, the external validity of which is estimated by sequential replication [41]. Following that rationale, we chose to replicate each experiment with a total of 10 subjects. The statistical power of each N-of-1 experiment for a randomization test was calculated a priori using the Single-Case Randomization Tests (SCRT) package [42] for R [43]. Statistical significance was set at $p < .05$. Given an ABA design with a total of 25 observations and a minimum length of 5 observations per phase, we estimated a total of 66 possible permutations, which rendered a minimum possible p-value of 0.015. Since this ABA design configuration allowed us to reach our target p-value, we proceeded to randomly generate 10 individual phase length sequences using the SCRT package for R [42]. Sequences were then assigned to each incoming participant sequentially [43, 44].

2.10 Analysis

An algorithm was developed in Stata to remove non-wear and sleep time from participants' activPAL data using information taken from participants' daily wear logs. Data were collapsed from 15-second epochs into daily summaries. Averages for each ABA phase were also summarized for each participant.

Randomization tests were used to test the null hypothesis of no intervention effect. A test statistic was calculated for each participant by taking the value of the difference between the mean of the intervention phase and the mean of the two "A" phases. A randomization distribution was generated by keeping the observed number of breaks from sitting fixed and calculating a test statistic for all 66 possible permutations of study phase lengths, keeping the requirements of a 5-day minimum per phase and the total of 25 days. The observed test statistic was then compared to the randomization distribution and the p-value was calculated by taking the proportion of test statistics equal to or greater than the observed test statistic. P-values for all 10 participants were calculated and then combined using Edgington's additive method [35] to determine whether there was a general significant result across all of the study participants. Effect size was calculated using a standard measure in N-of-1 design research, the percentage of data exceeding the median of the baseline phase (PEM). This metric ranges from 0% to 100%, with scores of 100% indicating that all data points in the

intervention condition exceeded the median of the control condition. If the treatment had no effect, it would be expected that half of the observations in the treatment phase would be above the median of the baseline phase. Thus, PEM under the null hypothesis is 50% and higher PEM scores translate to a greater effect size. A PEM of <70% is considered questionable or not effective, between 70% and 90% is considered moderately effective, and >90% is considered highly effective [45]. All statistical tests were conducted at an α level of 0.05 with a one-tailed test using SCRT v1.1.1 package for R [42]. To find the combined p-value and PEM scores, we used Single-Case Meta-Analysis (SCMA) package for R [46].

Visual inspections of the data were also conducted to see the effects of the intervention on daily number of breaks from sitting. Graphical representations of the data were developed plotting number of breaks per day on the y-axis and time on the x-axis. All graphs were developed using Single-Case Visual Analysis (SCVA) v1.1.1 package [47] for R.

Due to insufficient wear time or mechanical failures, 9 out of 250 days of data (3.6%) were replaced with median values of the respective phase. One day was dropped because the participant's first activPAL ran out of batteries the day before it was switched out. Four of these days were dropped because the second activPAL stopped recording in the afternoon on day 25. Four days were dropped because the participants did not wear the activPAL for more than 7 hours of their waking time. Rather than ignoring missing data, we used a single imputation method to replace missing values as described in a previous paper [48]. We used a median substitution method rather than the null hypothesis method to impute missing values due to the null hypothesis method being overly conservative [49]. Missing values were replaced with the median of the corresponding phase. In addition to the quantitative data, interview responses to questions about how the device affected their daily life are summarized to provide a participant perspective on acceptability.

3. Results

Recruitment letters were mailed to 75 individuals, and 19 expressed interest in participating. Of these, 7 were ineligible and 2 opted not to participate. A total of 10 participants were enrolled, and all participants completed 25 days of observation. Average activPAL waking wear time was 15 hours and 12 minutes per day, not including days with missing data.

3.1 Demographics

Participants were on average 68.3 years of age (SD = 7.6, range = 60–80), 30% were men, 60% a college or higher degree, 40% were retired, and 30% worked full or part time. The sample was 80% white with 20% not specifying their race or ethnicity. Regarding health conditions, 60% reported high blood pressure, 30% high cholesterol, and 33% arthritis. The mean BMI was 35.2 (SD = 2.8, range 30.9–39.7).

3.2 Changes in Breaks from Sitting

The number of breaks from sitting per day varied widely from participant to participant, as can be seen in Table 1. The highest average number of breaks per day during the baseline phase was 94.9 while the lowest was 42.1. The difference in the daily number of breaks from sitting between the “B” and mean of the two “A” phases also varied considerably from

participant to participant with the largest positive difference being 28.5 and the largest negative difference -10.5 . After averaging breaks from sitting for each study phase across all participants, the difference between the “B” and the mean of the two “A” phases was 7.22 breaks per day. Visual inspection of Figure 1 suggests that across N-of-1 trials, the intervention phase (B) led to an increase in breaks from sitting as compared to baseline (“A1”), and that when removed, it led to reduced breaks from sitting (“A2”). Overall, breaks from sitting were lower during A2 than A1. PEM effect sizes ranged from 40% to 100%. Six (P1, P2, P3, P6, P8, P10), out of 10 individuals had PEM values above 70%, with P10 obtaining a PEM of 100%. The pooled PEM effect size was 71%, which is considered moderately effective under the Scruggs’ et al. criterion [50]. Seven participants experienced reductions in breaks from sitting after removal of the intervention in the reversal condition, and 3 among them (P2, P6, and P10) had statistically significant p-values. P-values for individual participants ranged from 0.03 to 0.80. The combined p-value was 0.04.

Figure 2 shows graphs of each participant’s daily breaks from sitting plotted against study day with a dashed line representing the mean of the study phase. Visual inspection of the graphs suggests that wearing the prompting device did have an effect on breaks from sitting during the intervention phase. Seven out of 10 participants engaged in more breaks from sitting during the intervention phase than during their baseline and second “A” phases. This pattern is particularly pronounced when looking at graphs for P6 and P10. Three participants (P3, P4, P9) had lower average daily breaks from sitting during the intervention phase than their baseline phase. However, two of these (P3, P4) had higher breaks during the intervention than during their “A2” phase.

3.3 Changes in Other Metrics

There were no significant differences in daily sitting, standing, stepping time and step count between the intervention phase and the two “A” phases (see Table 2). Averaged across all participants, the length of daily standing time during the intervention phase was 17 minutes longer and daily sitting time was 14 minutes shorter. Participants also took 325 steps more, on average, during the intervention phase.

3.4 Qualitative Analysis

3.4.1 Acceptability of the Device—Participants generally had neutral or positive feedback on using the devices and found the devices acceptable to use. All reported that the devices were comfortable to wear, unobtrusive, and easy to use. Two participants had difficulty figuring out how to charge the Jawbone. No participants reported a prior history of using a device that had an inactivity alert.

3.4.2 Use of Inactivity Alerts—Table 3 summarizes participant descriptions of how they used the inactivity alerts in daily life. In response to the vibrations, individuals reported engaging in a variety of behaviors including briefly walking across the room, doing chores or productive activities, or helping others. Nearly all participants reported that the 15–20 minute setting was acceptable. For example, one person reported: “The vibration alert was – it seemed like it was an appropriate strength and duration in order to get your attention” (P9). Three participants reported they would have preferred less frequent prompts. One

person reported that they “disliked [Jawbone] intensely” and that it “Made me feel like a jack in the box” (P10). This participant thought the device should be set to vibrate less frequently such as every 30 minutes.

Nearly all participants reported willingness to use such inactivity alerts for longer than their study period. Participants ranged from willingness to wear it for 60 days up to indefinitely. Several participants reported finding other ways to prompt breaks from sitting after having to send back the device which could have led to sustained improvements in breaks from sitting during the reversal “A2” phase. One found a way to stand at work and use the automatic overhead lights which turn off every 15 minutes to remind her to stand up and turn the light back on (P3). Another set alarms on their cell phone (P6). One participant started setting a timer on their stove to remind them to keep taking breaks (P7).

3.4.3 Benefits of Inactivity Alerts—Overall participants felt that the alerts were not particularly disruptive and many looked forward to them: “There might have been once or twice where I kind of thought it was [disruptive]. But after a while, I did basically go like, ‘Oh, good, I can move. I have to move’” (P6). The majority reported that the device helped them become more aware of how much sitting they did in their daily life, serving as an effective cue to spark an inner dialogue with themselves about how active or inactive they had been throughout the day. This often served as motivation to stand up or move: “Well it just made me aware. I wasn’t aware before. I just wasn’t keeping track, and I sort of do that in my head now, and if I feel that I’m sitting, I can keep track by just checking the clock on the television if I’m watching it, and if it’s a certain amount of time that’s gone by, I’ll just get up” (P7). It was also helpful when participants viewed the cue as a flexible time frame for standing or moving and not feeling they had to do so at the exact moment they received the alert.

Nearly all participants recognized potential health benefits of using such a device to break up their sitting, including improving leg strength, mobility, sleep, joint stiffness, and circulation. One person stated, “It just allows you that extra few minutes to breathe and sort of take your mind off of it and refresh you and then come back to it. You might come back with a fresh thought on whatever you [were] doing or something” (P6). The participant who had a more negative view on the device reported that it did result in less stiffness (P10). Another participant noted, “Yeah, it’s helped me a lot. In fact, since I first started wearing it, I think I’ve lost about four pounds just in reminding me to keep moving. It was great” (P7). This participant found that going through the study helped them get through a difficult family loss and reported, “...mentally I feel better because I’m moving around more” (P7). One participant reported not believing that just standing up would promote better health (P4).

3.4.4 Barriers to Following Inactivity Alerts—Participants reported a variety of barriers including not feeling alerts, social norms, health problems that impede movement and annoyance if the device vibrated when they were trying to concentrate or when they were already moving. Some reported habituating to the vibration and not always feeling the alerts after a few days of wear. Others were slightly annoyed that the device sometimes gave an alert when they were standing, doing light activity, or in a vehicle and wished the

manufacturers could improve its accuracy (P8, P10). Overall, few health-related barriers were reported though one participant had a flare-up of multiple sclerosis that made it harder to stand up (P5).

Many reported that the device alerts pushed against social norms of sitting still while in public venues (movies, concerts) and during meetings, meals, or transportation. People dealt with these concerns in different ways. Some stood up anyway and at times explained the need to stand up or move; they, in part, used the device itself as the rationale and may not have felt as comfortable standing up without wearing a device. Some ignored the prompts while in meetings or at concerts. Others were willing to respond to the alerts in some contexts (e.g. at home, watching TV) but not others (e.g. when out in public). One participant stood up a few times when they received alerts while riding the bus though it was received with odd looks by some (P9). Another let their boss know they needed to sit in the back of a meeting auditorium in order to take breaks from sitting (P3). Participants also reported that being immersed in a task that required concentration or needed to be done while sitting contributed to their decisions to ignore the prompts at times.

4. Discussion

We found some support for the efficacy of inactivity alerts to increase breaks from sitting in adults over age 60 with obesity, a population that could greatly benefit from sedentary behavior reduction. The alerts improved breaks from sitting by a modest ~7 breaks per day. Our reversal condition indicated that when removing the device participants tended to take fewer breaks from sitting. Interestingly, many participants took fewer breaks during the reversal phase than the baseline phase. This could suggest an exhaustion effect of the intervention, some reactivity to the activPAL during the first few days of wearing it, or that individuals needed to keep using the fitness tracker which was supported by their views during interviews. If exhaustion occurred, it will be important for future studies to provide supportive interventions that gradually build towards a desired number of breaks from sitting over time. Given that no other intervention was provided except for the wearable device, effects could be even larger if paired with coaching or other contact through a mobile health technology. For example, a coach or mobile technology could help problem-solve barriers to responding to alerts such as social norms that made it difficult to respond to breaks.

The magnitude of our effect was modest. We had larger improvements than prior studies in older adults (using the same activPAL measurement device) that did not use inactivity alerts and found increases of 2 or fewer breaks per day [14, 15, 16]. However our improvement was smaller than an intervention for middle-aged and older adults (without obesity) that included a goal to take an additional 30 breaks from sitting per day as well as provided prompts and health education (13 additional breaks per day) [51]. However, in the context of a population that has low levels of physical activity and high sedentary time, our findings represent a potentially promising and simple approach. Whether this level of improvement results in meaningful changes in health outcomes should be examined in future studies.

Participants had small, non-significant reductions in sitting time (~17 minutes/ day) and increases in standing time (~14 minutes/day) during the intervention “B” phase that

disappeared in the reversal phase. There was also a small non-significant increase in stepping time and step counts between the initial “A1” phase and “B” phase that was maintained during the reversal phase. This suggests that the increase in breaks from sitting does not substantially alter time spent sitting, standing, and engaging in physical activity. Breaking up prolonged periods of sitting, even without concomitant changes in sitting, standing, or stepping time, could promote improved health. One recent study indicated that 5-minute standing breaks every 30 minutes can improve markers of cardio-metabolic health over the day [12].

Qualitative participant data suggest high acceptability and satisfaction with using the prompting devices. Only one person found the prompts irritating but this same individual suggested they would have preferred the prompts to alert every 30 minutes rather than every 15 minutes. Most people used the device with a flexible mindset and easily ignored the prompts if it was a non-ideal time to take a break from sitting or in the event that the device alerted them while they were standing or moving about. Many participants did report concerns about defying social norms. That being said, many were willing and able to take breaks from sitting when prompted even in social settings. At the same time, many made the decision not to take breaks from sitting when in public venues or during meals, asserting boundaries with the technology. Other common barriers to responding to inactivity alerts included needing to concentrate, doing activities that required sitting, and health problems. However, the fact that few health barriers were reported indicates that the focus on breaking up sitting time could be a highly feasible approach for older adults with obesity.

N-of-1 designs are a method that can be applied to obtain experimental data in a short timeframe to inform larger clinical trials in an efficient manner. They are also a favorable study design for exploring the processes and outcomes of health behavior interventions [52]. In particular, the reversal ABA phase design utilized in this study allowed us to observe an increase in breaks from sitting when the inactivity alerts were introduced and a subsequent decrease in breaks when the intervention was removed; this observation strengthens our evidence that the inactivity alerts had a direct effect on participants’ daily number of breaks from sitting.

Study limitations include a small sample size, technical difficulties with the activPAL leading to the loss of some data, and the short study duration. The use of a rigorous study design helps lessen concerns around small sample sizes. Additionally, the finding that breaks from sitting were lower during the reversal phase than the baseline phase is counter to the fact that participants reported many internal rewards from increasing their breaks from sitting. Therefore we would have expected either continued behavior change or slightly lower levels than the intervention phase but not lower than the baseline phase. One potential reason for the reduced level of breaks could be reactivity to initially wearing the activPAL which could have resulted in a higher baseline rate of breaks from sitting than usual. Another explanation could be that participants experienced exhaustion from the intervention and therefore it functioned as a competing contingency with the aforementioned internal rewards. Finally, it is possible that a higher rate of internal rewards was needed to make the inactivity alerts reinforcing in the long run. Further investigation of the longer term effects of inactivity alerts and what happens to behavior when alerts cease is warranted. Another

limitation is that we were unable to examine breaks from sitting in relation to when inactivity alert cues were given. Future studies will be needed to determine whether inactivity alerts are feasible, acceptable and effective to use for longer durations in a population aging with chronic conditions and whether there are any health impacts.

In sum, a cost-effective way to promote breaks from sitting could involve the use of inactivity alert features of commercially available fitness trackers. In combination with motivational coaching and other behavior change techniques, the effect on breaks from sitting could be larger within a population in great need of health-promoting interventions.

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Figure 1.

Average daily breaks from sitting across each Phase of all N-of-1 trials ($n = 10$). A1: Baseline; B: Intervention; A2: Intervention Reversal.

Figure 2.

Plots of daily breaks from sitting by study day for each participant. Baseline (A1), Intervention (B), and Reversal (A2) Phase means represented by dashed lines.

Table 1

Average daily number of breaks from sitting by study phase.

Participant	A1	B	A2	β	*	P-value	PEM**
P1	94.86	104.71	101.41	6.58	0.379		71%
P2	85.23	91.64	66.20	15.93	0.030		71%
P3	52.40	48.80	39.60	2.80	0.621		80%
P4	49.00	42.00	37.40	-1.20	0.364		44%
P5	44.86	47.27	45.80	1.94	0.515		69%
P6	63.40	79.17	66.29	14.32	0.030		83%
P7	61.33	70.90	69.00	5.73	0.227		60%
P8	47.44	56.00	49.00	7.78	0.424		75%
P9	65.67	53.00	61.50	-10.58	0.803		40%
P10	42.13	66.25	33.33	28.52	0.030		100%

Pooled PEM effect size: 71% (combined p-value = 0.04)

* = mean of baseline (A1) and reversal (A2) phases

** Percentage of data points exceeding the median of the control condition

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Table 2

Mean activPAL outcome measures.

Phase	Step count	Stepping hours	Standing hours	Sitting hours	Breaks from sitting
A1	7073	1.57	4.87	8.78	60.6
B	7771	1.65	5.15	8.49	66.0
A2	7820	1.67	4.87	8.68	57.0
B - *	325	0.03	0.28	-0.24	7.2
p-value	0.55	0.47	0.48	0.24	0.04

* = mean of baseline (A1) and reversal (A2) phases

Table 3

Participant quotes regarding acting on inactivity alerts.

Participant	Quote
P1	I would sometimes stand up and say if you can't start walking around, you can just stand up at least. So I did that. ... It was hard to do because like I said, I have to concentrate on my reading and studying quite a bit.
P2	If I could, if I wasn't in a situation where I was in some place where I'm tied to the chair, I would get up and walk around the room a little bit, or look out the window.
P3	...when I am sitting at my desk in the back room, I tend to sit here for hours and being reminded to get up every 15–20 minutes was excellent. Because it's something I know I should do but I'm not real good about doing it. ...Generally speaking, if the band vibrated, I got up...sometimes I would walk for a few minutes. Sometimes I would just kind of pace the room for 10–15 seconds. There was a three-hour meeting for faculty and staff and I just told the head master, "I'm going to be sitting at the end of the row and I'm gonna be getting up every 20 minutes." And I did.
P4	It was a good reminder that I have been sitting for a while. The only thing I did not like about it that sometimes even when I was active, moving, or in the kitchen – working in the kitchen standing up, it would buzz. And I said: "What is it reminding me of? I'm standing." It's annoying after a while. So that's the only thing. But otherwise, it was fine. It's a good reminder. And maybe the intervals should be a little longer.
P5	I remember one night I was sitting down and I was at my book group...and I stand up. I say, "Excuse me, I've got to stand up." And then I explained the study and all that.
P6	If I'm at work and sometimes I was in the middle of something where I couldn't move right then and there. But maybe within the next five minutes or so, ten minutes at the most, I would get up and move. Leave the desk area, go walk, or what have you.
P7	It was just, yeah, if I would sit down and get engrossed in some silly thing on television, then it would remind me to get up and I would get up and move around. I have my TV where I can do my chores as well, so it just helped me, I think it really met the criteria of helping me not sit. So I felt real positive about it.... I would get up and, I don't know, empty the dishwasher or step outdoors for a little bit with my dog, you know, just doing small activity but still enough that it would make me feel like I didn't really need to sit back down again because I would get interested in something else, just like a little kid getting engrossed in front of the television I guess. So I really changed my behavior, especially in the mornings when I would, I just felt that if the weather was permitting, I didn't need to go up and read for an hour, I could just go outside, and that's usually what I would do.
P8	Most of the time I would stand up and walk around the room for a short time and sometimes I would just stand up and sit back down within 30 seconds to maybe one minute.... Sometimes it wasn't possible. I think I was at the show one time and it was going off once in a while. I was at a lecture one time and I couldn't possibly stand up no matter what... When I watched TV I think it was useful. Because then I could say oh, maybe I ought to get up and walk around. That's fine. Good idea. But other than that it wasn't very useful except for that in my opinion.
P9	At home I always tried to act on it. Like even the situations where my wife and I would be watching a TV program and it would vibrate and then I would just stand up. ...So the first time I had to do that I said, "Okay, it's this thing telling me to do it." And she just kind of nodded her head like, "Oh, okay." Then after that when I would stand up when we were watching TV for ten, 20 seconds then I would sit back down, she would know that it's because of that. So, yeah, if I were at home, generally I would act on it.
P10	Okay, the ones where I acted on it, if I was sitting here watching TV, I would act on it no problem. If I was reading, I would act on it, but I would be irritated because I don't like being interrupted. You lose your concentration. If I was doing puzzles, I would get up and act on it because that's not a big deal. That wasn't a problem. If I was in the car, I would not. If I was sitting having a meal, I refused.