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Effect of an office-based intervention on visceral adipose tissue: The WorkACTIVE-P randomized controlled trial

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Abstract

Office-based activity reduces sedentariness, yet no randomized controlled trials (RCTs) have assessed how such activity influences visceral adipose tissue (VAT). This study examined the effect of an office-based, multicomponent activity intervention on VAT. The WorkACTIVE-P RCT enrolled sedentary office workers (body mass index: 31.4 standard deviation [SD] 4.4 kg/m^2) to an intervention (N=20) or control (N=20) group. For three months, the intervention group received an office-based pedal desk, further to an intervention promoting its use and increased walking. The control group maintained habitual activity. At baseline and follow-up, VAT, cardiometabolic disease markers, physical activity, and food intake were measured. Steps/day were not altered relative to control (P≥0.51), but the pedal desk was utilized for 127 (SD 61) min/day. The intervention reduced VAT relative to control (−0.15 kg; 95% confidence interval [95% CI] = −0.29, −0.01; P=0.04). Moreover, the intervention decreased fasting glucose compared to control (−0.29 mmol/L; 95% CI = −0.51, −0.06; P=0.01), but no differences in other cardiometabolic disease markers or food intake were revealed (P≥0.11). A multicomponent intervention decreased VAT in office workers who were overweight or obese. Though longer-term studies are needed, office-based, multicomponent activity regimens may lower cardiometabolic disease risk. Trial registered at ClinicalTrials.gov (NCT02561611).

Keywords

sedentary behavior; physical activity; cardiometabolic health; pedal desk; walking; workplace

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CONFLICT OF INTEREST STATEMENT: Dr. Tudor-Locke and her husband, Gerald Locke, co-invented and own intellectual property for the Pennington Pedal Desk™, which was built with support from the Pennington Medical Foundation. Dr. Corby Martin served as the Principal Investigator and Dr. Tudor-Locke had no contact with study participants or study data. The intellectual property surrounding the Remote Food Photography Method© and SmartIntake® application are owned by Louisiana State University/ Pennington Biomedical Research Center and Dr. Martin is an inventor. All other authors declare no conflicts of interest, and the study sponsor and funders had no role in the study design, data collection, data analysis, data interpretation, writing the report and the decision to submit the report for publication.

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INTRODUCTION

Sedentary behavior increases the risk of obesity, type 2 diabetes, cardiovascular disease (Wilmot et al. 2012), cancer (Biswas et al. 2015), and mortality (Diaz et al. 2017). Although the mechanisms have yet to be elucidated, sedentary behavior can lead to the development of excess visceral adipose tissue (VAT) (Slentz et al. 2005), which is linked to poor blood glucose regulation, insulin resistance, and cardiometabolic conditions (Bluher 2016). Decreasing sedentary time and increasing physical activity are consequently strategies that could attenuate VAT and deleterious metabolic issues.

Reducing sedentariness within the workplace is important since occupational sitting is the largest contributor to weekday sitting (Miller and Brown 2004). Researchers have attempted to decrease sedentary behavior within the workplace by integrating active workstations, principally through sit-stand desks and/or treadmills (Koepp et al. 2013; John et al. 2016; Bergman et al. 2018). These strategies appear to reduce sedentary time (Koepp et al. 2013; Bergman et al. 2018), but their influence on VAT is unclear. In a non-randomized single-arm trial, John et al. (2016) found that a treadmill workstation, which increased stepping time by 38 min/day after 9 months reduced waist circumference, a surrogate measure of VAT. Conversely, another treadmill intervention that stimulated an 18 min/day increase in walking did not change waist circumference (Bergman et al. 2018). These discrepancies illustrate the need for randomized controlled trials (RCTs) assessing workstations on direct measures of VAT. Moreover, changes in other cardiometabolic disease markers and food intake in response to such workplace regimens need to be evaluated. Indeed, the effect of workplace interventions on cardiometabolic changes is equivocal (John et al. 2016; Healy et al. 2017; Bergman et al. 2018), whilst alterations in food intake may mitigate beneficial effects of increased physical activity (Martin et al. 2019).

The promise of treadmill workstations notwithstanding, administrative and human resource difficulties suggest the adoption of these stations may not be sustainable (Tudor-Locke et al. 2014a). As a response to these challenges, we have studied the influence of a pedal desk in office settings (Proença et al. 2018). This is a semi-recumbent, pedal-based workstation that contains an adaptable desktop, enabling users to sit and complete tasks on a computer monitor whilst pedaling at a desired intensity (Proença et al. 2018). Encouragingly, the pedal desk has been acceptable to users (Proença et al. 2018), elevates energy expenditure (Tudor-Locke et al. 2014b), and acutely enhances insulin sensitivity after a meal (Han et al. 2018). While these studies indicate the pedal desk may improve metabolic function, the chronic effects of the pedal desk have not been studied, and many workplace interventions have evoked no changes in adiposity and cardiometabolic risk markers (Bergman et al. 2018). It is thus possible that larger improvements in VAT and cardiometabolic risk markers could be obtained if the pedal desk was implemented together with a simple daily walking-based strategy, which would potentially lower sedentary time further in combination with the office-based intervention.

Our primary objective was to test the effect of a 3-month, multicomponent pedal desk and daily walking intervention delivered in the workplace on VAT in office workers who were overweight or obese. We hypothesized that the intervention group would realize a decrease

in VAT compared to a control group. Our secondary objectives were to examine changes in other cardiometabolic risk markers and food intake in response to the multicomponent intervention.

METHODS

Ethics

The WorkACTIVE-P study was a 3-month parallel RCT performed between June 2016 and May 2018 (ClinicalTrials.gov Identifier: NCT02561611) by Pennington Biomedical Research Center (Baton Rouge, LA). The center's IRB approved the procedures and protocol of the WorkACTIVE-P study, and all outcome measurements were collected by Pennington Biomedical Research Center staff. All participants provided written informed consent prior to enrollment, and a data and safety monitoring board oversaw the study. All outcome assessors and investigators were blind to participant allocation, whereas participants, the project manager and interventionists prescribing and supervising the intervention were not blinded (single-blinded). Cessation of the trial occurred when the desired sample size had completed the study.

Study sample

We approached corporations in Louisiana that we have worked with previously for similar office interventions (Tudor-Locke et al. 2014a). The workplaces comprised a mixture of open- and closed-based spaces that had adequate room for our pedal desks. After meetings with the facilities' directors, human resources representatives, information technologists, department supervisors, and wellness coordinators, email and telephone communications were utilized within a site to recruit participants. No racial or gender biases occurred during the selection of corporations and participants.

We recruited office workers from five corporations whose job descriptions mainly required sitting-based administrative duties such as filing, scheduling, interacting via email and telephone, attending meetings, etc. To be eligible, participants had to be 18-64 years of age, overweight/obese, have a waist circumference > 102 cm (men) or > 88 cm (women), and satisfy at least one of the four defining criteria for metabolic syndrome, namely triglycerides ≥ 1.7 mmol/L, high-density lipoprotein (HDL) cholesterol < 1.0 mmol/L (men) or < 1.3 mmol/L (women), resting blood pressure ≥ 130 mmHg systolic and/or fasting glucose ≥ 5.6 mmol/L. Participants also had to be sedentary; that is, they averaged < 7500 steps/day at baseline (as measured by step counters, described below) and indicated in response to direct query that they "mostly sit during the day at work and do not walk about very much". Exclusion criteria included high resting blood pressure (systolic > 179 mmHg and/or diastolic > 99mmHg), cardiometabolic disease—Type 1 or Type 2 diabetes, serious arrhythmias, cardiomyopathy, congestive heart failure, stroke, transient ischemic cerebral attacks, peripheral vascular disease with intermittent claudication, and uncontrolled angina —and other medical conditions that would significantly impede conduction of the intervention or collection of outcome measures.

Experimental design

Interested participants received orientation, run-in, and screening visits to determine eligibility and indicate whether they could cope with the rigors of the study (Figure 1). The orientation was a 1-hour visit that detailed the procedures of the trial. During the run-in visit, descriptive characteristics, blood pressure, and medical history were obtained. Participants deemed eligible at this stage completed a screening visit at which a fasting blood sample was taken. Participants were additionally provided an accelerometer (GT3X+, ActiGraph, LLC, Pensacola, Florida, USA) and were instructed to wear this for seven days. This served to examine the participants' ability to comply with the wearing requirements of objective physical activity monitoring devices. If participants failed to wear the accelerometer for at least four days with at least ten hours of wear time recorded on each day, their compliance was deemed inadequate and they were excluded. Participants who complied with this requirement were deemed eligible and the data obtained from the 7 days of monitoring was utilized to determine if participants were sedentary (< 7500 steps/day).

Approximately 16 days after the screening visit, eligible participants completed a baseline visit at which all baseline measures (see below) were assessed. Participants were also randomized into a 3-month intervention or control arm. Randomization occurred via a computerized pseudo-random number generator by the study statistician, with equal numbers allocated to each group. Participants were notified of group allocation through sealed and numbered envelopes, which were provided by the project manager or interventionist.

Participants assigned to the control group were asked to maintain their typical work and lifestyle habits. By contrast, those assigned to the intervention arm received a combined behavior support program that aimed to promote use of a pedal desk and increase daily walking. The intervention focused on optimizing two components of the Social Cognitive Theory: self-efficacy and social support (Bandura 1986). Specifically, goals were set for both interventional components and these were scrutinized during weekly or biweekly phone contacts and scheduled group meetings with interventionists who had backgrounds in kinesiology or psychology and had experience delivering behavior change interventions. Individual meetings were also scheduled with interventionists in the participants' workplace when necessary and convenient. During contact time with participants, interventionists utilized methods that developed self-monitoring and goal fulfillment, including the provision of objective data detailing use and performance on intervention tools, as well as instructions on how to monitor these as part of the intervention. To further enhance feedback during contact sessions, data from intervention tools were transferred via the internet to interventionists, enabling remote programmatic oversight and tracking. Participant goals were highly specified and accounted for variations in work and personal schedules. For example, a participant may have been set a goal to use their pedal desk for 1 accrued hour/day but over time lift their goal up to 4 or more hours/day, depending on work schedules that may have required attendance at events/meetings outside of their office on short notice.

Intervention tools

The Pennington Pedal Desk™, which has been described before (Schuna et al. 2016), has been rated positively during computer-based tasks in office-based workers (Proença et al. 2018). Briefly, the pedal desk provides a maneuverable, fully automated tracking and intervention system that encompasses the user, the desk, and specialized pedal desk tracker software (Schuna et al. 2016). Participants randomized to the intervention group had a pedal desk placed in their usual workspace. To promote prolonged pedaling, a non-adjustable magnetic braking system provided a flywheel resistance of ≈0.30 kilopounds, which aimed to yield power outputs of 12-36 W when pedal rates were 30–90 revolutions per minute (Schuna et al. 2016). Furthermore, in accord with the intervention's goal to allow participants to monitor their usage, the pedal desk was designed to provide a real-time display of revolutions per minute and the time of pedal desk use via a pop-up box that appeared on the computer monitor (Schuna et al. 2016). Such tracking measures are important, as other measures of physical activity do not effectively monitor seated activity (Nelson et al. 2016). To facilitate attainment of pedal-based goals and address low usage, participants were trained to independently use aspects of the pedal desk tracking software, including how to interpret graphical displays in the pop-up box that illustrated time of use and distance, which was estimated from a product of wheel revolutions and wheel diameter (Schuna et al. 2016). These illustrations could present daily, weekly, and monthly accrued data, and were readily available to pedal desk users. We intended to transfer and retain this data via the internet within the system so interventionists could direct participants to achieve pedaling goals and we could accurately characterize pedal desk use. However, our software experienced technical faults when capturing the revolutions per minute data, and 15 participants in the intervention group (75%) reported problems with the tracking software. We consequently were unable to obtain estimates of power and energy expenditure as we had intended. Instead, we have used time of use as our determinant of pedal desk use as this feature worked more consistently.

The walking component of the intervention was based on the success of previous studies (Chan et al. 2004) and aimed to increase physical activity by ≥ 3000 steps/day. Participants in the intervention group were provided with Fitbit devices (Fitbit Zip, Fitbit Inc., San Francisco, CA) and instructed to wear these for the whole intervention except for water-based activities, such as showering, and during sleep. Fitbits were connected to internet monitoring software, which transferred data to an on-board visual display to track average steps/day. Participants were taught to monitor these data during the trial to facilitate the attainment of individualized stepping goals that were provided by interventionists. Additionally, interventionists obtained steps/day data each week from the Fitbit through internet connectivity and used these data to track compliance and assist participants in meeting specific goals during contact periods.

Outcomes

Body weight, body composition, and adipose tissue—At baseline and month 3, participants' body weight and waist circumference were determined using a Tanita Scale (Arlington Heights, IL, USA) and a non-extensible tape measurer (Gulick II, Sammons Preston, Chicago, IL), respectively.

Measurement of VAT was conducted using a magnetic resonance imaging (MRI) scanner (3.0 T Scanner, General Electric, Excite HD System, Milwaukee, WI), since this provides greater precision than anthropometric and DEXA measurements (Shuster et al. 2012). Participants were assessed in a supine position with their arms placed above their heads. A localizer and coronal images (T2 FGE) were used to locate measurement boundaries defined by the liver and the pubic synthesis. Specifically, images were obtained for the entire anatomy from the highest point of the liver through the pubic synthesis. A total of 240-340 images were acquired per participant. Images were analyzed by a blinded, trained analyst using Analyze™ software (AnalyzeDirect, Overland Park, KS). Total adipose tissue (TAT), VAT, and subcutaneous adipose tissue (SAT) were anatomically defined and quantified.

Following a 12-hour fast, a blood draw was taken to measure glucose, hemoglobin A1c (HbA1c), total cholesterol, and triglycerides (DXC600, Beckman Coulter, Brea, California, USA). High-density lipoprotein levels were also assessed with a DXC600 analyzer (Wako Chemicals, Richmond, Virginia, USA) and low-density lipoprotein (LDL) levels were calculated using the Friedewald equation (Friedewald et al. 1972). Fasting insulin was measured (Immulite 2000, Siemens, Los Angeles, California, USA) and utilized with fasting glucose to calculate homeostatic model assessment of insulin resistance (HOMA-IR) (Matthews et al. 1985). In addition, blood pressure was measured manually twice using a standard sphygmomanometer and an appropriately sized cuff, and the average was recorded. Participants were asked to refrain from consuming alcohol or engaging in physical activity 24 hours prior to these measurements.

Physical activity and sedentary time at baseline and follow-up—For seven days at baseline and seven days prior to trial cessation, sedentary time, physical activity, and steps/day were measured using validated GT3X+ accelerometers (ActiGraph, LLC). This accelerometer has been validated and is able to detect minute-by-minute physical activity using established activity cut points (Freedson et al. 1998; Matthews et al. 2008). These cut-points utilize accelerometer counts per minute (cpm), with < 100 cpm, 100–1951 cpm and ≥ 1952 cpm classified as sedentary time, light physical activity, and moderate-to-vigorous physical activity (MVPA), respectively (Freedson et al. 1998). Participants were instructed to wear accelerometers for approximately 24 hours/day, removing devices for activities involving water. Steps and time-based physical activity endpoints were divided by individual wear times and extrapolated to a 24-hour day in order to account for variations in wear time.

Food intake—Food intake data were captured for seven days at baseline and during the follow-up period with the Remote Food Photography Method © (RFPM) and SmartIntake® app as described elsewhere (Martin et al. 2009). The first 1-2 days represented a run-in period to habituate participants to the procedure, resulting in approximately 4-5 complete days of data per participant. Briefly, the RFPM relies on trained raters to individually estimate the proportion of food items in images captured by participants on an iPhone and compare them with a standard photo with a known portion size of the food being rated. Energy, carbohydrate, fat, and protein intake are then determined from the USDA Food and Nutrient Database for Dietary Studies (Ahuja et al. 2012) and manufacturer information (Martin et al. 2009).

Statistical analysis

The study had 80% power to detect a 21% difference in VAT between groups at the nominal 0.05 whilst accounting for a 10% attrition rate (De Souza et al. 2012). Linear mixed models examined the influence of the intervention on change in outcome measures, with group used as a fixed effect and between-group differences the primary hypotheses of interest. Age, sex, and race were included in preliminary change from baseline models as covariates. Without clear-cut data for clinically meaningful differences in the primary endpoint, absolute Cohen effect sizes (ES) were performed on change scores to supplement findings. Calculations were made by dividing the difference between the mean values by the pooled standard deviation (SD) from the model (Cohen 1988). Cohen ESs were considered small, moderate, and large if they spanned from 0.20-0.49, 0.50-0.79, and 0.80 or greater, respectively (Cohen 1988). Analyses were performed using SAS software version 9.3 of the SAS System for Windows (SAS Institute, Cary, North Carolina). Significance level for all analyses was set at the nominal 0.05, and unless otherwise stated, data are presented as least square (LS) means (95% confidence interval [95% CI]).

RESULTS

Study sample

In total, after exclusions, 20 participants were assigned to each group and all participants completed the intervention and were analyzed for the primary outcome (Figure 1). Trial cessation occurred when the targeted sample size completed the outcomes of the trial. The majority of participants recruited were female (31 [77.5%]) and white (28 [70.0%]), with a mean age of 46.4 (SD 10.5) years and a mean BMI of 31.4 (SD 4.4) kg/m^2. The control and intervention groups were not significantly different with respect to baseline demographic, anthropometric, and adipose tissue measures ($P \geq 0.07$; Table 1). Sedentary time, light physical activity, MVPA, and steps/day, as measured by the ActiGraph, were also similar between groups at baseline ($P \geq 0.39$), as were energy and macronutrient intake ($P \geq 0.27$) and cardiometabolic disease risk markers ($P \geq 0.19$; Table 1).

Physical activity and sedentary time

Participants in the intervention group used the pedal desk for a mean time of 127 (SD 61) min/day (Figure 2A). However, mean steps/day, as assessed with the Fitbit throughout the intervention period, were 6313 (SD 2371), indicating that the intervention did not successfully increase daily walking by the targeted 3000 steps/day (Figure 2B). Similarly, ActiGraph data showed participants in the intervention group did not increase steps/day (−83 steps/day; 95% CI = −946, 780; $P = 0.85$), and no between-group differences were seen ($P = 0.51$; ES = 0.19; Table 2; Supplementary Figure S1). The ActiGraph also revealed no differences in changes in sedentary time, light physical activity, and MVPA between the control and intervention groups ($P \geq 0.27$; ES ≤ 0.31; Table 2; Supplementary Figure S1).

Adipose tissue and anthropometry

Similar changes in SAT and TAT were seen between groups ($P \geq 0.58$; ES ≤ 0.15), yet there was a tendency for a within-group effect for VAT in the intervention group (−0.10 kg; 95%

CI −0.22, 0.01; $P = 0.08$) and the between-group comparison showed VAT was reduced in the intervention group versus control (−0.15 kg; 95% CI = −0.29, −0.01; $P = 0.04$; ES = 0.59; Table 3; Supplementary Figure S2). Change in weight, BMI, and waist circumference from baseline to month 3 did not, however, differ between the intervention and control groups ($P \geq 0.30$; ES ≤ 0.29; Table 3; Supplementary Figure S2).

Cardiometabolic disease risk factors

The intervention engendered a 0.29 mmol/L (95% CI = −0.51, −0.06) reduction in fasting blood glucose relative to control ($P = 0.01$; ES = 0.70), but changes in fasting insulin and HOMA-IR were comparable between groups ($P \geq 0.29$; ES ≤ 0.30; Table 3; Supplementary Figure S3). Change in HDL, LDL, total cholesterol, triglycerides, HbA1c, systolic blood pressure, and diastolic blood pressure were likewise not different between the control and intervention groups ($P \geq 0.11$; ES ≤ 0.45; Table 3; Supplementary Figure S3).

Food intake

The changes in total energy, carbohydrate, fat, and protein intake during the trial were similar between the intervention and control groups ($P \geq 0.11$; ES ≤ 0.47; Table 4; Supplementary Figure S4).

DISCUSSION

Our results show that sedentary office workers who received a 3-month multicomponent intervention, which aimed to increase energy expenditure via a workstation pedal desk and daily walking regimen, reduced VAT by 0.15 kg compared to a control group (0.10 kg within the intervention group alone). Though anthropometry, cardiometabolic disease risk markers, and food (specifically, energy and macronutrient) intake were unaffected, the intervention group also displayed a moderate 0.29 mmol/L decrease in fasting blood glucose relative to the control group.

Previous studies assessing the impact of workplace activity interventions on abdominal obesity have produced mixed results (Koepp et al. 2013; John et al. 2016; Bergman et al. 2018), possibly due to differences in research design and sensitivity of outcome measures. Using a gold-standard VAT measurement tool, which allowed us to detect changes in adipose tissue distribution that are not revealed with traditional measures (Shuster et al. 2012), we showed that sedentary office workers receiving a pedal desk and walking intervention displayed a 0.10 kg reduction in VAT (0.15 kg [8%] decrease in VAT compared to a control group). Most studies have used waist circumference as a proxy of VAT (Healy et al. 2017; Bergman et al. 2018), though as we demonstrated, moderate reductions in VAT occurred in the intervention group compared to the control group without observable differences in waist circumference. It is possible that the MRI allowed us to detect changes in adipose tissue distribution that were not revealed with traditional anthropometric measures (Shuster et al. 2012). The VAT changes could translate to health benefits, since increased VAT—through decreased adiponectin, greater inflammatory cytokine release, and a greater enrichment of regulatory proteins involved in the lipid cascade and increased lipolysis (Laurencikiene et al. 2011)—leads to greater activation of pro-inflammatory

pathways, which are associated with cardiometabolic disease (Bluher 2016). Although we cannot fully infer the mechanisms mediating the VAT changes in our study, the multicomponent regimen may have led to greater oxidation of VAT in the intervention group compared to the control group.

We also observed a 0.36 mmol/L reduction in fasting blood glucose in the intervention group (0.29 mmol/L reduction relative to the control group). Healy et al. (2017) found a 12-month standing intervention in workers' reduced fasting blood glucose by 0.34 mmol/L compared to a control group, although our results suggest that a combined pedal desk and daily walking intervention can induce similar improvements in metabolic function over a shorter period. It is possible the decrease in VAT in the intervention group relative to the control group herein suppressed adipocyte inflammation, stimulating the increase in adipocyte glucose uptake and the reduction in glucose concentrations in the plasma (Karpe and Pinnick 2015; Bluher 2016). Such deductions are nonetheless speculative, and further mechanistic studies, including those with measures of inflammation, are needed to understand the interconnections between reduced sedentary time, increased physical activity, VAT, and blood glucose.

Our multicomponent intervention did not improve body weight or other cardiometabolic disease risk markers, including HOMA-IR and HbA1C, in spite of the improvements in VAT and blood glucose. Although some researchers have shown workplace activity programs can improve these outcomes (John et al. 2016), our findings are in line with RCTs showing no changes in body weight, insulin, HbA1c, cholesterol, triglycerides, and blood pressure in response to regimens aimed to decrease sedentary time (Healy et al. 2017; Bergman et al. 2018). Our findings are particularly consistent with Healy et al. (2017) who, despite finding improvements in blood glucose, found their workplace activity program did not induce improvements in fasting insulin or HOMA measures. Further studies incorporating larger sample sizes are likely required to detect small improvements in body weight and cardiometabolic disease risk factors seen with these interventions (Healy et al. 2017). Simultaneous dietary strategies alongside our multicomponent intervention may also be necessary to induce larger energy deficits and greater improvements in weight and cardiometabolic disease risk markers.

Increased energy expenditure can lead to an elevation in food intake (Dorling et al. 2018), but changes during and after workplace interventions are not well characterized. Bergman et al. (2018) reported that participants provided with a workplace treadmill desk for 13 months appeared to decrease their energy intake, whereas another study documented no change in energy intake after a 9-month treadmill intervention (John et al. 2016). Similar to John and colleagues, we found that energy and macronutrient intake were unchanged when comparing the intervention and control groups over the trial, though daily energy intake in our trial seemed low and this qualifies our conclusions. This is at odds with studies suggesting that compensatory rises in food intake occur in response to *exercise* training (Turner et al. 2010; Martin et al. 2019). The reasons for these differences are not known, though it is possible that our very low-intensity regimen was not sufficient in triggering participants to perceive food as a reward for their raised activity (Dalton et al. 2013), meaning they were less likely

to increase food consumption. Likewise, it is possible our measure of energy intake was not sufficiently sensitive in this relatively small study.

To our surprise, although we implemented similar strategies that have successfully elevated steps/day in a previous study (Tudor-Locke et al. 2004), our intervention did not elevate step count by our target, and no changes in sedentary time, steps/day, or time-based measures of physical activity intensity were apparent. Work-related conflicts and the pressure to produce outputs in the workplace may have been too great for (some of) our participants to find time to augment their daily walking (Tudor-Locke et al. 2014a). Moreover, participants may have preferred the pedal desk to daily walking in this multicomponent intervention, as demonstrated by the relatively high engagement in that former aspect (127 min/day, on average). Activity on the pedal desk was unlikely to be tracked by the accelerometer or Fitbit and was thus possibly misclassified as sedentary time (Nelson et al. 2016), despite the time-based data from the pedal desk showing work-related activity was enhanced. Taken together, these findings could suggest that the pedal desk may have been the pivotal driver of the positive changes in VAT (Proença et al. 2018). This could have implications for adults in office settings because these individuals spend most working days confined to accrued bouts of sedentary behavior (Neuhaus et al. 2014). However, the intervention had two components (pedal desk and walking) and further work is needed to test the relative impact of different office-based activities—pedal desks, walking regimens, and treadmill desks—on reducing sedentary time and improving cardiometabolic risk markers. Such studies would ascertain the best office-based practices for metabolic health (Thompson and Levine 2011).

Limitations of our study include the relatively short duration, small sample size, and the potential individual level randomization, which may have led to treatment contamination between groups. Substantially larger controlled studies with durations beyond three months and cluster randomization are consequently needed. We also did not control for seasonal variations in weather, which could have affected step count outside of the office (Tucker and Gilliland 2007). Furthermore, our in-house pedal desk software was ultimately unable to consistently record reliable revolutions per minute data, making it difficult for participants and researchers to precisely characterize pedal desk use other than by duration of use. Though problems like this are liable to occur in settings akin to those in our trial, and our experiences are likely to inform longer-term studies in realworld environments where confounding factors are manifold (Tudor-Locke et al. 2014a), refinements in technical software are needed.

Conclusions

In summary, we showed that sedentary office workers who received a 3-month combined pedal desk and walking intervention reduced VAT and blood glucose compared to a control group. Longer-term, well-powered studies are now needed to ascertain the efficacy of individual components of the regimen and various workstation alternatives in reducing sedentary behavior and ameliorating cardiometabolic issues in workplaces.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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REFERENCES

Ahuja JKC, Montville JB, Omolewa-tomobi G, Heendeniya KY, Martin CL, Steinfeldt LC, Anand J, Adler ME, Lacomb RP, and Moshfegh AJ 2012 The USDA food and nutrient database for dietary studies, 5.0. Available from https://www.ars.usda.gov/ARSUserFiles/80400530/pdf/fndds/fndds5_doc.pdf [accessed 20 August 2012].

Bandura A 1986 Social foundations of thought and action: A social cognitive theory *In* PrenticeHall series in social learning theory. Prentice Hall, Englewood Cliffs, New Jersey.

Bergman F, Wahlström V, Stomby A, Otten J, Lanthén E, Renklint R, Waling M, Sörlin A, Boraxbekk CJ, Wennberg P, Öhberg F, Levine JA, and Olsson T 2018 Treadmill workstations in office workers who are overweight or obese: a randomised controlled trial. The Lancet Public Health 3(11): E523–535. doi:10.1016/S2468-2667(18)30163-4. [PubMed: 30322782]

Biswas A, Oh PI, Faulkner GE, Bajaj RR, Silver MA, Mitchell MS, and Alter DA 2015 Sedentary time and its association with risk for disease incidence, mortality, and hospitalization in adults a systematic review and meta-analysis. Annals of Internal Medicine 162: 123–132. doi:10.7326/M14-1651. [PubMed: 25599350]

Bluher M 2016 Adipose tissue inflammation: a cause or consequence of obesity-related insulin resistance? Clinical Science 130: 1603–1614. doi:10.1042/CS20160005. [PubMed: 27503945]

Chan CB, Ryan DAJ, and Tudor-Locke C 2004 Health benefits of a pedometer-based physical activity intervention in sedentary workers. Preventive Medicine 39(6): 456–462. doi:10.1016/j.ypmed.2004.04.053.

Cohen J 1988 Statistical power analysis for the behavioral sciences *In* Statistical Power Analysis for the Behavioral Sciences. Lawrence Erlbaum Associates, Hillsdale, New Jersey.

Dalton M, Finlayson G, Esdaile E, and King N 2013 Appetite, satiety, and food reward in obese individuals: A behavioral phenotype Approach. Current Nutrition Reports 2(4): 207–215. doi:10.1007/s13668-013-0060-4.

Diaz KM, Howard VJ, Hutto B, Colabianchi N, Vena JE, Safford MM, Blair SN, and Hooker SP 2017 Patterns of sedentary behavior and mortality in U.S. middle-aged and older adults a national cohort study. Annals of Internal Medicine 167: 465–475. doi:10.7326/M17-0212. [PubMed: 28892811]

Dorling J, Broom DR, Burns SF, Clayton DJ, Deighton K, James LJ, King JA, Miyashita M, Thackray AE, Batterham RL, and Stensel DJ 2018 Acute and chronic effects of exercise on appetite, energy intake, and appetite-related hormones: The modulating effect of adiposity, sex, and habitual physical activity. Nutrients 10(9): 1140. doi:10.3390/nu10091140.

Freedson PS, Melanson E, and Sirard J 1998 Calibration of the Computer Science and Applications, Inc. accelerometer. Medicine and Science in Sports and Exercise 30(5): 777–781. doi:10.1097/00005768-199805000-00021. [PubMed: 9588623]

Friedewald WT, Levy RI, and Fredrickson DS 1972 Estimation of the concentration of low-density lipoprotein cholesterol in plasma, without use of the preparative ultracentrifuge. Clinical Chemistry 18(6): 499–502. doi:10.1093/clinchem/18.6.499. [PubMed: 4337382]

Han H, Lim J, Viskochil R, Aguiar EJ, Tudor-Locke C, and Chipkin SR 2018 Pilot study of impact of a pedal desk on postprandial responses in sedentary workers. Medicine and Science in Sports and Exercise 50(10): 2156–2163. doi:10.1249/MSS.0000000000001679. [PubMed: 29864080]

Healy GN, Winkler EAH, Eakin EG, Owen N, Lamontagne AD, Moodie M, and Dunstan DW 2017 A cluster RCT to reduce workers' sitting time: Impact on cardiometabolic biomarkers. Medicine and Science in Sports and Exercise 49(10): 2032–2039. doi:10.1249/MSS.0000000000001328. [PubMed: 28538025]

John D, Thompson DL, Raynor H, Bielak K, Rider B, and Bassett DR 2016 Treadmill workstations: A worksite physical activity intervention in overweight and obese office workers. Journal of Physical Activity and Health 8: 1034–1043. doi:10.1123/jpah.8.8.1034.

Karpe F, and Pinnick KE 2015 Biology of upper-body and lower-body adipose tissue - Link to whole-body phenotypes. Nature Reviews Endocrinology 11(2): 90–100. doi:10.1038/nrendo.2014.185.

Koepp GA, Manohar CU, McCrady-Spitzer SK, Ben-Ner A, Hamann DJ, Runge CF, and Levine JA 2013 Treadmill desks: A 1-year prospective trial. Obesity 21: 705–711. doi:10.1002/oby.20121. [PubMed: 23417995]

Laurencikiene J, Skurk T, Kulyté A, Hedén P, Åström G, Sjölin E, Rydén M, Hauner H, and Arner P 2011 Regulation of lipolysis in small and large fat cells of the same subject. Journal of Clinical Endocrinology and Metabolism 96(12): E2045–E2049. doi:10.1210/jc.2011-1702. [PubMed: 21994963]

Martin CK, Han H, Coulon SM, Allen HR, Champagne CM, and Anton SD 2009 A novel method to remotely measure food intake of free-living individuals in real time: The remote food photography method. British Journal of Nutrition 101: 446–456. doi:10.1017/S0007114508027438.

Martin CK, Johnson WD, Myers CA, Apolzan JW, Earnest CP, Thomas DM, Rood JC, Johannsen NM, Tudor-Locke C, Harris M, and Church TS 2019 Effect of different doses of supervised exercise on food intake, metabolism, and non-exercise physical activity: The E-MECHANIC randomized controlled trial. American Journal of Clinical Nutrition 110(3): 583–592. doi:10.1093/ajcn/nqz054.

Matthews CE, Chen KY, Freedson PS, Buchowski MS, Beech BM, Pate RR, and Troiano RP 2008 Amount of time spent in sedentary behaviors in the United States, 2003-2004. American Journal of Epidemiology 167(7): 875–881. doi:10.1093/aje/kwm390. [PubMed: 18303006]

Matthews DR, Hosker JP, Rudenski AS, Naylor BA, Treacher DF, and Turner RC 1985 Homeostasis model assessment: insulin resistance and β-cell function from fasting plasma glucose and insulin concentrations in man. Diabetologia 28: 412–419. doi:10.1007/bf00280883. [PubMed: 3899825]

Miller R, and Brown W 2004 Steps and sitting in a working population. International Journal of Behavioral Medicine 11(4): 219–224. doi:10.1207/s15327558ijbm1104_5. [PubMed: 15657022]

Nelson MB, Kaminsky LA, Dickin DC, and Montoye AHK 2016 Validity of consumer-based physical activity monitors for specific activity types. Medicine and Science in Sports and Exercise 48(8): 1619–1628. doi:10.1249/MSS.0000000000000933. [PubMed: 27015387]

Neuhaus M, Healy GN, Dunstan DW, Owen N, and Eakin EG 2014 Workplace sitting and height-adjustable workstations: A randomized controlled trial. American Journal of Preventive Medicine 46(1): 30–40. doi:10.1016/j.amepre.2013.09.009. [PubMed: 24355669]

Proença M, Schuna JM, Barreira TV, Hsia DS, Pitta F, Tudor-Locke C, Cowley AD, and Martin CK 2018 Worker acceptability of the Pennington Pedal DeskTM occupational workstation alternative. Work 60(3): 499–506. doi:10.3233/WOR-182753. [PubMed: 30040784]

Schuna JM, Tudor-Locke C, Proença M, Barreira TV, Hsia DS, Pitta F, Vatsavai P, Guidry RD, Magnusen MR, Cowley AD, and Martin CK 2016 Validation of an integrated pedal desk and electronic behavior tracking platform. BMC Research Notes 9: 74. doi:10.1186/s13104-016-1882-0. [PubMed: 26857115]

Shuster A, Patlas M, Pinthus JH, and Mourtzakis M 2012 The clinical importance of visceral adiposity: A critical review of methods for visceral adipose tissue analysis. British Journal of Radiology 85: 1–10. doi:10.1259/bjr/38447238.

Slentz CA, Aiken LB, Houmard JA, Bales CW, Johnson JL, Tanner CJ, Duscha BD, and Kraus WE 2005 Inactivity, exercise, and visceral fat. STRRIDE: a randomized, controlled study of exercise intensity and amount. Journal of Applied Physiology 99: 1613–1618. doi:10.1152/japplphysiol.00124.2005. [PubMed: 16002776]

De Souza RJ, Bray GA, Carey VJ, Hall KD, LeBoff MS, Loria CM, Laranjo NM, Sacks FM, and Smith SR 2012 Effects of 4 weight-loss diets differing in fat, protein, and carbohydrate on fat

mass, lean mass, visceral adipose tissue, and hepatic fat: Results from the POUNDS LOST trial. American Journal of Clinical Nutrition 95(3): 614–625. doi:10.3945/ajcn.111.026328.

Thompson WG, and Levine JA 2011 Productivity of transcriptionists using a treadmill desk. Work 40(4): 473–477. doi:10.3233/WOR-2011-1258. [PubMed: 22130064]

Tucker P, and Gilliland J 2007 The effect of season and weather on physical activity: A systematic review. Public Health 121(12): 909–922. doi:10.1016/j.puhe.2007.04.009. [PubMed: 17920646]

Tudor-Locke C, Bell RC, Myers AM, Harris SB, Ecclestone NA, Lauzon N, and Rodger NW 2004 Controlled outcome evaluation of the First Step Program: A daily physical activity intervention for individuals with type II diabetes. International Journal of Obesity 28: 113–119. doi:10.1038/sj.ijo.0802485. [PubMed: 14569279]

Tudor-Locke C, Hendrick CA, Duet MT, Swift DL, Schuna JM, Martin CK, Johnson WD, and Church TS 2014a Implementation and adherence issues in a workplace treadmill desk intervention. Applied Physiology, Nutrition, and Metabolism 39: 1104–111. doi:10.1139/apnm-2013-0435.

Tudor-Locke C, Schuna JM, Frensham LJ, and Proenca M 2014b Changing the way we work: Elevating energy expenditure with workstation alternatives. International Journal of Obesity 38: 755–765. doi:10.1038/ijo.2013.223. [PubMed: 24285335]

Turner JE, Markovitch D, Betts JA, and Thompson D 2010 Nonprescribed physical activity energy expenditure is maintained with structured exercise and implicates a compensatory increase in energy intake. American Journal of Clinical Nutrition 92(5): 1009–1016. doi:10.3945/ajcn.2010.29471.

Wilmot EG, Edwardson CL, Achana FA, Davies MJ, Gorely T, Gray LJ, Khunti K, Yates T, and Biddle SJH 2012 Sedentary time in adults and the association with diabetes, cardiovascular disease and death: Systematic review and meta-analysis. Diabetologia 55(11): 2895–2905. doi:10.1007/s00125-012-2677-z. [PubMed: 22890825]

NOVELTY BULLETS:

- In WorkACTIVE-P, a multicomponent activity intervention decreased visceral adipose tissue relative to control in office workers
- The intervention also reduced glucose compared to control, though other metabolic risk markers and food intake were not altered
- Such multicomponent interventions could help reduce cardiometabolic disease risk, but longer studies are needed

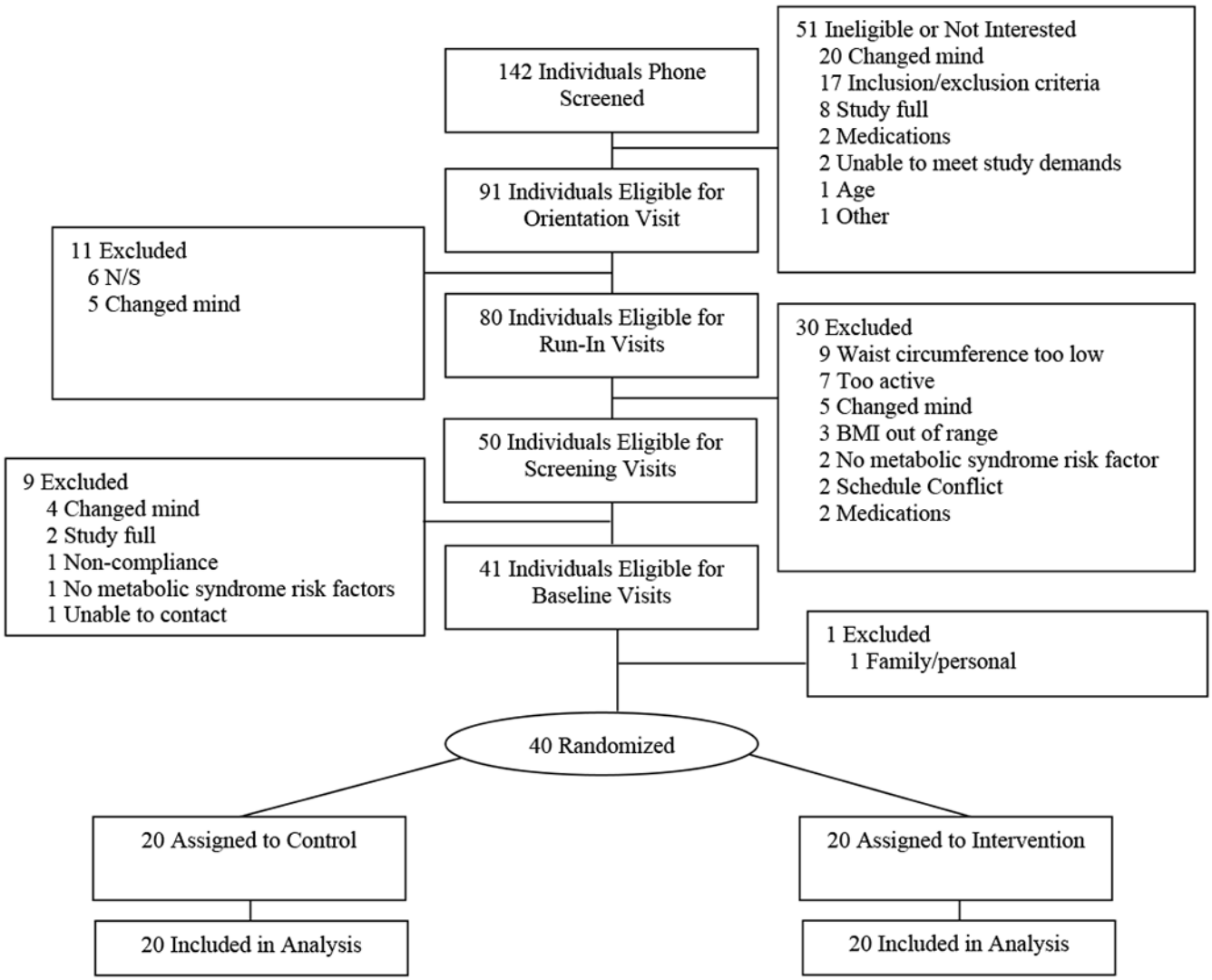

Figure 1.
WorkACTIVE-P flow chart.

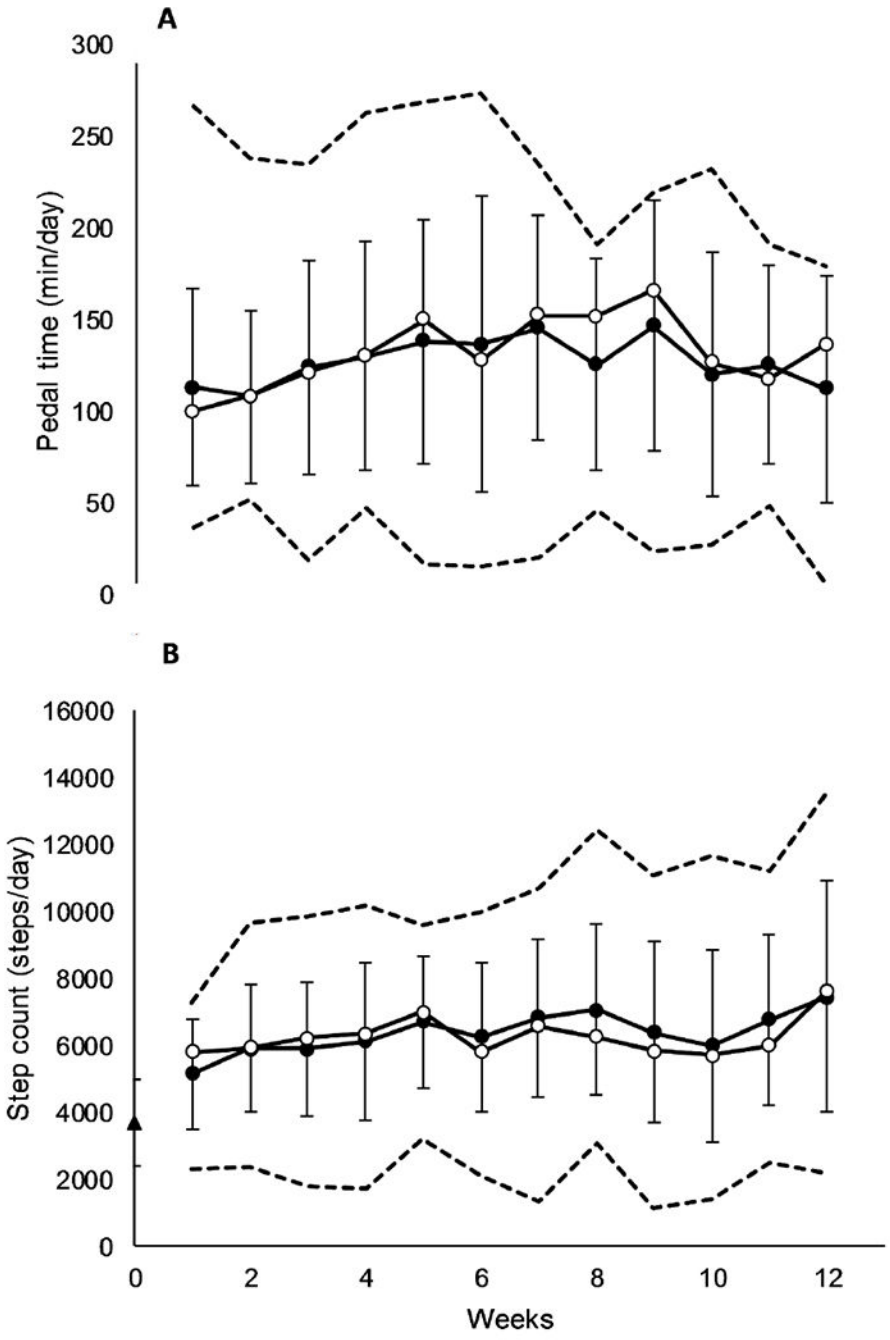

Figure 2.

Average time of pedal desk use (A) and steps/day measured with the Fitbit (B) in the intervention group during the WorkACTIVE-P trial. *Closed circles* represent the mean; *open circles* represent the median; *error bars* represent the standard deviation; *dashed lines* represent the maximum and minimum; *triangle* represents the mean value at baseline derived from the ActiGraph.

Table 1.

Baseline characteristics of WorkACTIVE-P participants.

	Control (N = 20)	Intervention (N = 20)	*P*
Age (years)	46.7 (9.8)	46.2 (11.4)	0.88
Sex			
Male	6 (30.0%)	3 (15.0%)	0.26
Female	14 (70.0%)	17 (85.0%)	
Race			
White	15 (75.0%)	13 (65.0%)	0.49
African American	5 (25.0%)	7 (35.0%)	
Physical activity and sedentary time			
Sedentary time (min/day)	1265 (56)	1249 (63)	0.42
Light (min/day)	165 (52)	181 (61)	0.39
MVPA (min/day)	10 (8)	9 (6)	0.87
Steps/day	3400 (1239)	3722 (1289)	0.42
Adipose tissue and anthropometry			
VAT (kg)	1.93 (1.12)	1.97 (0.92)	0.90
SAT (kg)	7.82 (2.24)	9.78 (4.07)	0.07
TAT (kg)	9.75 (2.80)	11.76 (4.05)	0.08
Height (cm)	166.8 (7.8)	167.8 (8.9)	0.71
Weight (kg)	86.1 (14.0)	89.6 (16.6)	0.48
BMI (kg/m2)	30.8 (3.4)	32.0 (5.3)	0.43
Waist circumference (cm)	98.9 (11.9)	99.1 (10.2)	0.97
Cardiometabolic disease risk factors			
Glucose (mmol/L)	5.15 (0.29)	5.30 (0.61)	0.32
Insulin (uU/mL)	16.6 (18.2)	17.4 (25.0)	0.90
HOMA-IR	3.8 (4.1)	4.2 (5.8)	0.83
HDL (mmol/L)	1.40 (0.33)	1.48 (0.36)	0.47
LDL (mmol/L)	2.84 (0.82)	2.97 (0.71)	0.62
Total cholesterol (mmol/L)	4.89 (0.92)	5.00 (0.96)	0.72
Triglyceride (mmol/L)	1.41 (0.77)	1.20 (0.66)	0.35
HbA1c	5.3 (0.3)	5.4 (0.4)	0.19
SBP (mm Hg)	114.0 (12.0)	116.8 (10.9)	0.44
DBP (mm Hg)	74.1 (6.4)	76.8 (10.4)	0.32
Food intake			
Energy intake (kcal)	1587 (439)	1474 (431)	0.43
Carbohydrate (g)	170 (61)	148 (56)	0.27
Fat (g)	68 (20)	67 (21)	0.83
Protein (g)	70 (15)	65 (20)	0.38

Note: No significant difference between groups ($P > 0.05$).

Values are mean (SD), except for sex and race, which are N (%).

Abbreviations: BMI, body mass index; DBP, diastolic blood pressure; ES, effect size; HbA1c, haemoglobin 1c; HDL, high-density lipoprotein; HOMA-IR, homeostatic model assessment of insulin resistance; LDL, low-density lipoprotein; MVPA, moderate-to-vigorous physical activity; SAT, subcutaneous adipose tissue; SBP, systolic blood pressure; SD, standard deviation; TAT, total adipose tissue; VAT, visceral adipose tissue.

Table 2.

Changes in ActiGraph physical activity and sedentary time in the WorkACTIVE-P trial.

	Control (N = 20)	Intervention (N = 20)	Difference		
	LS mean (95% CI)	LS mean (95% CI)	LS mean (95% CI)	*P*	ES
Physical activity and sedentary time					
Sedentary time (min/day)	36 (2, 70)†	48 (12, 85)†	12 (−31, 56)	0.57	0.16
Light (min/day)	−35 (−67, −2)†	−50 (−85, −16)†	−15 (−57, 26)	0.46	0.21
MVPA (min/day)	−1 (−5, 3)	2 (−3, 7)	3 (−3, 9)	0.27	0.31
Steps/day	−422 (−1236, 391)	−83 (−946, 780)	339 (−702, 1380)	0.51	0.19

†*Note:* Significant within-group difference pre- versus post-intervention ($P < 0.05$).

Abbreviations: CI, confidence interval; ES, effect size; LS, least square; MVPA, moderate-to-vigorous physical activity.

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Table 3.

Changes in adipose tissue, anthropometry, and cardiometabolic disease risk factors in the WorkACTIVE-P trial.

	Control (N = 20)	Intervention (N = 20)	Difference		
	LS mean (95% CI)	LS mean (95% CI)	LS mean (95% CI)	*P*	ES
Adipose tissue and anthropometry					
VAT (kg)	0.04 (−0.07, 0.15)	−0.10 (−0.22, 0.01)	−0.15 (−0.29, −0.01) *	0.04	0.59
SAT (kg)	−0.11 (−0.39, 0.18)	−0.08 (−0.38, 0.22)	0.02 (−0.34, 0.38)	0.89	0.04
TAT (kg)	−0.06 (−0.41, 0.29)	−0.18 (−0.56, 0.19)	−0.12 (−0.56, 0.32)	0.58	0.15
Weight (kg)	−0.3 (−1.3, 0.6)	−0.9 (−1.8, 0.1)	−0.5 (−1.7, 0.7)	0.37	0.25
BMI (kg/m2)	−0.1 (−0.4, 0.3)	−0.3 (−0.6, 0.1)	−0.2 (−0.6, 0.2)	0.30	0.29
Waist circumference (cm)	0.4 (−1.7, 2.5)	0.3 (−1.9, 2.6)	−0.0 (−2.7, 2.7)	0.98	0.01
Cardiometabolic disease risk factors					
Glucose (mmol/L)	−0.08 (−0.26, 0.10)	−0.36 (−0.55, −0.17) †	−0.29 (−0.51, −0.06) *	0.01	0.70
Insulin (uU/mL)	−1.1 (−7.8, 5.6)	−4.6 (−11.7, 2.5)	3.5 (−12.0, 5.0)	0.41	0.23
HOMA-IR	−0.3 (−1.8, 1.3)	−1.3 (−3.0, 0.3)	−1.1 (−3.1, 0.9)	0.29	0.30
HDL (mmol/L)	0.01 (−0.09, 0.10)	−0.03 (−0.12, 0.07)	−0.03 (−0.15, 0.08)	0.58	0.15
LDL (mmol/L)	−0.14 (−0.36, 0.08)	0.09 (−0.14, 0.33)	0.23 (−0.05, 0.51)	0.11	0.45
Total cholesterol (mmol/L)	−0.20 (−0.49, 0.09)	−0.04 (−0.35, 0.28)	0.16 (−0.21, 0.53)	0.38	0.24
Triglyceride (mmol/L)	−0.15 (−0.49, 0.19)	−0.22 (−0.58, 0.14)	−0.07 (−0.50, 0.36)	0.73	0.10
HbA1c (%)	0.00 (−0.07, 0.08)	−0.04 (−0.12, 0.04)	−0.04 (−0.14, 0.06)	0.38	0.25
SBP (mm Hg)	0.8 (−3.7, 5.3)	−0.8 (−5.6, 4.0)	−1.7 (−7.4, 4.1)	0.56	0.16
DBP (mm Hg)	−0.7 (−3.9, 2.4)	−2.3 (−5.7, 1.0)	−1.6 (−5.6, 2.4)	0.43	0.22

* *Note:* Significant difference between control and intervention group ($P < 0.05$).

† Significant within-group difference pre-versus post-intervention ($P < 0.05$).

Abbreviations: BMI, body mass index; CI, confidence interval; DBP, diastolic blood pressure; ES, effect size; HbA1c, haemoglobin 1c; HDL, high-density lipoprotein; HOMA-IR, homeostatic model assessment of insulin resistance; LDL, low-density lipoprotein; LS, least square; SAT, subcutaneous adipose tissue; SBP, systolic blood pressure; TAT, total adipose tissue; VAT, visceral adipose tissue.

Table 4.

Changes in food intake in the WorkACTIVE-P trial.

	Control (N = 20)	Intervention (N = 20)	Difference		
	LS mean (95% CI)	LS mean (95% CI)	LS mean (95% CI)	*P*	ES
Food intake					
Energy intake (kcal)	−64 (−227, 100)	−161 (−339, 17)	−97 (−306, 112)	0.35	0.27
Carbohydrate (g)	−11 (−33, 11)	−6 (−30, 17)	5 (−23, 33)	0.73	0.10
Fat (g)	−1 (−10, 8)	−9 (−19, 1)	−8 (−20, 3)	0.15	0.43
Protein (g)	−4 (−13, 4)	−13 (−22, −4) †	−9 (−20, 2)	0.11	0.47

† *Note:* Significant within-group difference pre-versus post-intervention ($P < 0.05$).

Abbreviations: CI, confidence interval; ES, effect size; LS, least square.

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