Pilot Study of Impact of a Pedal Desk on Postprandial Responses in Sedentary Workers

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ABSTRACT

HAN, H., J. LIM, R. VISKOCHIL, E. J. AGUIAR, C. TUDOR-LOCKE, and S. R. CHIPKIN. Pilot Study of Impact of a Pedal Desk on Postprandial Responses in Sedentary Workers. *Med. Sci. Sports Exerc.*, Vol. 50, No. 10, pp. 2156–2163, 2018. Physical inactivity has been linked to rates of obesity, diabetes, and heart disease through insulin resistance and other mechanisms. Although sedentary workplace environments have unintentionally contributed to the risk for chronic diseases, innovations in the workplace environment could potentially rectify this public and occupational health problem. **Purpose**: To evaluate the effects of light-intensity physical activity using a pedal desk (PD) compared with a standard desk (STD) in a pilot study on postprandial metabolic responses and work skills. **Methods**: Twelve overweight/obese full-time sedentary office workers (six men and six women; body mass index, $28.7 \pm 3.6\ kg \cdot m^{-2}$) were tested in two conditions: 1) PD, pedaling at self-selected light-intensity pace for 2 h and 2) STD, remaining seated for 2 h in a conventional workstation setup while performing scripted computer-based work tasks. Blood samples were analyzed for plasma glucose, insulin, and free-fatty acids in response to a standardized meal and work skills were evaluated. Paired samples *t*-tests were used to examine the differences in metabolic responses and work performance tasks between the conditions. **Results**: Pedal desk use required significantly less insulin to maintain glucose concentrations compared with STD condition (peak insulin concentration, 42.1 $\mu U \cdot mL^{-1}$ vs 66.9 $\mu U \cdot mL^{-1}$; $P = 0.03$; and area under the curve, 302.6 vs 441.8 $\mu U \cdot min^{-1} \cdot mL^{-1}$; $P < 0.001$). No significant changes in plasma glucose and free-fatty acid concentrations were observed at any timepoints (all $P > 0.05$). In addition, pedaling at a self-paced rate caused no adverse effects on work skills ($P > 0.05$). **Conclusions**: The PD resulted in lower postmeal insulin concentrations without an overall negative impact on work skills. Thus, the PD could have the potential to achieve public and occupational health goals in sedentary work environments. **Key Words:** INSULIN, PREDIABETES, LIGHT-INTENSITY PHYSICAL ACTIVITY

APPLIED SCIENCES

Sedentary behavior, defined as waking activities in a seated or reclining posture that require an energy expenditure < 1.5 METs (1), has been linked to an increased risk of obesity and type 2 diabetes (T2D) through increased insulin resistance and abnormal insulin action when controlled for moderate-to-vigorous physical activity levels (2–4). Contemporary growth in business technology has led to decreases in workplace physical activity (5). In fact, excess sitting time in an office-based workplace environment has become the single largest contributor (52%) to total weekday sitting time (6). A recent report on sedentary behavior in the workplace environment concluded that employees spent about two thirds of their working hours (equivalent to approximately 5 h per working day) in prolonged, unbroken periods of sitting lasting > 30 min (7,8).

Just as sedentary behavior induces insulin resistance, physical activity can increase insulin sensitivity and improve insulin action. Even light-intensity physical activity (e.g., transitions from sitting to standing) can positively affect the postprandial elevations of blood glucose and insulin that occur in insulin-resistant individuals (9,10). Sedentary office workers are thus a key target group for reducing prolonged sitting time, or replacing it with even light-intensity activity, with the goal to decrease insulin resistance.

Workplace innovations may be able to help interrupt sedentary behavior and replace it with light-intensity activity and reduce insulin resistance for sedentary employees. Some interventions have demonstrated a benefit of intermittent light-intensity activity breaks on diminishing postprandial metabolic responses (9,11). However, many employees may not have the resources or scheduling autonomy to incorporate light-intensity activity breaks into their workflow. Another approach has been to incorporate light-intensity activity into workplace settings using specially designed "standing desks" or "treadmill desks." However, these workstations can

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have limitations including: 1) a decrease in work performance and motor skills (e.g., typing), 2) limited access for those with musculoskeletal conditions, and 3) feelings of fatigue and discomfort after prolonged standing (12). A recent review concluded that substantial research gaps prevent evaluating the overall effectiveness of standing and treadmill desks to reduce sedentary time and improve health (13).

Desks configured with a seated pedal apparatus (see Figure, Supplemental Digital Content 1, Figure of pedal desk [PD], http://links.lww.com/MSS/B294) could be an important alternative tool for reducing workplace inactivity because they are: 1) self-paced, 2) easier to use for workers with existing musculoskeletal problems or reduced mobility, 3) oriented toward non–weight-bearing activities, 4) minimally disruptive to the primary work-related tasks, and 5) require smaller footprints than treadmill desks in the workplace (12,13). However, their use cannot be advocated without documenting an impact on metabolic consequences of inactivity. The primary purpose of this study was to evaluate the effects of light-intensity physical activity using a PD compared with a control condition using a standard desk (STD) on postprandial glucose, insulin, and fat concentrations in a pilot study among overweight/obese sedentary office workers in a simulated work environment. A secondary aim was to determine the effectiveness of a PD (compared with a STD) on work skills performed during routine sedentary office work.

METHODS

Participants

Participants consisted of 12 (six men and six women) full-time sedentary office workers who were recruited from the Amherst, MA area. The study inclusion criteria required that all participants were overweight or obese (body mass index [BMI], > 25 $kg \cdot m^{-2}$), age 21 to 64 yr, and self-reported employment in a sedentary occupation (i.e., mainly seated during working hours). Individuals were excluded if they self-reported weight > 250 lb (limitation of the prototype PD), recent injuries or other major health conditions (e.g., cancer, heart disease, liver, or kidney disease, etc.), which would prevent using the PD, self-reported diagnosis of diabetes, or a history of reactive hypoglycemia. The study protocol was approved by the institutional review board at the University of Massachusetts Amherst, and written informed consent was obtained from each participant before enrollment in the study.

Study Procedures

Participants attended two separate randomly assigned visits (at least 6 d in between tests) to the laboratory: 1) PD condition, participants pedaled at a self-selected light intensity for the duration of the experiment (120 min) and 2) STD condition, participants remained seated throughout the experimental period in a conventional workstation set up (i.e., an office chair with standard height desk). There were no rest breaks permitted during the experimental period. Participants were asked to maintain their usual sedentary lifestyle and to eat similar diets for the 2 d leading up to testing. At the first visit, additional verbal explanation of the study details was provided as well as an orientation to the use of the PD. Height (cm) was measured on the first visit, and weight (kg) was taken on both visits.

At both experimental visits, participants rested for 20 min and had an intravenous catheter placed in the forearm, which was used for venous blood sampling. After baseline fasting sample collection, the participant was given a standardized meal (i.e., cornflakes, heavy cream and whole milk) with known carbohydrate (75 g) and fat (50 g) content (a total of 837.5 kcal) to be ingested over a 10-min period. Blood samples for glucose, insulin, and free fatty acid (FFA) concentrations were collected every 15 min during the remainder of the postmeal test while participants were performing scripted computer-based work tasks (Fig. 1).

Measures

Anthropometrics. Participant's height was measured to the nearest 0.1 cm using a portable stadiometer (ShorrBoard®; Weight and Measure, LLC, Olney, MD). A dual-frequency total body composition analyzer (Tanita DC-430U; Tanita Corporation, Tokyo, Japan) was used to measure a participant's body weight and BMI. All measurements were taken twice, and a third measurement was taken if the first two measurements of height and weight were greater than 0.5 cm and 0.5 kg apart, respectively. The average of two closest measurements was used for analysis.

Measures of pedaling performance. An accelerometer-based cadence sensor (Garmin Vector™ 2S; Garmin®, USA) paired with a Garmin EDGE® 820 GPS bike computer (Garmin®, USA) was used to continuously track cadence,

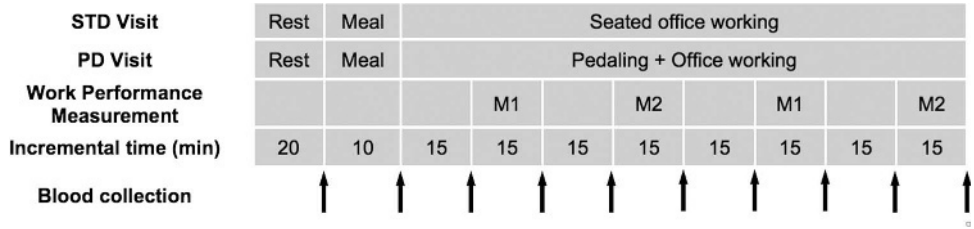

FIGURE 1—Study protocol. M1 represents the timepoint of the measurement 1 including tests for Stroop task and motor speed and accuracy. M2 represents the timepoint of measurement 2 including tests for typing and reading comprehension.

power and total time in pedaling performed for the duration of experiments. A fixed level of flywheel resistance (≈0.30 kiloponds) was used for enabling prolonged duration of pedaling. Participants were not provided with any feedback on their pedaling performances.

Work Skills

Stroop test. A computerized version of the Stroop Test (e.g., Stroop Color and Word Test) was used to assess the participants' executive processing ability, information processing, as well as selective attention capacity and skills (14). The test consisted of three sections with 60 items per section including: 1) black trial—containing 3 color words (i.e., red, blue, and green) displayed in black color; 2) congruent trial—containing the color words displayed in a congruent color (e.g., the word "blue" displayed in blue color); and 3) incongruent trial—containing the color words displayed in an incongruent color (e.g., the word "green" displayed in red color). The three sections were presented to participants in random order with a 30-s rest between sections. At the beginning of the test, participants practiced responding to the experimental stimuli, which were presented at the center of the computer screen and remained on the screen until a response was made, as quickly and accurately as possible by pressing the key corresponding to either *red, blue,* or *green* color. The test was repeated for all participants in the next cycle (Fig. 1). A custom-written MATLAB program (The MathWorks, Inc., Natick, MA) recorded the accuracy of the performance and time to complete each section. The average of the two measurements was retained for analysis.

Mouse proficiency. A mouse clicking and a drag-and-drop tests were performed using a custom-written MATLAB program to determine a participant's computer mouse proficiency (15). In the mouse-clicking test, the participant was instructed to click as quickly as possible on 1 of 25 squares that randomly turned green in color until all squares were clicked. The total time was measured and averaged across tests. Twenty-five squares were located at predetermined positions to ensure that the movement distance was equal across the tests.

The drag-and-drop test involved dragging and dropping an appeared-square into a larger white box located at the bottom of the computer screen. A square appeared until successfully dropped into the box, after which another square on the screen appeared in a random location. The total amount of time taken to complete each test was recorded.

Typing. Typing performance was measured using a typing software program (TypingMaster Pro 10 Premium; TypingMaster, Inc., Helsinki, Finland) to evaluate typing skills (e.g., speed and accuracy) (16,17). Participants were asked to type a nontechnical moderately difficult script for 1 min as quickly and as accurately as possible. Two of four similarly intense scripts were consecutively presented on the screen in a counterbalanced order. The other two scripts were performed at the second visit. Upon completion of typing the scripts, typing speed and accuracy were recorded and averaged.

Reading comprehension. Four graduate record examination (GRE) reading comprehension tests (multiple-choice questions only with one answer choice) were used to assess working cognitive performance. The reading comprehension question of the GRE is designed to test a wide range of abilities to understand, summarize, and analyze information, and has been used in previous studies (15,18). Each test consisted of seven questions of similar difficulty and was timed for completion within 10 min. Two of four tests were randomly administered for the first visit, and the remainder of the tests was used in the second visit. Reading speed and accuracy of responses were averaged for the two tests given under each condition.

Blood Collection, Storage, and Analyses

All the blood samples were collected in vacutainers containing sodium fluoride and potassium oxalate (5:4) mixture (glucose) and ethylenediaminetetraacetic acid (insulin and FFA) and immediately centrifuged at 3300 rpm for 15 min. Plasma samples were subsequently aliquoted into cryotubes and stored in a −80°C freezer until all participants had completed both test protocols.

Glucose: Plasma glucose concentrations were determined using the glucose oxidase method (Analox Instruments, Atlanta GA). Pedal desk and STD samples were analyzed together in duplicate with an interassay coefficient of variability of < 5%.

Insulin: Plasma insulin concentrations were determined using a commercially available radioimmunoassay (Millipore, Billerica, MA). Samples from both trials for each participant were measured in duplicate on the same assay to minimize intra-assay variability, with an interassay coefficient of variability of < 10%.

Free-fatty acids: Circulating FFA concentrations were determined using a colorimetric assay (Sigma Aldrich, St. Louis, MO). Samples were assayed in duplicate with an interassay coefficient of variability of < 10%.

Statistical Analysis

Statistical analyses were conducted using IBM SPSS Statistics 22 for Windows (IBM Corp. Armonk, NY) and SAS/STAT software, Version 9.4 of the SAS System for Windows (SAS Institute Inc., Cary, NC). Descriptive statistics were used to summarize participant characteristics, pedaling performance, and work skills presented as means, SD, counts, and percentages. Linear Mixed Models (PROC MIXED with Toeplitz covariance structure to account for repeated measures) were used to determine main condition effects (PD vs STD) over time for serum glucose, insulin, and FFA levels (adjusted for baseline measures). Where a significant condition–time interaction was observed, the tests of effect slices allowed for comparison of differences in serum glucose, insulin, and FFA levels at each timepoint between the respective conditions. For the primary analysis (linear mixed models presented above), no additional adjustments were made for age, sex, or BMI due to the small

TABLE 1. Participant characteristics and measurements for 2-h pedaling performance.

	Mean (SD) or Pct.
Characteristics	
Age (yr)	38.9 (10.9)
Sex	6 women, 6 men
Height (cm)	170.8 (11.9)
Weight (kg)	83.4 (12.4)
BMI ($kg \cdot m^{-2}$)	28.7 (3.6)
Weight classification	8 overweight/4 obese
Work hours seated/day (self-reported)	8.7 (2.2)
Pedaling performance	
Average total time in pedaling (min)	120.3 (1.9)
Cadence (rpm)	60.50 (10.6)
Power (W)	40.5 (9.2)
Cadence CV in 1-min epoch (%)	9.3
Power CV in 1-min epoch (%)	13.8

CV, coefficient of variation; rpm, revolution per minute.

sample size of this pilot study. However, we conducted an additional (preliminary and exploratory) *ad hoc* examination of the effects of sex, age, and BMI interactions, by adding them to the linear mixed models for glucose, insulin, and FFA. These exploratory results are reported in the Discussion section. Appropriate caution is advised concerning the interpretation of these findings given the small sample size and limited statistical power for these analyses. Additionally, insulin, glucose, and FFA area under the curve (AUC) and incremental AUC (iAUC) were calculated using the trapezoid rule and compared between the two conditions using a paired *t*-test. Cohen's *d* effect sizes were calculated for differences in AUC between conditions, where effect size magnitudes of *d* as 0.2, 0.5, 0.8 were considered small, medium, and large, respectively (19). Statistical significance was set at $P < 0.05$ for all analyses.

RESULTS

The participants recruited for this pilot study were all sedentary office workers (average age of 38.9 ± 10.9 yr), with estimated average time sitting at work as 8.7 ± 2.2 $h \cdot d^{-1}$. These participants were overweight or obese with an average BMI of 28.7 ± 3.6 $kg \cdot m^{-2}$. All participants (six men, six women) completed both PD and STD trials and were included in the analyses. Mean values of participant characteristics and quantified pedaling performance are presented in Table 1. On average, participants pedaled at a cadence of 60.5 ± 10.6 rpm throughout the 2-h PD trial, resulting in a power output of 40.5 ± 9.2 W which falls within the range of 30 to 50 W, consistent with stationary bicycling of "very light to light effort" (20). Pedaling cadence and power output generated remained relatively stable throughout the 2-h PD trial (9.3% and 13.8% of coefficients of variations, respectively) (see Figure, Supplemental Digital Content 2, Example of a single participant's pedaling power output and cadence throughout the 2-h PD trial, http://links.lww.com/MSS/B295).

Mixed Meal Responses

Baseline fasting glucose, insulin, and FFA concentrations were not significantly different between PD or STD conditions (Table 2). Interestingly, nine of the subjects had fasting glucose concentrations between 100 and 126 $mg \cdot dL^{-1}$, consistent with impaired fasting glucose (21). There was no main effect of condition (PD vs STD) on glucose ($P = 0.96$), and there were no significant differences in peak glucose concentration (134.4 $mg \cdot dL^{-1}$ vs 132.3 $mg \cdot dL^{-1}$ for PD and STD, respectively, $P = 0.70$) or plasma glucose concentrations at any of the examined timepoints (all $P > 0.05$). In addition, there was no significant difference in the AUC for glucose (1118.0 $mg \cdot min^{-1} \cdot dL^{-1}$ vs 1122.1 $mg \cdot min^{-1} \cdot dL^{-1}$, $P = 0.87$) (Fig. 2A and B). Furthermore, a Cohen's *d* of 0.02 indicates no differences in glucose AUC between conditions.

A main effect of condition was observed for insulin ($P = 0.004$), as well as a desk–time interaction ($P = 0.04$). Although there were no differences between PD and STD during the initial 30 min of the mixed meal tolerance test, insulin concentrations were significantly lower with the PD than the STD beginning at 45 min and persisting through all subsequent timepoints (test of effect slices for desk–time from 45 to 120 min, all $P < 0.05$) (Fig. 2C). Additionally, the AUC (302.6 $\mu U \cdot min^{-1} \cdot mL^{-1}$ vs 441.8 $\mu U \cdot min^{-1} \cdot mL^{-1}$, $P < 0.001$) and the peak insulin concentration (42.1 $\mu U \cdot mL^{-1}$ vs 66.9 $\mu U \cdot mL^{-1}$, $P = 0.03$) were significantly lower for the PD session (Fig. 2D). In addition, a Cohen's *d* of 0.8 indicates a large effect size for the difference in insulin AUC between conditions.

There was no main effect of condition on FFA ($P = 0.40$), and there were no significant differences between conditions in peak FFA concentration (173.4 $\mu mol \cdot L^{-1}$ vs 175.1 $\mu mol \cdot L^{-1}$, $P = 0.91$) or plasma FFA concentrations at any of the examined timepoints (all $P > 0.05$). There was also no significant difference

TABLE 2. Outcome measures.

	PD		STD		
Tasks	Mean	SD	Mean	SD	*P*
Baseline concentrations					
Glucose ($mg \cdot dL^{-1}$)	113.5	15.8	110.6	13.8	0.31
Insulin ($\mu U \cdot mL^{-1}$)	10.0	5.4	9.2	4.8	0.32
FFA ($mmol \cdot L^{-1}$)	185	47.6	181	53.8	0.79
Stroop test					
Time to complete[a] (s)					
Black	43.77	7.99	44.52	7.13	0.39
Congruent	41.50	7.84	43.79	6.86	0.12
Incongruent	56.31	14.33	55.51	13.05	0.59
Accuracy[b] (%)					
Black	96.73	2.54	96.95	2.02	0.33
Congruent	97.15	2.25	98.26	1.40	0.14
Incongruent	95.76	4.30	95.82	3.10	0.96
Mouse proficiency test					
Time to complete[a] (s)					
Clicking	59.83	5.66	57.65	4.47	0.01
Drag-and-Drop	70.64	8.47	69.24	6.51	0.21
Choice reaction test					
1 key RT[a] (ms)	305.11	42.81	293.22	33.27	0.23
8 keys RT[a] (ms)	573.98	155.10	580.51	136.93	0.69
Typing					
Typing speed[b] (net WPM)	49.31	16.23	46.65	13.55	0.15
Typing accuracy[b] (%)	94.07	5.09	92.50	10.18	0.58
Reading comprehension					
Reading speed[a] (s)	373.42	141.18	395.50	146.72	0.43
Reading accuracy[b] (%)	54.11	17.54	46.99	15.65	0.58

n, number; RT, reaction time; SCWT, Stroop Color and Work Test; Net WPM, word per minute excluding any errors made.
[a]High score is considered worse in terms of work performance.
[b]High score is considered better in terms of work performance.

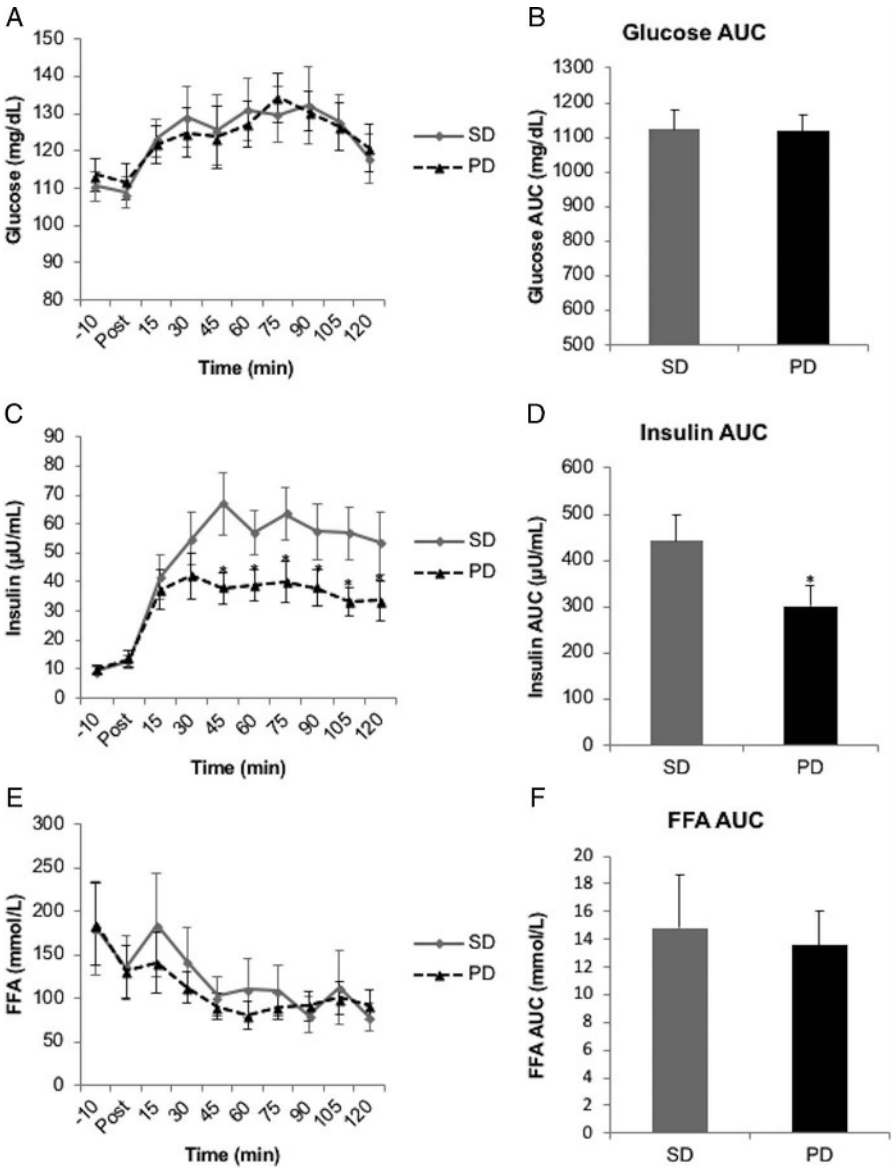

FIGURE 2—The effect of PD and STD conditions on postprandial blood glucose concentration (A); glucose AUC (B); postprandial blood insulin concentration (C); insulin AUC (D); postprandial blood FFA concentrations (E); FFA AUC (F). Data are presented as means ± standard error of the mean. *Significant difference between the conditions at $P < 0.05$.

in the FFA AUC (12.9 mmol·min^{-1}·L^{-1} vs 14.8 mmol·min^{-1}·L^{-1}, $P = 0.29$) between the two conditions (Fig. 2E and F). Furthermore, a Cohen's d of 0.2 also indicates a small (trivial) effect size for the difference in FFA AUC between conditions.

In addition to the standard AUC results presented above and in Figure 2, we also calculated iAUC values (see Table, Supplemental Digital Content 3, AUC and iAUC for responses for glucose, insulin and FFA, http://links.lww.com/MSS/B296). The findings for iAUC followed the same pattern as the standard AUC results, with significant changes only observed for insulin iAUC (213.6 mmol·min^{-1}·L^{-1} vs 358.8 mmol·min^{-1}·L^{-1}; $P < 0.01$).

Work Skills

The work skill measures are summarized in Table 2. Overall, there were no significant differences in any of the measures of work skills between the PD and STD conditions ($P > 0.05$) except one; the mouse clicking response was slower for the PD (mean ± SD, 59.8 ± 5.7 s vs 57.7 ± 4.5 s, respectively; $P = 0.01$). The PD was not significantly different than the STD for either time to complete or response accuracy for the Stroop Test (all $P > 0.05$) which assessed cognitive processing. The response time was shortest for congruent stimuli (mean ± SD, 41.5 ± 7.8 s for PD, 43.8 ± 6.9 s for STD) followed by black (43.8 ± 8.0 s vs 44.5 ± 7.1 s) and incongruent stimuli (56.3 ± 41.3 s vs 55.5 ± 13.1 s); the accuracy rates occurred in the reverse order for both conditions. The speed of information processing measured by reaction time test for 1 key or for 8 keys was not different between PD and STD (1-key RT, 305.1 ± 42.8 ms for PD; 293.2 ± 33.2 ms for STD; 8-key RT, 578.9 ± 155.1 ms for PD, 580.5 ± 136.9 ms for STD). Similarly, in the reading

comprehension test, the PD was not worse than the STD for reading speed or accuracy ($P = 0.43$ and 0.58, respectively).

The PD was associated with a significantly longer response time in mouse clicking compared with the STD condition ($P = 0.01$). However, the average difference between PD and STD was only 2.2 s over approximately 1 min of testing. There were no significant differences (all $P > 0.05$) for other tests assessing computer mouse and typing skills (i.e., Mouse Drag-and-Drop and typing tests).

DISCUSSION

The primary goal of this study was to determine whether use of a PD in a high-risk group of sedentary workers would positively affect postprandial metabolic parameters without negatively impacting work-related activities. Pedal desk use was associated with significant decreases in insulin concentrations beginning at 45 min after consuming a mixed carbohydrate/fat meal relative to STD condition, although no significant changes in plasma glucose and FFA concentrations were observed. In terms of work skills, self-selected light-intensity pedaling while working generally demonstrated no significant differences in the ability to complete work-related activities compared with the STD condition.

The significant decreases in insulin levels from 45 to 120 min and decrease in AUC (large effect size) suggest a benefit of the light-intensity activity resulting from use of the PD. Such a continued light-intensity physical activity has been shown to be effective on improving insulin sensitivity. For instance, an improvement in insulin sensitivity has been reported after replacing sitting time with a long duration minimal-intensity physical activity (e.g., 2-h standing and 4-h walking at a leisure pace) compared with energy-matched 1-h moderate- to vigorous-intensity physical activity in a day (22). An approximately 5% increase in insulin sensitivity can be achieved by replacing 30 min of sedentary time with light-intensity physical activity in those with a high risk of T2D (23). Herein, participants were instructed at the beginning of the PD visit to pedal at a speed that was comfortable for them. They were not coached or reminded to pedal during the test period. Nonetheless, participants pedaled steadily (i.e., without break) for the entire 2 h at a continuous pace consistent with light-intensity physical activity. These current findings suggest that using a PD in a workplace environment is appropriate for sedentary office workers at high risk for T2D to lower postprandial insulin levels.

It is likely that lower insulin concentrations in the postprandial period have the potential to benefit sedentary workers. In addition to potential improvements in insulin sensitivity induced by light-intensity physical activity, lower insulin concentrations realized during the meal tolerance test while using the PD may also be beneficial for beta cell function. Insulin resistance is often recognized as the first step in the pathophysiology linking obesity to T2D (24); however, the transition from normoglycemia to hyperglycemia is characterized by inadequate pancreatic insulin secretion (25,26). The preservation of beta cell function, or the ability to maintain appropriate insulin supply (e.g., secretion), to match increases to insulin demand (i.e., resistance), thus represents a key component of diabetes prevention (27).

The observation that glucose concentrations were similar between trials despite significantly lower insulin concentrations when using the PD suggests that glycemic control during light-intensity pedaling was partially accomplished through skeletal muscle contraction. Contraction-mediated glucose uptake represents a potential mechanism by which insulin secretion can be "spared" while still maintaining normal blood glucose control (28) and has been linked to cardiometabolic health improvements in sedentary adults at risk for T2D (29,30), as well as reduced hyperglycemia in adults with T2D (31,32). Studies evaluating contraction-mediated glucose uptake have often used a moderate-intensity exercise protocol (e.g., 30-min walk after meals), which may not be feasible in an office setting, or may negatively impact work productivity. Results from this study suggest that light-intensity pedaling is sufficient to induce contraction-mediated glucose uptake, without any practical decrements in selected workplace skills. If muscle contractions result in lower circulating insulin concentrations through reduced insulin secretion, light-intensity postprandial cycling may represent a potent means to preserve insulin secretory capacity and beta cell function. Interestingly, the PD may also be able to assess the direct consequences of muscle contractility independent of other factors affected by changes in posture, such as vascular flow.

The lack of significant change in glucose and FFA may have several possible explanations. First, the intensity of the activity performed may have been insufficient to lower glucose concentrations. These participants were not known to have glucose abnormalities and would not have been expected to respond to a meal differently between conditions. The decrease in insulin concentrations associated with use of a PD in a cohort comprised largely of sedentary workers suggests an improvement in insulin sensitivity. We cannot exclude increased clearance as an alternative explanation for the lower insulin concentrations. However, because insulin is not cleared by skeletal muscle, there is no reason to expect light-intensity physical activity to cause an increase in insulin clearance. A second reason for lower insulin concentrations without impacting glucose or FFA might be that the duration of a single 2-h bout of light-intensity activity was insufficient. Greater durations of PD use or repeated bouts may be needed to impact postprandial changes in glucose concentrations. Previous studies have documented postprandial changes after repeated bouts versus a single bout of activity (33). This is feasible to study in the future because the PD could be used throughout the day and on repeated days in an office environment. Third, a greater sample size may be needed to demonstrate a change in glucose or FFA. Review of the FFA data (Fig. 2E) note that samples during minutes 15 to 75 of the PD were apparently (but not significantly) lower for the PD visit compared with the STD. The study of additional participants might provide sufficient analytical power

to demonstrate further separation in these parameters. Lastly, the test meal contained fixed amounts of carbohydrate and fat; the impact of the PD on meals with higher concentrations of fat or carbohydrate might produce different outcomes.

In addition to the primary analyses discussed above, we also conducted an additional *ad hoc* exploration of sex, age, and BMI covariate interactions in the linear mixed model analyses for glucose, insulin, and FFA. For glucose, although there was a main effect for age ($P = 0.02$), there was no desk–age interaction ($P = 0.42$). There were no main or interaction effects for sex or BMI (all $P > 0.05$). For insulin, there were no main effects for sex, age, or BMI (all $P > 0.05$). However, upon closer inspection of the data (test of effect slices for desk–time–sex; and figures [see Figure, Supplemental Digital Content 4, Sex-dependent effects of PD and STD conditions, http://links.lww.com/MSS/B297]), females displayed significantly higher insulin values in the STD versus PD condition from 45 to 120 min (all $P < 0.05$). In contrast, men only displayed a significantly higher insulin value in the STD versus PD condition at 45 min ($P = 0.0055$) and trended toward significance at 60 min ($P = 0.0543$), with all timepoints thereafter not significantly different. For FFA, there was a main effect for sex ($P = 0.02$), and an interaction effect for desk–sex ($P = 0.04$). More specifically, females tended to display higher FFA values overall (sex main effect), but particularly so for the STD condition (desk–sex interaction), as compared with men (test of effect slices for desk–time–sex: STD condition, men vs women from −10 to 105 min, all $P < 0.05$; for PD condition, men vs women from −10 to 15 min, all $P < 0.05$, timepoints thereafter not significantly different). This may explain, at least in part, the aforementioned apparent (but not statistically significant) differences between STD and PD observed in Figure 2E from 15 to 75 min. In addition, although there was an overall main effect for age ($P = 0.03$), there was no desk–age interaction ($P = 0.11$), hence age was not retained in the model for further analysis. Finally, there was no main or interaction effect for BMI ($P > 0.05$). Again, we reiterate that these additional *ad hoc* analyses were exploratory and should be interpreted with caution given that this was a pilot study with a relatively small sample size. Further studies (with more adequately powered samples) should be conducted to more definitively assess sex, age, and BMI covariate interactions.

The PD compared favorably with a STD in regard to work-related activities. We chose different skills: executive processing via the Stroop Word Color Test; computer proficiency using mouse click, drop-and-drag and typing; and reading comprehension via GRE questions. All measures except the mouse click test (2.2 s of approximately 1 min) were equivalent between the PD and the STD conditions. The lack of differences in the multiple work skills between PD and STD is consistent with previous results that a seated active workstation (e.g., pedaling) does not interfere with work performance and/or cognitive function (33,34). Interestingly, slightly slower responses (<1 s) on mouse performance tests were also observed while performing the seated active workstations compared with sedentary workstation in previous studies although the differences were negligible (17,33). The equivalent results for work skills between PD and STD in this study would suggest that the PD could be a viable option for occupational health without interfering with work performance.

We recognize the limitations of this study. First, the sample size was small and may have limited detecting impacts on parameters besides insulin. Second, although we asked participants to maintain their usual lifestyle and diet for 2 d before the testing sessions, we did not document those behaviors. However, participants were required to fast for 12 h, refrain from caffeine and other stimulants, and avoid moderate- to vigorous-intensity exercise before attending the laboratory. Third, we did not adjust the standardized meal quantity based on individual BMI, that is, a fixed quantity meal was provided. However, we do not believe this was a major limitation given the small variance in BMI. Fourth, we only examined a single 2-h bout of PD use (without breaks). Fifth, we tested specific work tasks as markers of work performance. We did this to allow comparisons between conditions but recognize that these simulated work-related tasks may not fully represent daily routine sedentary office work activities. Although the tests were performed multiple times throughout the 2-h test trials, the short task durations (4–10 min) may not be sufficient to simulate true work responsibilities. In addition, our sample size would likely not detect small changes in assessments of work skills. Nonetheless, these results support the concept that light-intensity physical activity using a PD can positively impact the adverse impact of sedentary work behaviors with apparently minimal impact on work-related skills. Future studies will need to consider longer exposures to the PD (>2 h and including breaks to simulate real-world scenarios) and examination of other metabolic indices and additional measures of insulin sensitivity in real workplace environments.

In summary, this pilot study demonstrated that 2 h of light activity using a PD resulted in lower insulin concentrations after a mixed meal. Our subjects were overweight/obese office workers who reported sedentary lifestyles and had characteristics suggesting increased risk for diabetes and cardiovascular disease. These results have established a proof-of-concept that participants can perform consistent light-intensity physical activity at a self-selected cadence without an obvious negative impact on work skills. If this initial metabolic benefit persists with extended use, habitual use of the PD could have a significant impact on the health of sedentary workers. Further controlled studies and feasibility trials are needed to more fully understand the dose–response effects of the PD at varying intensities of pedaling and/or over longer durations among individuals with newly diagnosed, as well as more longstanding diabetes.

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Dr. Catrine Tudor-Locke and Mr. Gerald R. Locke, coinvented and thus own intellectual property for the Pennington Pedal Desk™. A management plan was established for financial conflicts of interest that included electronic data capture, a third party audit of the data and manuscript, and designation of Dr. Stuart Chipkin as the Principal Investigator who managed the study. Dr. Tudor-Locke did not determine study design and had no contact with study participants or study data. None of the other authors have a potential conflict of interest.

The results of the present study do not constitute endorsement by the American College of Sports Medicine. The results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

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