Effects of an “Active-Workstation” Cluster RCT on Daily Waking Physical Behaviors

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ABSTRACT

ARGUELLO, D., A. N. THORNDIKE, G. CLOUTIER, A. MORTON, C. CASTANEDA-SCEPPA, and D. JOHN. Effects of an “Active-Workstation” Cluster RCT on Daily Waking Physical Behaviors. *Med. Sci. Sports Exerc.*, Vol. 53, No. 7, pp. 1434–1445, 2021. **Purpose:** This study aimed to evaluate the effects of sit-to-stand and treadmill desks on sedentary behavior during a 12-month, cluster-randomized multicomponent intervention with an intent-to-treat design in overweight office workers. **Methods:** Sixty-six office workers were cluster-randomized into a control (n = 21; 8 clusters), sit-to-stand desk (n = 23; 9 clusters), or treadmill desk (n = 22; 7 clusters) group. Participants wore an activPAL™ accelerometer for 7 d at baseline, month 3, month 6, and month 12 and received periodic feedback on their physical behaviors. The primary outcome was total daily sedentary time. Exploratory outcomes included total daily and workplace sedentary, standing and stepping time, and the number of total daily and workplace sedentary, standing, and stepping bouts. Intervention effects were analyzed using random-intercept mixed linear models accounting for repeated measures and clustering effects. **Results:** Total daily sedentary time did not significantly differ between or within groups after 12 months. Month 3 gains were observed in total daily and workplace standing time in both intervention groups (sit-to-stand desk: mean Δ ± SD, 1.03 ± 1.9 $h \cdot d^{-1}$ and 1.10 ± 1.87 h at work; treadmill desk: mean Δ ± SD, 1.23 ± 2.25 $h \cdot d^{-1}$ and 1.44 ± 2.54 h at work). At month 3, the treadmill desk users stepped more at the workplace than the control group (mean Δ ± SD, 0.69 ± 0.87 h). Month 6 gains in total daily stepping were observed within the sit-to-stand desk group (mean Δ ± SD, 0.82 ± 1.62 $h \cdot d^{-1}$), and month 3 gains in stepping at the workplace were observed for the treadmill desk group (mean Δ ± SD, 0.77 ± 0.83 h). These trends were sustained through month 12 in only the sit-to-stand desk group. **Conclusions:** Active-workstation interventions may cause short-term improvements in daily standing and stepping. Treadmill desk users engaged in fewer sedentary bouts, but sit-to-stand desks resulted in more frequent transitions to upright physical behaviors. **Key Words:** SIT-TO-STAND DESKS, TREADMILL DESKS, SEDENTARY BEHAVIOR, PHYSICAL ACTIVITY PROMOTION, WORKPLACE WELLNESS, SEATED OFFICE WORKERS

Prolonged sedentary behavior is associated with an increased susceptibility for disability, morbidity, and mortality from chronic disease (1). A substantial proportion of the US workforce is employed in full-time seated desk jobs (2,3) and hence at risk for these health hazards. As a result, the Centers for Disease Control and Prevention has recognized the workplace as a priority setting for health promotion (4). Active workstations such as sit-to-stand and treadmill desks (3,5) provide the opportunity for office workers to replace prolonged sitting at work with standing and/or light-intensity physical activity. Thus, these active workstations have gained popularity as alternatives to traditional seated workstations.

Although popular, little is known about their long-term effects in reducing sedentary behavior and increasing standing and stepping physical behaviors. A recent review of experimental studies (n = 24) that implemented sit-to-stand desks at the workplace reported a wide range of the effects of these desks in reducing short-term sedentary behavior (range, 0.1–3.6 $h \cdot d^{-1}$) and in increasing standing (range, 0.5–3.1 $h \cdot d^{-1}$) and movement (range, 0–0.6 $h \cdot d^{-1}$) (6). Most of these studies lacked a robust study design and/or were of short duration (1 d or up to 12 wk) (6). There have been just two cluster-randomized sit-to-stand desk trials with a long-term follow-up of at least 12 months that have been published till date (7,8). The first study reported significant short- and long-term reductions in overall sedentary behavior in the intervention group relative to the controls (i.e., 1.30 $h \cdot d^{-1}$ at 3 months, 0.61 $h \cdot d^{-1}$ at 12 months) with corresponding increases in overall standing time (i.e., 1.26 $h \cdot d^{-1}$ at 3 months, 0.69 $h \cdot d^{-1}$ after 12 months) (7). The second study reported significant medium- and long-term reductions in overall sedentary behavior in the intervention group relative to controls (i.e., 0.99 $h \cdot d^{-1}$ after 6 months, 1.37 $h \cdot d^{-1}$ after 12 months) with corresponding increases in

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overall standing time (i.e., 0.93 $h \cdot d^{-1}$ after 6 months, 1.05 $h \cdot d^{-1}$ after 12 months) (8). However, neither study found meaningful effects on stepping time (7).

Fewer studies have examined the effect of treadmill desks on sedentary behavior (n = 7) (9–15). Similar to sit-to-stand desks, studies on treadmill desk have reported high variability in reducing sedentary behavior (range, 0.1–2.1 $h \cdot d^{-1}$) (16) and in increasing stepping time (range, 0.1–1.3 $h \cdot d^{-1}$) (16). Only four studies had long-term follow-up (range, 9–13 months), and one study reported positive intervention effects on daily standing time (i.e., 1.8 $h \cdot d^{-1}$ after 3 months, 1.5 $h \cdot d^{-1}$ after 9 months) (9–11,15). More long-term experimental studies are required to draw inferences on the effect of this intervention in improving daily waking physical behaviors.

This study analyzed physical behavior outcomes in a 12-month, three-arm cluster-randomized control trial to "sit less, stand and move more" (17) using sit-to-stand and treadmill desks at the workplace among sedentary overweight or obese office workers. The primary outcome of this study was total daily sedentary behavior. Aim 1a assessed the *a priori* hypothesis that decreases in total daily sedentary behavior would be greatest in the sit-to-stand desk group and lowest in the control group. Aim 1b was exploratory and analyzed the effect of sit-to-stand and treadmill desks on workplace sedentary behavior. Aims 2 and 3 analyzed the effect of sit-to-stand and treadmill desks on the following exploratory outcomes: total daily and workplace standing and stepping time, step counts, and the number of total daily and workplace sedentary, standing, and stepping bouts.

METHODS

Study Design and Participants

Sixty-six office workers were recruited from Massachusetts General Hospital and Northeastern University in Boston, MA. A total of 24 office clusters (i.e., Massachusetts General Hospital: 19 clusters, n = 60; Northeastern University: 5 clusters, n = 6) were randomized to the seated-desk control (8 clusters, n = 21), sit-to-stand desk (9 clusters, n = 23), or treadmill desk group (7 clusters, n = 22; see the figure in Supplemental Digital Content 1, enrollment, participation, attrition, and analyses for total daily time, http://links.lww.com/MSS/C246). Participant clusters were identified based on office space such that clusters were separated by walls or were located on a different floor or building. Separations were aimed at not allowing participants in one cluster to be visible to other clusters during day-to-day office activities. Partners HealthCare and Northeastern University institutional review boards approved the study in March of 2014, and all participants provided written informed consent.

To be eligible for the trial, office workers had to be between 18 and 65 yr of age, have a body mass index (BMI) greater than 25 $kg \cdot m^{-2}$, not engage in any structured physical activity on more than 2 $d \cdot wk^{-1}$, be employed in a seated desk job, and be free of limitations that prevented walking and standing in bouts lasting 40 to 60 min. An additional criterion for women was that they were not pregnant or planning to become pregnant in the next year. Subjects were also screened for hypertension, diabetes, cardiovascular disease, and musculoskeletal conditions (i.e., joint, bone, or muscle conditions) using a medical history questionnaire at baseline.

Office workers who were enrolled in the study performed telephone and/or computer-based tasks in administrative and support roles. Although no shift workers were enrolled in the study, neither institution enforced a standard 9 AM to 5 PM work schedule for day-time workers. Additional details on the recruitment and eligibility of worksites can be found in supplemental material (see the procedures in Supplemental Digital Content 2, subject selection and enrollment, http://links.lww.com/MSS/C247).

Study Procedures

Sedentary behavior interventions have been shown to be more efficacious when multifaceted approaches such as individual education/behavioral strategies, social support, and environmental modification are integrated to promote behavior change (18). Hence, before randomization, all 66 participants received a 30-min face-to-face counseling session with a trained researcher on the benefits of reducing daily sitting and increasing daily standing and movement. In addition, before modifying individual workspaces, supervisors of workers enrolled in the sit-to-stand and treadmill desk groups were provided with individual onsite training on the benefits of decreasing sedentary behavior at the workplace and provided verbal encouragement to employees. Supervisors reinforced the importance of decreasing sedentary behavior at regular department meetings during the intervention. Both individual counseling sessions and supervisor trainings were repeated after 3, 6, and 9 months for the sit-to-stand and treadmill desk clusters. During these sessions, participants were also given feedback on their measured physical behaviors (described hereinafter) using hourly pictorial breakdowns of workplace and daily behavior patterns.

Training to use workstations. The height-adjustable desks used in this study were the WorkFit-D from Ergotron® Inc. For the treadmill desk group, a WorkFit-D desk was retrofitted with a treadmill (TR1200 DT-3; LifeSpan Fitness Inc.) for each participant. The control panel for the treadmill was placed on the desktop of the WorkFit-D.

Treadmill desk group. Training pertaining to standing and sitting at the height-adjustable desk while working followed recommendations from the Occupational Safety and Health Administration (19). Briefly, training involved selecting the appropriate height of the work surface and maintaining proper posture (20) in the sitting and standing positions. The appropriate height of the work surface was selected by measuring and adjusting the height of the tabletop and the horizontal position of the keyboard, mouse, and monitor and their angles relative to the horizontal plane to ensure a neutral posture that felt natural and comfortable and put minimal stress on the body (21). Participants were also trained on the use of the

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treadmill desk for walking while working, which was based on qualitative feedback from our previous work (22). These included the following: "i) acclimate to walking on the treadmill during the first week at a speed between 0.7 to 1.0 mph, ii) walk and stand for short bouts of 10-min during acclimation, iii) after acclimation, walk at a speed between 1.0 and 2.0 mph as this range allows you to simultaneously perform work and minimally affects work performance (22–25), and iv) after acclimation, accumulate periods of walking and standing during the course of the day in bouts lasting between 10 and 30 min." Based on workstation use in our prior research, we recommended participants to accumulate at least 2 h of walking and 1 h of standing per day (10).

Sit-to-stand desk group. Training for the sit-to-stand desk group pertaining to sitting and standing postures while working was similar to that of the treadmill desk group. Similarly, we recommended participants to acclimate themselves to standing during the first week of using the sit-to-stand desk and to accumulate at least 3 h of standing per day in bouts lasting 10 to 30 min after acclimation. The 3-h recommendation aimed to ensure that the prescribed reduction in sedentary time for the sit-to-stand desk group matched the prescription for the treadmill desk group.

Control group. We recommended the control group to engage in three 10-min bouts of moderate-to-vigorous walking during the workday: one during each of the morning and afternoon sessions of work and during the lunch break. This recommendation aimed to enable the participants to meet the 2008 federal physical activity guidelines (26).

Activity monitoring. Participants wore an activPAL™ 3C activity monitor (PAL Technologies Ltd., Glasgow, United Kingdom) on their right thigh for a period of 7 d at baseline and after 3, 6, and 12 months during waking hours. The device used in this study has an 8-bit digital capacitive accelerometer (sampling rate, 20 Hz). Sensor data were processed using proprietary software (PALanalysis 7.0; PAL Technologies Ltd.) and algorithms to obtain various outcomes (described hereinafter) on volume and bouts of physical activity and sedentary behavior. In addition, participants were asked to complete a daily log to self-report when the monitor was not worn (e.g., showering, sleep) and time spent at the workplace.

Activity monitor data processing and outcome variables. Sensor data were first processed to verify wake-wear intervals using a combination of the self-report logs and signal visualization (27). Wake-wear data were used to quantify total daily time spent sedentary (i.e., sitting/lying), standing, and stepping, and bout statistics of the same (described hereinafter). For inclusion in the primary analyses, there needed to be at least four valid days of sensor data consisting of at least 10 h of wake-wear per day from a participant (28).

There was poor compliance on self-report logs specific to reporting time spent at the workplace. In addition, both study sites did not follow the typical 9 AM to 5 PM work schedule. Although there was variability in schedules between individuals, intraindividual schedules were consistent in general. Therefore, unavailable log work hours was statistically predicted at an individual level by calculating the typical start and end times of a subject's workday (Monday–Friday) from compliant logs at other time points in the study. For inclusion in this prediction, subjects had to have at least four valid days of logged work time over the four physical behavior measurements of the study (see the figure in Supplemental Digital Content 3, enrollment, participation, attrition, and analyses for daily time at the workplace, http://links.lww.com/MSS/C248). Cases that did not meet this criterion were handled as missing data (described hereinafter; see the figure in Supplemental Digital Content 3, enrollment, participation, attrition, and analyses for daily time at the workplace, http://links.lww.com/MSS/C248).

Outcome variables. The primary outcome variable was the average total daily hours of wake-time spent sedentary that was examined for intervention effects in aim 1a. The study was powered to detect changes in the primary outcome, which was based on data from our previous pilot study (see sample size estimation details hereinafter). Aim 1b was an exploratory analysis of average sedentary hours at the workplace. Exploratory outcomes for aim 2 were the average total daily hours and daily time at the workplace spent standing and stepping, and average step counts for the total day and at the workplace. Exploratory outcomes for aim 3, which aimed to determine the frequency of transitioning from sedentary to upright physical behaviors, were the average number of total daily and workplace sedentary, standing, and stepping bouts.

Sample size and statistical analyses. All analyses were conducted using SAS 9.4 (SAS Institute Inc., Cary, NC).

Sample size estimation. Sample size calculation was based on conservative power estimates derived using change in total daily sedentary behavior observed among participants (n = 12) in our preliminary treadmill desk intervention (10). Study arms with at least 17 per group was determined to provide 85% power (5% two-tailed significance) to detect an effect size of 1.06 between groups. Accounting for potential clustering effects, power estimates were based on an effective sample size of 51 subjects with an intraclass correlation coefficient (ICC) of 0.01. A SD of 2.7 h for change in total daily sedentary behavior observed in our pilot study corresponds to a mean detectable difference of 2.9 h between groups. The sample size of 66 accounts for an attrition rate of 20%.

Handling missing data. Losses to follow-up (see the figures in Supplemental Digital Content 1 and 3, enrollment, attrition, participation, and analyses for total daily time and at the workplace, respectively, http://links.lww.com/MSS/C246 and http://links.lww.com/MSS/C248) were handled as intent-to-treat. Missing daily waking physical behavior outcomes attributable to unsystematic factors were imputed using joint multiple imputation (29,30). Missingness was determined to be completely at random (i.e., varying subjects had missing physical behavior outcome data at varying time points of the study) and attributable to unsystematic factors, such as monitor malfunction, sickness, improper device placement, and forgetfulness to wear devices and/or log work hours. Multiple imputation is the gold standard for retaining lost statistical power arising from such missing data (29).

Analyses of outcome variables. We used random-intercept mixed linear models that accounted for repeated measures and clustering effects to assess between- and within-group differences in the 1-yr study for all outcome variables. Data checks ensured that the underlying assumptions of the statistical modeling used on our data were not violated. *Post hoc* pairwise comparisons for the primary outcome in aim 1 were adjusted for multiple comparisons using a Bonferroni correction, yielding a between-group pairwise comparison α of 0.0042 (4 time points × 3 groups = 12 comparisons) with (1 − 0.0042 α)% confidence intervals (CI), and a within-group pairwise comparison α of 0.0028 (6 comparisons/group = 18 comparisons) with (1 − 0.0028 α)% CI. Cluster effects for all outcomes were tested by calculating the ICCs and their statistical significance ($P < 0.05$).

For exploratory outcomes examined in aims 1, 2, and 3, we present *post hoc* determination of treatment-effect trends for behavior change indicated by unidirectional 95% CI, which do not overlap the null value. This exploratory approach avoids confirmatory statistical significance conclusions based on *P* values and thus does not require the application of Bonferroni corrections. Exploratory analyses are appropriate to use when the objective is to develop new hypotheses to further study observed phenomena (31).

To eliminate confounding of outcome analyses due to differences in activity monitor wear time, mixed linear models were used to compare wear time at different time points (i.e., average daily wear hours and average number of valid wear days beyond minimum inclusion criteria). This testing did not detect any significant differences, and hence, no adjustment of wear time was necessary during mixed linear modeling of primary and exploratory outcomes. We also tested for statistically significant differences at baseline for all outcome variables and participant demographics (age, BMI, sex, ethnicity, and race) using mixed linear models for continuous variables and χ^2 tests for categorical variables. A significant between-group difference was found for age. Thus, mixed linear models for outcome variables were adjusted for age. Cohen's *d* effect sizes were calculated for all between- and within-group comparisons and categorized using standardized thresholds (i.e., 0.01, very small; 0.2, small; 0.5, medium; 0.8, large; 1.2, very large; and 2.0, huge) (32).

In addition, sensitivity analysis included a completers' analysis ($n = 42$) from baseline to month 12 performed for the primary outcome. This aimed to determine if the overall effect of the two interventions was altered when examining a less conservative and ideal scenario of intervention compliance and to evaluate the sensitivity of primary outcome findings to the handling of missing data (33). *Post hoc* pairwise comparisons for the sensitivity analysis were adjusted for multiple comparisons using a Bonferroni correction, yielding a between-group pairwise comparison α of 0.0083 (2 time points × 3 groups = 6 comparisons) with (1 − 0.0083 α)% CI, and a within-group pairwise comparison α of 0.0167 (1 comparison/group = 3 comparisons) with (1 − 0.0167 α)% CI.

RESULTS

Participant Characteristics

The control group comprised 20 women and 1 man (8 African American/Black, 12 non-Hispanic Caucasians, and 1 Hispanic Caucasian; age, 41.9 ± 11.5 yr; BMI, 33.3 ± 5.9 kg·m^{-2}). The sit-to-stand desk group comprised 21 women and 2 men (2 African American/Black, 16 non-Hispanic Caucasians, 3 Hispanic Caucasians, 1 Asian, and 1 other race/ethnicity; age, 43.6 ± 12.2 yr; BMI, 30.8 ± 6.0 kg·m^{-2}). The treadmill desk group comprised 18 women and 4 men (5 African Americans/Black, 15 non-Hispanic Caucasians, 1 Hispanic Caucasian, and 1 other race/ethnicity; age, 50.4 ± 12.0 yr; BMI, 33.5 ± 4.9 kg·m^{-2}). Self-reporting of medical history showed a prior or current history of hypertension in 11 participants (8 sit-to-stand desk, 2 treadmill desk, and 1 control), diabetes in 5 participants (3 sit-to-stand desk and 2 treadmill desk), cardiovascular disease in 2 participants (2 treadmill desk), and musculoskeletal conditions in 24 participants (6 sit-to-stand desk, 9 treadmill desk, and 9 controls). Sample sizes after losses to follow-up and mean activity monitor wear times for the total day and at the workplace are reported in Table 1.

Cluster Effects

The cluster effect did not significantly (all, $P > 0.05$) account for the variability in any of the outcome variables (see

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TABLE 1. Sample sizes after losses to follow-up and activity monitor wear times by group × time point.

			Mean Activity Monitor Wear Time			
			Total Time		Workplace	
Group	Time Point	*n*	Days ± SD	Daily Hours ± SD	Days ± SD	Daily Hours ± SD
Control	Baseline	21	5.79 ± 2.57	14.15 ± 2.13	4.08 ± 1.82	7.83 ± 1.39
Sit-to-stand desk		23	6.18 ± 1.76	12.96 ± 2.00	3.87 ± 1.62	7.46 ± 1.37
Treadmill desk		22	6.59 ± 1.01	13.98 ± 1.36	3.64 ± 1.61	7.41 ± 0.82
Control	Month 3	15	5.92 ± 2.60	14.62 ± 1.97	5.11 ± 1.32	8.46 ± 1.21
Sit-to-stand desk		21	6.25 ± 2.44	13.67 ± 1.69	4.91 ± 2.14	7.91 ± 1.33
Treadmill desk		22	5.74 ± 2.71	13.97 ± 2.83	3.64 ± 2.09	8.30 ± 1.66
Control	Month 6	14	7.77 ± 2.80	15.51 ± 1.71	6.43 ± 5.79	8.06 ± 1.85
Sit-to-stand desk		20	5.99 ± 2.62	13.49 ± 3.48	4.28 ± 1.49	6.76 ± 1.96
Treadmill desk		19	7.74 ± 3.22	14.68 ± 1.76	5.05 ± 4.42	7.89 ± 1.83
Control	Month 12	18	6.65 ± 1.20	14.94 ± 1.84	3.86 ± 2.82	8.40 ± 1.96
Sit-to-stand desk		20	6.68 ± 1.90	14.37 ± 1.69	4.56 ± 1.24	7.79 ± 1.28
Treadmill desk		20	6.01 ± 2.56	14.17 ± 2.78	4.18 ± 2.22	8.32 ± 1.55

the table in Supplemental Digital Content 4, ICCs for worksite clustering at baseline, http://links.lww.com/MSS/C249).

Aim 1a: Primary Outcome Analyses of Total Daily Sedentary Behavior

Mean total daily sedentary time did not significantly differ (all, $P > 0.0042$) between groups at 3, 6, or 12 months (Fig. 1A, Table 2). Similarly, there were no significant changes (all, $P > 0.0028$) observed in within-group comparisons (Table 2).

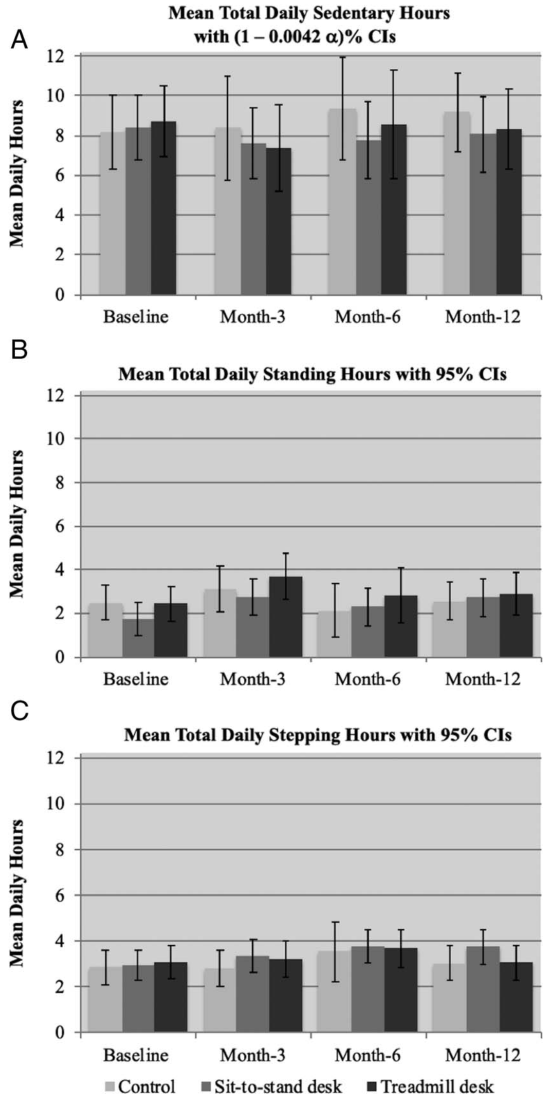

FIGURE 1—Mean total daily waking time spent in physical behaviors by randomization group × time point, adjusted for age. There were no significant between group differences at the multiple-comparison Bonferroni-adjusted rejections α of 0.0042 for daily sedentary behavior volume. There were also no unidirectional between group trends for daily standing and stepping behavior volume. Sample sizes after loss to follow-up: baseline (21 control, 23 sit-to-stand desk, 22 treadmill desk), month 3 (15 control, 21 sit-to-stand desk, 22 treadmill desk), month 6 (14 control, 20 sit-to-stand desk, 19 treadmill desk), and month 12 (18 control, 20 sit-to-stand desk, 20 treadmill desk).

Aim 1b: Exploratory Analyses of Daily Workplace Sedentary Behavior

No between- or within-group unidirectional trends were observed in mean daily workplace sedentary time after 3, 6, or 12 months (see the table in Supplemental Digital Content 5, *post hoc* comparisons of time spent in physical behaviors at the workplace, http://links.lww.com/MSS/C250). The mean number of daily sedentary, standing, and stepping hours at the workplace (group × time point) are reported in the supplemental material (see the table in Supplemental Digital Content 6, summary of time spent in physical behaviors at the workplace, http://links.lww.com/MSS/C251).

Aim 2: Exploratory Analyses of Standing and Stepping Behavior

Standing behavior. *Total daily time.* No between-group unidirectional trends were observed in mean total daily standing time after 3, 6, or 12 months (Fig. 1B, Table 3).

However, unidirectional within-group increasing trends in mean total daily standing time were observed from baseline to month 3 for both the sit-to-stand (mean Δ ± SD, 1.03 ± 1.90 $h \cdot d^{-1}$; 95% CI, 0.10–1.97 $h \cdot d^{-1}$; $P = 0.0304$; medium effect size, 0.55) and treadmill desk groups (mean Δ ± SD, 1.23 ± 2.25 $h \cdot d^{-1}$; 95% CI, 0.16–2.30 $h \cdot d^{-1}$; $P = 0.0248$; medium effect size, 0.55; Table 3). Only the sit-to-stand desk group sustained this trend through month 12 (mean Δ ± SD from baseline, 0.99 ± 1.88 $h \cdot d^{-1}$; 95% CI, 0.05–1.94 $h \cdot d^{-1}$; $P = 0.0394$; medium effect size, 0.53; Table 3).

Workplace. No between-group unidirectional trends were observed in mean daily standing time at the workplace after 3, 6, or 12 months (see the table in Supplemental Digital Content 5, *post hoc* comparisons of time spent in physical behaviors at the workplace, http://links.lww.com/MSS/C250).

Similar to total daily time, unidirectional within-group increasing trends in daily workplace standing time were observed from baseline to month 3 for both the sit-to-stand (mean Δ ± SD, 1.10 ± 1.87 $h \cdot d^{-1}$; 95% CI, 0.21–1.99 $h \cdot d^{-1}$; $P = 0.0151$; medium effect size, 0.59) and treadmill desk groups (mean Δ ± SD, 1.44 ± 2.54 $h \cdot d^{-1}$; 95% CI, 0.19–2.69 $h \cdot d^{-1}$; $P = 0.0242$; medium effect size, 0.57; see the table in Supplemental Digital Content 5, *post hoc* comparisons of time spent in physical behaviors at the workplace, http://links.lww.com/MSS/C250). However, contrary to total daily time, only the treadmill desk group sustained this workplace trend through month 12 (mean Δ ± SD from baseline, 1.61 ± 2.20 $h \cdot d^{-1}$; 95% CI, 0.56–2.66 $h \cdot d^{-1}$; $P = 0.0027$; medium effect size, 0.73; see the table, Supplemental Digital Content 5, *post hoc* comparisons of time spent in physical behaviors at the workplace, http://links.lww.com/MSS/C250).

Stepping behavior. *Total daily time.* No between-group unidirectional trends were observed in mean total daily stepping time after 3, 6, or 12 months (Fig. 1C, Table 4).

However, a unidirectional within-group increasing trend in mean total daily stepping time was observed from baseline to month 6 for the sit-to-stand desk group (mean Δ ± SD,

TABLE 2. Between- and within-group comparisons of mean total daily sedentary time, adjusted for age.

Comparison	Sample Sizes n_1	n_2	Mean Difference ± SD [(1 − α)% CI], h	Cohen's *d* Effect Size	*P*
Between-group comparisons					
B: Sit-to-stand desk–Control	23	21	0.27 ± 2.79 [−2.05 to 2.60]	0.10	0.7462
B: Treadmill desk–Control	22	21	0.54 ± 2.86 [−1.88 to 2.96]	0.19	0.5394
B: Treadmill desk–Sit-to-stand desk	22	23	0.27 ± 2.77 [−2.01 to 2.55]	0.10	0.7470
M3: Sit-to-stand desk–Control	21	15	−0.79 ± 3.04 [−3.66 to 2.09]	0.26	0.4488
M3: Treadmill desk–Control	22	15	−1.01 ± 3.41 [−4.20 to 2.19]	0.29	0.3796
M3: Treadmill desk–Sit-to-stand desk	22	21	−0.22 ± 3.17 [−2.90 to 2.46]	0.07	0.8201
M6: Sit-to-stand desk–Control	20	14	−1.60 ± 3.06 [−4.60 to 1.40]	0.52	0.1352
M6: Treadmill desk–Control	19	14	−0.78 ± 3.60 [−4.34 to 2.79]	0.22	0.5319
M6: Treadmill desk–Sit-to-stand desk	19	20	0.82 ± 3.54 [−2.33 to 3.98]	0.23	0.4672
M12: Sit-to-stand desk–Control	20	18	−1.10 ± 2.84 [−3.67 to 1.47]	0.39	0.2331
M12: Treadmill desk–Control	20	18	−0.83 ± 2.92 [−3.47 to 1.82]	0.28	0.3823
M12: Treadmill desk–Sit-to-stand desk	20	20	0.27 ± 2.96 [−2.33 to 2.88]	0.09	0.7712
Within-group comparisons					
Control: Δ B to M3	21	15	0.22 ± 3.09 [−2.87 to 3.31]	0.07	0.8001
Control: Δ B to M6	21	14	1.19 ± 3.01 [−1.88 to 4.27]	0.40	0.1860
Control: Δ B to M12	21	18	0.99 ± 2.84 [−1.69 to 3.67]	0.35	0.1709
Control: Δ M3 to M6	15	14	0.97 ± 3.21 [−2.62 to 4.56]	0.30	0.3552
Control: Δ M3 to M12	15	18	0.77 ± 3.05 [−2.40 to 3.95]	0.25	0.3830
Control: Δ M6 to M12	14	18	−0.20 ± 2.97 [−3.35 to 2.96]	0.07	0.8281
Sit-to-stand desk: Δ B to M3	23	21	−0.84 ± 2.73 [−3.24 to 1.57]	0.31	0.2016
Sit-to-stand desk: Δ B to M6	23	20	−0.68 ± 2.85 [−3.23 to 1.86]	0.24	0.3436
Sit-to-stand desk: Δ B to M12	23	20	−0.38 ± 2.79 [−2.87 to 2.12]	0.13	0.5885
Sit-to-stand desk: Δ M3 to M6	21	20	0.16 ± 2.88 [−2.48 to 2.80]	0.05	0.8325
Sit-to-stand desk: Δ M3 to M12	21	20	0.46 ± 2.82 [−2.13 to 3.05]	0.16	0.5201
Sit-to-stand desk: Δ M6 to M12	20	20	0.30 ± 2.94 [−2.43 to 3.03]	0.10	0.6956
Treadmill desk: Δ B to M3	22	22	−1.32 ± 3.21 [−4.15 to 1.50]	0.41	0.0742
Treadmill desk: Δ B to M6	22	19	−0.12 ± 3.48 [−3.32 to 3.07]	0.04	0.8929
Treadmill desk: Δ B to M12	22	20	−0.37 ± 2.94 [−3.03 to 2.29]	0.13	0.5902
Treadmill desk: Δ M3 to M6	22	19	1.20 ± 3.78 [−2.27 to 4.67]	0.32	0.2320
Treadmill desk: Δ M3 to M12	22	20	0.95 ± 3.30 [−2.03 to 3.93]	0.29	0.2365
Treadmill desk: Δ M6 to M12	19	20	−0.25 ± 3.56 [−3.60 to 3.11]	0.07	0.7985

Bonferroni-adjusted rejection α values: between-group comparisons, 0.0042; within-group comparisons, 0.0028.
B, baseline; M3, month 3; M6, month 6; M12, month 12 follow-ups; n_1, sample size of the first comparison group; n_2, sample size of the second comparison group.

0.82 ± 1.62 h·d^{-1}; 95% CI, 0.17–1.47 h·d^{-1}; P = 0.0133; medium effect size, 0.50), which was sustained through month 12 (mean Δ ± SD from baseline, 0.81 ± 1.64 h·d^{-1}; 95% CI, 0.13–1.49 h·d^{-1}; P = 0.0191; medium effect size, 0.50; Table 4).

Workplace. Between-group comparisons showed that after 3 months, the treadmill desk group had a unidirectional trend of spending more daily time stepping at the workplace relative to the control group (mean Δ ± SD, 0.69 ± 0.87 h·d^{-1}; 95% CI, 0.13–1.25 h·d^{-1}; P = 0.0165; medium effect size, 0.79; see the table in Supplemental Digital Content 5, *post hoc* comparisons of time spent in physical behaviors at the workplace, http://links.lww.com/MSS/C250).

Within-group comparisons showed that the treadmill desk group had increasing unidirectional trends in time spent stepping at the workplace from baseline to month 3 (mean Δ ± SD, 0.77 ± 0.83 h·d^{-1}; 95% CI, 0.34–1.20 h·d^{-1}; P = 0.0004; large effect size, 0.93), month 6 (mean Δ ± SD, 0.89 ± 1.01 h·d^{-1}; 95% CI, 0.30–1.48 h·d^{-1}; P = 0.003; large effect size, 0.88), and month 12 (mean Δ ± SD, 0.54 ± 0.80 h·d^{-1}; 95% CI, 0.11–0.97 h·d^{-1}; P = 0.014; medium effect size, 0.67; see the table in Supplemental Digital Content 5, *post hoc* comparisons of time spent in physical behaviors at the workplace, http://links.lww.com/MSS/C250). Contrary to total daily time, no such within-group trends were observed at the workplace for the sit-to-stand desk group.

Step counts. Mean total daily and workplace step counts (group × time point) are reported in Table 5.

Total daily steps. No between-group unidirectional trends were observed in mean total daily step counts after 3, 6, or 12 months.

However, unidirectional within-group increasing trends in mean total daily step counts were observed for both intervention groups after 3 and 6 months. The trend observed in the sit-to-stand desk group from baseline to month 3 (mean Δ ± SD, 1811 ± 3876 steps per day; 95% CI, 247–3375 steps per day; P = 0.0233; small effect size, 0.47) was sustained through month 6 (mean Δ ± SD from baseline, 2390 ± 3853 steps per day; 95% CI, 835–3944 steps per day; P = 0.0026; medium effect size, 0.62). Similarly, the trend observed in the treadmill desk group from baseline to month 3 (mean Δ ± SD, 2332 ± 4483 steps per day; 95% CI, 738–3927 steps per day; P = 0.0042; medium effect size, 0.52), was sustained through month 6 (mean Δ ± SD from baseline, 2087 ± 4493 steps per day; 95% CI, 236–3938 steps per day; P = 0.0272; small effect size, 0.46).

Steps at the workplace. Between-group comparisons showed that after 3 months, the treadmill desk group had unidirectional trends of higher daily step counts at the workplace relative to both the control (mean Δ ± SD, 3054 ± 5780 steps per day; 95% CI, 605–5502 steps per day; P = 0.0145; medium effect size, 0.53) and sit-to-stand desk groups (mean Δ ± SD, 2640 ± 4024 steps per day; 95% CI, 379–4900 steps per day; P = 0.0221; medium

TABLE 3. Between- and within-group comparisons of mean total daily standing time, adjusted for age.

Comparison	Sample Sizes n_1	n_2	Mean Difference ± SD [95% CI] (Hours)	Cohen's *d* Effect Size	*P*	U Trend ↗
Between-group comparisons						
B: Sit-to-stand desk–Control	23	21	−0.76 ± 1.85 [−1.85 to 0.34]	0.41	0.1755	----
B: Treadmill desk–Control	22	21	−0.05 ± 1.90 [−1.19 to 1.09]	0.03	0.9294	----
B: Treadmill desk–Sit-to-stand desk	22	23	0.70 ± 1.87 [−0.39 to 1.80]	0.38	0.2081	----
M3: Sit-to-stand desk–Control	21	15	−0.33 ± 2.03 [−1.69 to 1.02]	0.16	0.6293	----
M3: Treadmill desk–Control	22	15	0.56 ± 2.32 [−0.93 to 2.06]	0.24	0.4607	----
M3: Treadmill desk–Sit-to-stand desk	22	21	0.90 ± 2.27 [−0.46 to 2.25]	0.40	0.1943	----
M6: Sit-to-stand desk–Control	20	14	0.16 ± 2.17 [−1.34 to 1.66]	0.07	0.8337	----
M6: Treadmill desk–Control	19	14	0.71 ± 2.62 [−1.07 to 2.49]	0.27	0.4358	----
M6: Treadmill desk–Sit-to-stand desk	19	20	0.55 ± 2.45 [−1.00 to 2.09]	0.22	0.4879	----
M12: Sit-to-stand desk–Control	20	18	0.19 ± 1.92 [−1.04 to 1.41]	0.10	0.7666	----
M12: Treadmill desk–Control	20	18	0.38 ± 2.06 [−0.93 to 1.68]	0.18	0.5700	----
M12: Treadmill desk–Sit-to-stand desk	20	20	0.19 ± 2.08 [−1.10 to 1.48]	0.09	0.7700	----
Within-group comparisons						
Control: Δ B to M3	21	15	0.61 ± 1.99 [−0.52 to 1.74]	0.31	0.2898	----
Control: Δ B to M6	21	14	−0.36 ± 2.13 [−1.69 to 0.97]	0.17	0.5934	----
Control: Δ B to M12	21	18	0.05 ± 1.89 [−0.93 to 1.04]	0.03	0.9175	----
Control: Δ M3 to M6	15	14	−0.97 ± 2.23 [−2.46 to 0.52]	0.44	0.2009	----
Control: Δ M3 to M12	15	18	−0.56 ± 2.00 [−1.73 to 0.61]	0.28	0.3495	----
Control: Δ M6 to M12	14	18	0.41 ± 2.14 [−0.94 to 1.77]	0.19	0.5501	----
Sit-to-stand desk: Δ B to M3	23	21	1.03 ± 1.90 [0.10 to 1.97]	0.55	0.0304	↗
Sit-to-stand desk: Δ B to M6	23	20	0.56 ± 1.89 [−0.39 to 1.51]	0.29	0.2518	----
Sit-to-stand desk: Δ B to M12	23	20	0.99 ± 1.88 [0.05 to 1.94]	0.53	0.0394	↗
Sit-to-stand desk: Δ M3 to M6	21	20	−0.48 ± 1.96 [−1.50 to 0.54]	0.24	0.3582	----
Sit-to-stand desk: Δ M3 to M12	21	20	−0.04 ± 1.96 [−1.05 to 0.97]	0.02	0.9361	----
Sit-to-stand desk: Δ M6 to M12	20	20	0.44 ± 1.95 [−0.58 to 1.46]	0.22	0.3997	----
Treadmill desk: Δ B to M3	22	22	1.23 ± 2.25 [0.16 to 2.30]	0.55	0.0248	↗
Treadmill desk: Δ B to M6	22	19	0.40 ± 2.43 [−0.92 to 1.71]	0.16	0.5537	----
Treadmill desk: Δ B to M12	22	20	0.48 ± 2.07 [−0.53 to 1.49]	0.23	0.3516	----
Treadmill desk: Δ M3 to M6	22	19	−0.83 ± 2.70 [−2.30 to 0.64]	0.31	0.2686	----
Treadmill desk: Δ M3 to M12	22	20	−0.75 ± 2.38 [−1.95 to 0.46]	0.31	0.2252	----
Treadmill desk: Δ M6 to M12	19	20	0.08 ± 2.55 [−1.34 to 1.51]	0.03	0.9079	----

B, baseline; M3/M6/M12, month 3/6/12 follow-ups; n_1, sample size of the first comparison group; n_2, sample size of the second comparison group; U Trend = unidirectional trend (N,----; Y, ↗).

effect size, 0.66). This trend was sustained between the treadmill and sit-to-stand desk groups after 12 months (mean Δ ± SD, 2013 ± 3053 steps per day; 95% CI, 117–3908 steps per day; P = 0.0375; medium effect size, 0.66).

Unlike total daily steps, within-group unidirectional increasing trends in mean daily step counts at the workplace were only observed for treadmill desk group from baseline to month 3 (mean Δ ± SD, 3648 ± 3789 steps per day; 95% CI, 1549–5748 steps per day; P = 0.0007; large effect size, 0.96) and were sustained through month 6 (mean Δ ± SD from baseline, 3440 ± 3848 steps per day; 95% CI, 1155–5726 steps per day; P = 0.0032; large effect size, 0.89) and month 12 (mean Δ ± SD from baseline, 2653 ± 3048 steps per day; 95% CI, 954–4351 steps per day; P = 0.0022; large effect size, 0.87).

Aim 3: Exploratory Analyses of the Number of Sedentary, Standing, and Stepping Bouts

The mean number of total daily and workplace sedentary, standing, and stepping bouts (group × time point) is reported in Table 5.

Daily sedentary bouts. ***Total daily bouts.*** Between-group comparisons showed that after 12 months, the treadmill desk group had a unidirectional trend of engaging in fewer total daily sedentary bouts relative to both the control and sit-to-stand desk groups (see the table in Supplemental Digital Content 7, *post hoc* comparisons of the number of total daily bouts of physical behaviors, http://links.lww.com/MSS/C252).

A unidirectional within-group increasing trend in total daily sedentary bouts was observed from baseline to month 12 in the sit-to-stand desk group (see the table in Supplemental Digital Content 7, *post hoc* comparisons of the number of total daily bouts of physical behaviors, http://links.lww.com/MSS/C252).

Bouts at the workplace. Between-group comparisons showed that after 6 months, the treadmill desk group had a unidirectional trend of engaging in fewer daily sedentary bouts at the workplace relative to the control (see the table in Supplemental Digital Content 8, *post hoc* comparisons of the number of daily bouts of physical behaviors at the workplace, http://links.lww.com/MSS/C253). After 12 months, the treadmill desk group sustained this trend relative to the control, and also had a unidirectional trend of engaging in fewer daily sedentary bouts at the workplace relative to the sit-to-stand desk group (see the table in Supplemental Digital Content 8, *post hoc* comparisons of the number of daily bouts of physical behaviors at the workplace, http://links.lww.com/MSS/C253).

A unidirectional within-group decreasing trend in daily sedentary bouts at the workplace was observed from baseline to month 12 in the treadmill desk group (see the table in Supplemental Digital Content 8, *post hoc* comparisons of the number of daily bouts of physical behaviors at the workplace, http://links.lww.com/MSS/C253).

Daily standing bouts. ***Total daily bouts.*** Between-group comparisons showed that there were no unidirectional trends in both intervention groups relative to the control group after 3, 6, or 12 months. However, the sit-to-stand desk group

TABLE 4. Between- and within-group comparisons of mean total daily stepping time, adjusted for age.

Comparison	Sample Sizes n_1	n_2	Mean Difference ± SD [95% CI] (Hours)	Cohen's *d* Effect Size	*P*	U Trend
Between-group comparisons						
B: Sit-to-stand desk–Control	23	21	0.07 ± 1.65 [−0.91 to 1.05]	0.04	0.8830	----
B: Treadmill desk–Control	22	21	0.21 ± 1.72 [−0.82 to 1.24]	0.12	0.6892	----
B: Treadmill desk–Sit-to-stand desk	22	23	0.14 ± 1.64 [−0.81 to 1.09]	0.08	0.7792	----
M3: Sit-to-stand desk–Control	21	15	0.58 ± 1.59 [−0.48 to 1.63]	0.36	0.2834	----
M3: Treadmill desk–Control	22	15	0.44 ± 1.72 [−0.67 to 1.54]	0.25	0.4384	----
M3: Treadmill desk–Sit-to-stand desk	22	21	−0.14 ± 1.77 [−1.19 to 0.91]	0.08	0.7928	----
M6: Sit-to-stand desk–Control	20	14	0.21 ± 2.13 [−1.31 to 1.73]	0.10	0.7838	----
M6: Treadmill desk–Control	19	14	0.14 ± 2.18 [−1.41 to 1.70]	0.07	0.8555	----
M6: Treadmill desk–Sit-to-stand desk	19	20	−0.07 ± 1.73 [−1.15 to 1.01]	0.04	0.9014	----
M12: Sit-to-stand desk–Control	20	18	0.70 ± 1.64 [−0.35 to 1.74]	0.42	0.1905	----
M12: Treadmill desk–Control	20	18	0.03 ± 1.66 [−1.02 to 1.07]	0.02	0.9626	----
M12: Treadmill desk–Sit-to-stand desk	20	20	−0.67 ± 1.72 [−1.73 to 0.39]	0.39	0.2156	----
Within-group comparisons						
Control: Δ B to M3	21	15	−0.06 ± 1.64 [−0.76 to 0.64]	0.04	0.8656	----
Control: Δ B to M6	21	14	0.68 ± 2.15 [−0.66 to 2.02]	0.31	0.3198	----
Control: Δ B to M12	21	18	0.19 ± 1.65 [−0.49 to 0.87]	0.12	0.5794	----
Control: Δ M3 to M6	15	14	0.74 ± 2.08 [−0.61 to 2.09]	0.35	0.2838	----
Control: Δ M3 to M12	15	18	0.25 ± 1.56 [−0.44 to 0.94]	0.16	0.4738	----
Control: Δ M6 to M12	14	18	−0.49 ± 2.10 [−1.81 to 0.84]	0.23	0.4706	----
Sit-to-stand desk: Δ B to M3	23	21	0.44 ± 1.61 [−0.18 to 1.06]	0.27	0.1634	----
Sit-to-stand desk: Δ B to M6	23	20	0.82 ± 1.62 [0.17 to 1.47]	0.50	0.0133	Y
Sit-to-stand desk: Δ B to M12	23	20	0.81 ± 1.64 [0.13 to 1.49]	0.50	0.0191	Y
Sit-to-stand desk: Δ M3 to M6	21	20	0.38 ± 1.66 [−0.32 to 1.07]	0.23	0.2895	----
Sit-to-stand desk: Δ M3 to M12	21	20	0.37 ± 1.68 [−0.35 to 1.09]	0.22	0.3103	----
Sit-to-stand desk: Δ M6 to M12	20	20	0.00 ± 1.69 [−0.75 to 0.74]	0.00	0.9921	----
Treadmill desk: Δ B to M3	22	22	0.17 ± 1.79 [−0.44 to 0.77]	0.09	0.5895	----
Treadmill desk: Δ B to M6	22	19	0.61 ± 1.75 [−0.03 to 1.26]	0.35	0.0619	----
Treadmill desk: Δ B to M12	22	20	0.01 ± 1.72 [−0.58 to 0.59]	0.00	0.9819	----
Treadmill desk: Δ M3 to M6	22	19	0.45 ± 1.84 [−0.25 to 1.15]	0.24	0.2109	----
Treadmill desk: Δ M3 to M12	22	20	−0.16 ± 1.81 [−0.81 to 0.49]	0.09	0.6336	----
Treadmill desk: Δ M6 to M12	19	20	−0.61 ± 1.76 [−1.29 to 0.08]	0.34	0.0827	----

B, baseline; M3/M6/M12, month 3/6/12 follow-ups; n_1, sample size of the first comparison group; n_2, sample size of the second comparison group; U Trend, unidirectional trend (N,----; Y,).

had a unidirectional trend of engaging in a greater number of total daily standing bouts relative to the treadmill desk group after 6 months, which continued increasing through 12 months (see the table in Supplemental Digital Content 7, *post hoc* comparisons of the number of total daily bouts of physical behaviors, http://links.lww.com/MSS/C252).

A unidirectional within-group increasing trend in total daily standing bouts was observed from baseline to month 6 in the sit-to-stand desk group, which continued increasing through month 12 (see the table in Supplemental Digital Content 7, *post hoc* comparisons of the number of total daily bouts of physical behaviors, http://links.lww.com/MSS/C252). On the contrary, the treadmill desk group showed a unidirectional within-group decreasing trend in total daily standing bouts from months 6 to 12 (see the table in Supplemental Digital Content 7, *post hoc* comparisons of the number of total daily bouts of physical behaviors, http://links.lww.com/MSS/C252).

Bouts at the workplace. Between-group comparisons showed that the treadmill desk group had a unidirectional trend of engaging in fewer daily standing bouts at the workplace relative to the control at baseline, and the magnitude of this difference did not change through month 12 (see the table in Supplemental Digital Content 8, *post hoc* comparisons of the number of daily bouts of physical behaviors at the workplace, http://links.lww.com/MSS/C253). However, the sit-to-stand desk group showed a unidirectional trend of engaging

TABLE 5. Summary of mean daily step counts and the number of waking physical behavior bouts for the total day and at the workplace by randomization group × time point, adjusted for age.

Group	Time Point	*n*	Daily Step Counts (Steps ± SD) Total Time	At Work	Mean Daily Sedentary Bouts (*n* ± SD) Total Time	At Work	Mean Daily Standing Bouts (*n* ± SD) Total Time	At Work	Mean Daily Stepping Bouts (*n* ± SD) Total Time	At Work
Control	Baseline	21	6522 ± 4000	3182 ± 2798	44.28 ± 15.63	30.23 ± 16.99	99.39 ± 31.97	63.88 ± 35.04	54.82 ± 19.03	35.13 ± 19.65
Sit-to stand desk		23	6476 ± 3745	3270 ± 2494	41.17 ± 15.21	24.02 ± 13.08	96.51 ± 31.43	54.05 ± 24.62	54.29 ± 18.65	29.82 ± 13.56
Treadmill desk		22	6725 ± 4129	2683 ± 2526	36.25 ± 15.53	21.31 ± 13.41	89.96 ± 32.75	44.63 ± 25.51	52.94 ± 19.75	23.76 ± 13.96
Control	Month 3	15	6691 ± 3764	3277 ± 2869	43.06 ± 15.06	26.04 ± 14.73	96.91 ± 30.53	57.63 ± 28.54	55.56 ± 17.88	30.26 ± 16.78
Sit-to-stand desk		21	8287 ± 4002	3692 ± 2507	42.35 ± 15.62	26.68 ± 14.07	106.49 ± 31.83	64.01 ± 27.12	62.51 ± 18.95	37.58 ± 15.54
Treadmill desk		22	9057 ± 4810	6331 ± 4725	32.43 ± 18.29	18.59 ± 15.86	84.74 ± 37.75	45.97 ± 32.40	51.14 ± 21.76	26.96 ± 17.06
Control	Month 6	14	8010 ± 4940	4822 ± 6602	48.59 ± 16.36	32.18 ± 13.97	103.26 ± 29.35	63.85 ± 33.33	55.47 ± 20.33	31.74 ± 19.70
Sit-to-stand desk		20	8866 ± 3958	4188 ± 3026	48.75 ± 17.08	28.13 ± 16.72	114.06 ± 34.80	65.06 ± 28.38	64.39 ± 19.93	35.15 ± 14.95
Treadmill desk		19	8812 ± 4829	6124 ± 4819	37.76 ± 19.97	19.09 ± 17.75	103.62 ± 41.73	47.17 ± 36.73	62.38 ± 28.34	29.37 ± 18.28
Control	Month 12	18	6613 ± 3782	3936 ± 3121	47.27 ± 15.64	29.18 ± 15.56	103.75 ± 32.01	59.06 ± 29.41	57.79 ± 18.48	29.49 ± 15.36
Sit-to-stand desk		20	8063 ± 4038	3323 ± 2539	50.56 ± 17.52	30.40 ± 14.39	119.06 ± 36.17	67.83 ± 28.84	66.94 ± 21.01	35.38 ± 14.98
Treadmill desk		20	7794 ± 4244	5336 ± 3492	31.50 ± 16.26	14.18 ± 13.48	84.60 ± 33.83	38.20 ± 25.64	51.40 ± 20.63	26.19 ± 15.34

in a greater number of daily standing bouts at the workplace relative to the treadmill group after 3 months, which continued to increase through month 12 (see the table in Supplemental Digital Content 8, *post hoc* comparisons of the number of daily bouts of physical behaviors at the workplace, http://links.lww.com/MSS/C253).

A unidirectional within-group increasing trend in daily standing bouts at the workplace was observed from baseline to month 12 in the sit-to-stand desk group (see the table in Supplemental Digital Content 8, *post hoc* comparisons of the number of daily bouts of physical behaviors at the workplace, http://links.lww.com/MSS/C253).

Daily stepping bouts. *Total daily bouts.* Between-group comparisons showed that the sit-to-stand desk group had a unidirectional trend of engaging in a greater number of total daily stepping bouts relative to the treadmill group after 12 months (see the table in Supplemental Digital Content 7, *post hoc* comparisons of the number of total daily bouts of physical behaviors, http://links.lww.com/MSS/C252).

A unidirectional increasing trend in total daily stepping bouts was observed from baseline to month 3 in the sit-to-stand desk group and continued increasing through months 6 and 12 (see the table in Supplemental Digital Content 7, *post hoc* comparisons of the number of total daily bouts of physical behaviors, http://links.lww.com/MSS/C252).

Bouts at the workplace. Between-group comparisons showed that the sit-to-stand desk group had a unidirectional trend of engaging in a greater number of daily stepping bouts at the workplace relative to the treadmill group after 3 months (see the table in Supplemental Digital Content 8, *post hoc* comparisons of the number of daily bouts of physical behaviors at the workplace, http://links.lww.com/MSS/C253).

A unidirectional within-group increasing trend in daily stepping bouts at the workplace was observed from baseline to month 3 in the sit-to-stand desk group (see the table in Supplemental Digital Content 8, *post hoc* comparisons of the number of daily bouts of physical behaviors at the workplace, http://links.lww.com/MSS/C253).

Sensitivity Analyses

Similar to the intent-to treat analyses, sensitivity analyses involving complete cases only did not show intervention effects for total daily sedentary time (see the table in Supplemental Digital Content 9, sensitivity analyses, http://links.lww.com/MSS/C254).

DISCUSSION

Overall, we found that the use of both sit-to-stand and treadmill desks resulted in office workers reducing daily sedentary time in favor of increased standing and stepping time. Correspondingly, treadmill desks resulted in office workers engaging in fewer total daily and workplace sedentary bouts but sit-to-stand desk users transitioned to upright physical behaviors more frequently both over the whole day and at the workplace. Hereinafter, we discuss the effects of sit-to-stand and treadmill desks on total durations of behavior and the implications of our findings when compared with prior studies. This is followed by a discussion on the observed frequency of transitioning between types of physical behavior bouts when using these desks.

Total daily and workplace sedentary, standing, and stepping time. Compared with Healy et al. (7), where office workers using sit-to-stand desks over a 12-month period were able to considerably replace sedentary time with standing time at both the workplace and over the total-day, our study demonstrated smaller short-term reductions in total sedentary behavior in the sit-to-stand group relative to the control group. That is, after 3 months, sit-to-stand desk users in Healy et al. reduced total daily and workplace sedentary behavior by an additional 30.0 and 36.1 min over those observed in our study, respectively. Compared with Healy et al. (7), long-term sedentary behavior reduction in our study was smaller at the workplace but greater over the total day. That is, after 12 months, sit-to-stand desk users in Healy et al. reduced sedentary behavior by an additional 4.6 min at the workplace over what was observed in our study, but over the total day, sit-to-stand desk users in our study demonstrated improved reduction by an additional 29.7 min per total day over what was observed by Healy et al. These dissimilarities may be attributable to a higher level of sedentariness (~20%) among participants at baseline and a larger sample size (n = 231) in Healy et al. (7). Compared with our study, a more recent trial by Edwardson et al. (8) reported smaller short-term reductions in sedentary behavior in the sit-to-stand group relative to the control, but larger long-term reductions. That is, after 3 month, sit-to-stand desk users in our study reduced total daily and workplace sedentary behavior by an additional 13.9 and 12.4 min over those observed by Edwardson et al., respectively. However, after 12 months, sit-to-stand desk users in Edwardson et al. reduced total daily and workplace sedentary behavior by an additional 35 and 20.3 min over those observed in our study, respectively. Compared with Healy et al. (7), Edwardson et al. (8) and our study may have been successful in enabling larger long-term reductions in daily sedentary behavior due to more periodic feedback on measured workplace and daily behavior patterns throughout the study. Participants in Healy et al. (7) received no researcher input or feedback on their physical behaviors between months 3 and 12. Taking the findings from the three studies, it would seem that a practical estimate of long-term reductions in workplace sedentary behavior among users of sit-to-stand desk may be approximately 60 $min \cdot d^{-1}$ on average.

Similar to Edwardson et al. (8), users of sit-stand desks in our study increased short- (3 months) and long-term (12 months) workplace and total daily standing time by about an hour. Relative to our trial, standing time gains by sit-to-stand desk users in Healy et al. (7) were greater in the short term both at the workplace (36.2 min) and over the total day (13.7 min), but were similar in the long term.

Although the effect of sit-to-stand and treadmill desks on the accumulation of stepping time was variable in our study, increasing trends in accumulated daily stepping time were suggestive of positive effects. Sit-to-stand desk users demonstrated short- and long-term increases in total daily stepping time (i.e., about an hour at both 3 and 12 months), whereas the treadmill desk users demonstrated short- and long-term stepping time increases at the workplace (i.e., about 45 min at 3 month and 30 min at 12 months). Notably, although the concept of a sit-to-stand desk does not specifically encourage increased physical activity, having an intervention along with periodic counseling during the study to encourage participants to "sit less, stand and move more" may enable users to be more active (17). In a 13-month RCT study by Bergman et al. (15) that exclusively examined the effect of treadmill desks in office workers, there were no significant reductions in total daily sitting or standing time but a significant increase in steps per day. Compared with Bergman et al. (15), treadmill desk users in our study demonstrated greater short- and long-term reductions in sedentary behavior relative to the control group. That is, in the short-term (i.e., 3 months in our trial and 2 months in Bergman et al.) treadmill desk users in our study reduced total daily sedentary behavior by 27 more minutes per day over that observed in Bergman et al. In the long-term (i.e., 12 months in our trial and 13 months in Bergman et al.), treadmill desk users in our study reduced total daily sedentary behavior by an additional 40 $\text{min}\cdot\text{d}^{-1}$ over that observed by Bergman et al. Although users of treadmill desks in our study increased daily steps per day after 6 months, similar to Bergman et al. (15), gains in steps per day were not sustained in the long term. Gains in daily steps counts ranging from ≈1800 to 2400 steps per day in both intervention groups after 3 and 6 months in our study represent a relative increase of 25%–35% in step volume. This aligns with the 2018 Physical Activity Guidelines Advisory Committee's viewpoint that any gain in the overall volume of active movement among sedentary individuals contributes to health benefits (34).

Because all other intervention components were similar for both the sit-to-stand and treadmill desk groups in our study, findings suggest that sit-to-stand and treadmill desks may elicit a different behavior change response among users. Access to a sit-to-stand desk may enable gains in positive behavior to be accrued both at and outside the workplace. It seems that the availability of a treadmill desk at work may encourage office workers to accumulate most of the gains in standing and stepping time at the workplace. We are unable to determine the reason for this variable response in our study, which may be explored in future work. Thus, interventions using treadmill desks may need specific messaging that also promote overall daily movement to ensure that users avoid prolonged sedentary bouts when they are not at the workplace.

Number of total daily and workplace sedentary, standing, and stepping bouts. In summary, (i) compared with controls and sit-to-stand desks, treadmill desks enabled positive long-term reductions in the number of total daily and workplace sedentary bouts (i.e., at 12 months by 16 and 19 bouts over the whole day and by 15 and 16 bouts at the workplace, respectively); (ii) compared with treadmill desks, sit-to-stand desks facilitated greater increases in the number of total daily standing bouts (i.e., at 12 months by 34 bouts) and workplace standing bouts (i.e., at 3 and 12 months by 18 and 30 bouts, respectively); and (iii) compared with treadmill desks, sit-to stand desks also facilitated greater increases in the total number of total daily stepping bouts (i.e., at 12 months by 16 bouts) and workplace stepping bouts (i.e., at 3 months by 11 bouts).

The aforementioned findings suggest that sit-to-stand desks may be more successful than treadmill desks in breaking up daily sedentary behavior more frequently and in sustaining this pattern for a longer period of time; this needs to be explored in future larger studies. Thus, sit-to-stand desks may allow users to meet the 2018 Physical Activity Guidelines Advisory Committee Scientific Report's recommendation to frequently break and replace daily sedentary behavior with light intensity physical activity. The report considers standing during work tasks as light-intensity activity (34) and states that individuals who perform no or little moderate-to-vigorous physical activity could reduce their risks for cardiovascular disease and diabetes and that for all-cause mortality by replacing sedentary behavior with light-intensity activity (34).

CONCLUSIONS

In addition to increasing short-term standing at the workplace, our findings suggest the use of sit-to-stand desks may also translate into increased medium- (6 months) and long-term (12 months) overall daily stepping. Our findings among users of treadmill desks suggested that stepping gains did not extend outside the workplace. More work is required to investigate the reasons for observed discrepancies between sit-to-stand and treadmill desks. In addition, translating short-term sedentary behavior reductions attributable to the initial novelty factor of the interventions to habitual behavior may require a higher frequency of motivation, support, and coaching than what was provided in this study.

Our work may serve as a foundation to develop new hypotheses to test the following: 1) strategies that leverage desk-based behavior change at the workplace to positively impact overall daily behavior; 2)if both sit-to-stand and treadmill desks enable office workers to engage in fewer daily sedentary bouts and helps them engage in upright physical behaviors more frequently; and 3) if users of sit-to-stand desks sustain potentially beneficial behavior patterns to a greater extent than users of treadmill desks.

Strengths and limitations. Strengths of our study included a cluster randomized controlled intervention design with a 1-yr follow-up and a head-to-head comparison of sit-to-stand and treadmill desks.

Although losses to follow-up are unlikely to have biased the results given that data were determined to be missing at random, the generalizability of this study's findings may be limited by the fact that some attrition rates (see the figures in Supplemental Digital Content 1 and 3, enrollment, participation, attrition, and analyses for total daily time and at the workplace, respectively, http://links.lww.com/MSS/C246 and

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http://links.lww.com/MSS/C248) were higher than what the study was powered to handle (i.e., 20%). Relatedly, a smaller sample in comparison to the few other long-term active workstations intervention studies that are currently available may have resulted in a reduced ability to detect intervention effects. Another limitation of this study is the inability to provide an analysis of the "24-h activity cycle" because we did not measure sleep. In addition, a higher number of women in our study limit the generalizability of our findings with regard to male seated office workers. Although there were several intervention components, the specific contributions of each component on the observed effects were not determined. Furthermore, our study did not use a preinvestigation educational approach (7,8) of assessing participant's baseline knowledge of the risks of sedentary behavior to enhance the acceptability and responsiveness of the intervention.

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The authors report no conflict of interest. The results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation. The results of the present study are an original investigation and do not constitute endorsement by the American College of Sports Medicine.

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