Active Workstations Do Not Impair Executive Function in Young and Middle-Age Adults

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ABSTRACT

EHMANN, P. J., C. J. BRUSH, R. L. OLSON, S. N. BHATT, A. H. BANU, and B. L. ALDERMAN. Active Workstations Do Not Impair Executive Function in Young and Middle-Age Adults. *Med. Sci. Sports Exerc.*, Vol. 49, No. 5, pp. 965–974, 2017. **Purpose**: This study aimed to examine the effects of self-selected low-intensity walking on an active workstation on executive functions (EF) in young and middle-age adults. **Methods**: Using a within-subjects design, 32 young (20.6 ± 2.0 yr) and 26 middle-age (45.6 ± 11.8 yr) adults performed low-intensity treadmill walking and seated control conditions in randomized order on separate days, while completing an EF test battery. EF was assessed using modified versions of the Stroop (inhibition), Sternberg (working memory), Wisconsin Card Sorting (cognitive flexibility), and Tower of London (global EF) cognitive tasks. Behavioral performance outcomes were assessed using composite task *z*-scores and traditional measures of reaction time and accuracy. Average HR and step count were also measured throughout. **Results**: The expected task difficulty effects were found for reaction time and accuracy. No significant main effects or interactions as a function of treadmill walking were found for tasks assessing global EF and the three individual EF domains. Accuracy on the Tower of London task was slightly impaired during slow treadmill walking for both age-groups. Middle-age adults displayed longer planning times for more difficult conditions of the Tower of London during walking compared with sitting. A 50-min session of low-intensity treadmill walking on an active workstation resulted in accruing approximately 4500 steps. **Conclusions**: These findings suggest that executive function performance remains relatively unaffected while walking on an active workstation, further supporting the use of treadmill workstations as an effective approach to increase physical activity and reduce sedentary time in the workplace.

Key Words: COGNITIVE CONTROL, TREADMILL DESK, PHYSICAL ACTIVITY, SITTING, SEDENTARY BEHAVIOR, COGNITION

Modern sedentary lifestyles have been linked with many of the leading causes of morbidity and mortality, including cardiovascular disease, diabetes, and some forms of cancer (4,22). The workplace is a particular aspect of our modern lifestyle that poses a challenge toward increasing physical activity and decreasing sedentary time and may serve as an ideal context to implement evidence-based interventions (35). In 2015, an expert panel was commissioned to address sedentary behaviors in the workplace and recommended that workers initially strive to accumulate 2 h of standing and light activity (light walking) across the work day to reduce the risk of cardiometabolic diseases and premature mortality associated with sitting (7). One innovative approach to meet these goals involves implementing sit-to-stand active workstations or "treadmill desks" in the workplace. Active workstations have received considerable attention for the past decade (21,38,40) and represent an effective approach to break up the long hours of sitting typical of the modern working environment.

Several psychological and physiological health benefits (e.g., reducing stress and increasing energy expenditure) may be accrued as a result of using treadmill desks in the workplace (17,21,28). For instance, Koepp et al. (18) reported that office workers undergoing a 1-yr treadmill desk intervention experienced significant improvements in weight loss ($\Delta = -1.4$ kg), serum HDL levels ($\Delta = +4.0$ mg·dL^{-1}), systolic blood pressure ($\Delta = -3.0$ mm Hg), and waist circumference ($\Delta = -4.0$ cm), all of which are known risk factors for cardiovascular disease. Despite these promising health benefits, it remains unclear whether walking on a treadmill desk interferes with job performance. Early studies reported impairments in office-based tasks involving fine motor skills, such as typing and computer mouse use, while walking at slow speeds on a treadmill (16,33). However, others suggested that these dual-task–related impairments may be reduced if individuals are allowed to habituate to a treadmill desk (36). More recently, investigators have focused on whether light treadmill walking, as would be implemented during the work day, results in impairments in

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higher-level executive function or cognitive control processes (1,19,20). Executive function refers to a subset of higher-order processes (e.g., problem solving, reasoning, and planning) that manage more basic cognitive functions and emotions to help guide effortful goal-directed behaviors, especially in circumstances when automatic instincts or intuitions are insufficient or unnecessary. These cognitive processes are particularly relevant for success in the workplace, as they are instrumental to problem solving, taking the time to think before acting, staying focused, and meeting novel, unanticipated challenges (12).

Using a between-subjects design, Larson et al. (19) randomized 69 participants to either a walking (1.5 mph) or a sitting condition while having them simultaneously complete modified versions of Eriksen flanker and go/no go tasks on a treadmill workstation. They examined executive control measures of conflict adaptation, posterror slowing, and response inhibition and found no significant differences between conditions for any of the cognitive control measures. Similarly, Alderman et al. (1) used a within-subjects design where participants completed the Stroop test, a modified flanker task, and a test of reading comprehension while at rest and while walking at a self-selected speed on a treadmill desk. No significant differences in reaction time or accuracy were found for any of the tasks between the sitting and the treadmill walking conditions. Although the selected cognitive tasks in both of these studies only assessed one domain of executive function (i.e., inhibition), although it is generally believed that there are three core domains of executive function: inhibition, working memory (or updating), and cognitive flexibility (or switching [24]). It is possible that the dual-task nature of walking on a treadmill desk may impair select executive function domains, yet this possibility has yet to be thoroughly examined. In addition, it may be that relatively simple experimental tasks used to assess each of the specific domains of executive function are less susceptible to dual-task impairments, whereas more complex, demanding tasks that involve multiple executive functions (i.e., global executive function) may be impaired. Furthermore, participants in nearly all of the most recent studies examining the potential influence of walking at a treadmill desk on task-related performance or cognitive function have been of college age (1,19,20). It is possible that cognitive function and task performance among older adults is differentially influenced while walking on a treadmill desk relative to young adults. In a recent study examining the moderating influence of age on the relationship between walking and cognitive function, Tomporowski and Audiffren (37) assessed cognitive flexibility using an auditory switch task in younger (20.8 yr) and older adults (71.5 yr) while standing, treadmill walking at a self-selected speed, and treadmill walking at 150% of their self-selected speed. As walking speed increased, behavioral performance declined linearly in older adults but remained stable in young adults. Findings from this study suggest that the cognitive flexibility domain of executive function may be susceptible to impairments in dual-task performance among older, but not younger adults. To establish the efficacy and feasibility of incorporating treadmill desks into the workplace, research examining the effects of slow treadmill walking on the three core executive function domains among a wider population of working-age adults is warranted.

Accordingly, the primary purpose of this study was to examine the effects of slow walking at a treadmill workstation on executive function in both young and middle-age adults. To more comprehensively understand whether executive function is affected by slow treadmill walking, the domains of inhibition, working memory, and cognitive flexibility were assessed, along with a more complex cognitive task that relies on multiple executive function domains for successful performance. On the basis of previous studies, it was hypothesized that executive function would not be affected by slow walking relative to sitting in younger adults, but subtle deficits would be apparent in middle-age adults due to the dual-task nature of walking and simultaneous computerized cognitive testing. This subtle dual-task impairment was expected during performance of the more complex global executive function task (Tower of London), but not for tasks of the individual executive function domains. Lastly, an exploratory aim of the study was to quantify HR and step count during a 50-min treadmill walking condition to estimate the influence of this brief intervention in meeting recommendations toward increasing physical activity and reducing sedentary time in the workplace (7).

METHODS

Participants

Individuals between the ages of 18 and 65 yr from Rutgers University and the surrounding communities were recruited to participate through the use of posted flyers and advertisements. Participants in the middle-age group were between 31 and 65 yr of age, whereas participants in the younger group were between 18 and 28 yr old. All participants were native English speakers and reported normal or corrected-to-normal vision without color blindness. Exclusion criteria included the presence or history of cardiovascular, neurological, or musculoskeletal problems that would affect exercise or treadmill walking ability, past or present history of psychiatric or neurological disorders (e.g., attention deficit hyperactivity disorder, clinical depression or anxiety, and any head injury with loss of consciousness), or medication use aside from oral contraceptives. Sixty-one participants (28 females) met the inclusion criteria; however, three participants completed the initial familiarization session but failed to follow-up or complete one or both of the experimental sessions and were therefore removed from all analyses. Thus, a total of 58 participants (32 young and 26 middle-age adults) completed all three testing sessions. All participants provided written informed consent in accord with study procedures approved by the Institutional Review Board at Rutgers, The State University of New Jersey.

Procedures

Participants visited the laboratory on three separate occasions, each separated by at least 48 h. Participants were asked to avoid exercise for 24 h and stimulants (e.g., caffeine and nicotine) for 3–4 h before each session. During the initial session, participants provided written informed consent and completed health history and physical activity readiness (PAR-Q) questionnaires to ensure safety for the aerobic fitness assessment and treadmill walking. The initial testing day served as a familiarization to the treadmill desk (TrekDesk, Phoenix, AZ) and executive function test battery. Participants were allowed to choose a walking speed (between 0.5 and 2.5 mph at 0% grade) they felt most comfortable with while using a desktop computer that sat on the treadmill desk. The height of the desk was adjusted so that the computer monitor was situated approximately 24 inches from each participant at eye level. The speed and height was noted and used for the subsequent experimental sessions. During this session, participants were familiarized to the four executive function tasks. Practice trials were performed for all tasks while walking and sitting at the adjustable workstation, with the purpose of understanding task directions and becoming comfortable and proficient with completing the tasks using a Logitech keyboard and mouse. Before completing each task, written and verbal instructions were provided and any questions were answered. The familiarization session lasted approximately 54 ± 14 min. After familiarization, participants completed a maximal graded exercise test on the treadmill for the determination of peak cardiorespiratory fitness ($\dot{V}O_{2peak}$).

To reduce potential order effects, participants completed sitting and walking conditions on the adjustable workstation in a counterbalanced order across two experimental sessions. When participants arrived to the laboratory, an accelerometer was affixed to their waistband at the hip above knee line to assess the number of steps taken during the testing session. Participants were given a 5-min familiarization period of slow walking at the treadmill workstation at their preferred speed (see Larson et al. [19]) before commencing the cognitive tasks. For the walking condition, the desk was adjusted to the predetermined height and participants maintained their preferred walking speed while completing the executive function test battery. During the sitting condition, the desk was again adjusted to the predetermined height and participants remained seated on an adjustable elevated chair while completing the executive function test battery. Participants were instructed to respond as quickly and as accurately as possible for all cognitive tasks. The four cognitive tasks were presented in random order with a 2-min rest period between each task. In the walking condition, participants continued to walk during rest periods to simulate a workplace environment whereas participants in the sitting condition remained seated. At the conclusion of the third session, participants were briefed about the purpose of the study and compensated $25 for participating.

Executive Function Tasks

The four executive function tasks were administered in random order using the open-source Psychology Experiment Builder Language v0.14 for Windows [25]. Previous studies have demonstrated adequate validity and test–retest reliability of the Psychology Experiment Builder Language tasks assessing individual domains of executive function and higher-order problem solving abilities (e.g., Piper et al. [29]).

Stroop color–word task. Participants completed a modified version of the Stroop Color–Word Task (34) as a measure of inhibition. Stimuli were words of different colors (i.e., red, blue, green, and yellow) printed in either same (congruent trials; e.g., the word RED in red ink) or different (incongruent trials; e.g., the word RED in green ink) ink color. Participants were instructed to respond (using a number pad) to the color of the ink, while inhibiting the meaning of the word. Stimuli were presented on the computer screen for 2000 ms after a 1000-ms fixation cross (+). Participants completed six blocks of 32 trials with random and equiprobable congruent and incongruent trials. Dependent measures for the Stroop task included reaction time (ms) and accuracy (%).

Sternberg working memory task. A visual Sternberg task (32) was used as a measure of working memory. At the beginning of each test block, participants were asked to remember (encode) variable lists of three, five, or seven letters (e.g., MFB, GSZKQ, and DJSQVTN). After encoding the list, a random sequence of single letters was presented, and participants were asked to identify whether each single letter was presented in the original three-, five-, or seven-letter list. Participants pressed the left Shift key to indicate that the letter was present and the right shift key to indicate that the letter was absent from the original encoded list. After an incorrect response, the original list appeared as a refresher. Participants completed six blocks of 50 trials, with two blocks dedicated to each list length. Reaction time (ms) and accuracy (%) measures were recorded and used as dependent measures.

Wisconsin card sorting test. The Wisconsin Card Sorting Test (3) was used as a measure of cognitive flexibility. In this task, participants were asked to match stimulus cards with four category cards fixated at the top of the screen that varied according to shape (triangle, star, cross, or square), color (red, yellow, green, or blue), and number (one, two, three, or four). Each category defined a sorting rule, and the stimuli included one red triangle, two yellow stars, three green crosses, and four blue circles. The objective of the task was to match a preordained sorting rule given feedback (“Correct” or “Incorrect”) after each sort. After correctly sorting 10 consecutive trials, the rule changed and participants had to adapt and match cards according to a new sorting rule. Participants completed 128 trials and were unaware of the correct sorting principle and sorting rule shifts during the task. Two types of errors were possible: perseverative errors (PE), when the previous rule set was maintained despite a change in rule, and nonperseverative errors (NPE), when a card was sorted incorrectly based on a different rule than the previous rule set. More PE indicated a lack of flexibility, whereas more NPE indicated an ineffective switching strategy. Overall accuracy (%) was also used as a dependent measure.

Tower of London task. A modified Tower task (31) was used to assess the planning aspect executive function and because it is a more complex cognitive task that taps multiple executive function domains. This task measures problem-solving abilities by having participants model a pile of colored discs from their original location to a desired orientation in as few moves as possible within 120 s. Before the first move, participants were encouraged to plan out the solution to the problem in the least amount of moves as possible. A successful completion of this task requires participants to plan and solve the problem cognitively before actually moving the discs. Thirty trials of increasing difficulty were administered: 10 trials requiring four moves, 10 trials requiring five moves, and 10 trials requiring six moves. Dependent measures included planning time (ms), total execution time (ms), and accuracy (%). Planning time (PT) is the time between the presentation of the initial disc arrangement and the first move. Total execution time (TET) is the time between stimulus onset and completion of the trial (for successful trials), and accuracy was assessed by how many of the problems were solved in the minimum number of moves divided by the total number of trials. Lower planning and total execution time and higher accuracy reflect greater global executive function.

Additional Measures

HR. HR was assessed throughout the experimental sessions using a Polar RS800CX HR monitor and transmitter (Polar, Kempele, Finland). Continuous HR data were averaged across the entire session for each experimental condition. Before familiarization procedures, resting HR was assessed during a 5-min resting period in a seated, upright position.

Step count. Step count data were collected throughout each session using a FitBit Zip™ tri-axial accelerometer (FitBit, San Francisco, CA). In addition, walking speed and time taken to complete the executive function test battery were recorded to the nearest 0.1 mph and min, respectively.

Cardiorespiratory fitness. Cardiorespiratory fitness ($\dot{V}O_{2peak}$) was assessed using a modified Bruce protocol (2), which involved increasing the speed and grade of the treadmill every 2 min until volitional exhaustion was reached. A Polar HR monitor was used to record HR throughout the test. $\dot{V}O_{2peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$) was determined from direct expired gas exchange data from a computerized metabolic system (Parvo Medics True Max 2400 Metabolic Cart; ParvoMedics, Inc., Sandy, UT) and averaged across 15-s intervals. $\dot{V}O_{2peak}$ was defined as the maximal rate of oxygen consumption per kilogram of body weight at the point when at least three of the following four criteria were met: 1) a plateau in oxygen consumption corresponding to an increase of less than 150 mL in oxygen uptake despite a progressive increase in workload, 2) HR within 10 bpm of age-predicted maximal values (220 bpm − age in years), 3) an RER greater than 1.10, or 4) an RPE greater than or equal to 17. Upon completion of the assessment, a 5-min cooldown was administered at 2.5 mph and 0% grade.

Sample Size Calculation

The sample size needed to achieve statistical power >80% to detect a small effect size (global executive function performance during walking relative to sitting) of Cohen's $f = 0.13$ was based on a meta-analytic review of executive function task performance during exercise (Cohen's $d = 0.26$; see [10]). We conducted a power analysis in G*Power (v 3.9.1.2) for a two-group, repeated-measures ANOVA that tests the within–between factors interaction with the correlation among repeated-measures set at 0.80 (see [6]). At least 50 participants (25 per group) were needed to attain sufficient power to test the primary hypothesis (i.e., a significant age × condition interaction for the global executive function task).

Statistical Analyses

Descriptive statistics were conducted to examine differences in participant demographics using individual independent sample *t*-tests. In addition, intensity manipulation and step count data were assessed using paired samples *t*-tests to compare average HR and steps by condition. The independent variables in the experiment were condition (sitting and walking) and age (young and middle-age). The dependent variables included the cognitive performance outcomes for each of the four executive function tasks. The behavioral performance across tasks was screened for normality, and reaction times were omitted from analyses if the response was undetected, incorrect (except for the Wisconsin card sorting test), or ±3 SD from the mean for a block of trials. To reduce the number of statistical tests performed, composite *z*-scores of cognitive performance outcomes for the Stroop, Sternberg, Wisconsin card sorting, and Tower of London tasks were calculated to reflect overall performance for each domain and for global executive function. For reaction time measures, *z*-scores were inverted so that a higher score reflected better performance. To calculate a composite score for each executive function domain, an average *z*-score was calculated from the outcome measures for each task.

Differences in cognitive outcomes were analyzed using mixed-design ANOVAs with condition and cognitive task condition as within-subjects factors and age as a between-subjects factor. Composite *z*-scores for each task were assessed using a 2 (condition: walking and sitting) × 2 (age: young and middle-age) ANOVA. The Stroop task was analyzed using a 2 (condition: walking and sitting) × 2 (congruency: congruent and incongruent) × 2 (age: young and middle-age) ANOVA to assess inhibition. For the Sternberg task, a 2 (condition: walking and sitting) × 3 (set size: 3, 5, and 7) × 2 (age: young and middle-age) ANOVA was

TABLE 1. Participant demographics by age (mean ± SD).

Characteristic	Young Adults	Middle-Age Adults
Sample size (♀)	32 (15)	26 (11)
Age (yr)*	20.6 ± 2.0	45.6 ± 11.8
BMI (kg·m^{-2})	23.2 ± 3.3	24.1 ± 3.5
Resting HR (bpm)	72.6 ± 8.6	71.1 ± 9.1
$\dot{V}O_{2peak}$ (mL·kg^{-1}·min^{-1})*	43.6 ± 11.4	32.6 ± 10.2

*Significant difference, unpaired *t*-test between groups, $P < 0.05$.

conducted to examine working memory performance. Because the Wisconsin card sorting test has only one task condition, a 2 (condition: sitting and walking) × 2 (age: young and middle-age) mixed-design ANOVA was used to analyze cognitive flexibility performance. Global executive function using the Tower of London task was analyzed using a 2 (condition: sitting and walking) × 3 (number of moves: 4, 5, and 6) × 2 (age: young and middle-age) ANOVA.

To explore the potential influence of cardiorespiratory fitness in the relationship between acute exercise and cognition (9), separate mixed-design ANOVAs were conducted with $\dot{V}O_{2peak}$ as a between-subjects factor. To account for age- and sex-related differences in cardiorespiratory fitness, a median split was conducted on $\dot{V}O_{2peak}$ data within each age (young and middle-age) and sex (male and female) category. A two-tailed familywise error rate of $P < 0.05$ was used for all statistical analyses, and when sphericity was violated, the Greenhouse–Geisser epsilon correction was used to adjust probability values (15). *Post hoc* Bonferroni corrected *t*-tests were conducted for multiple comparisons, and effect size estimates are reported as partial eta-squared (η^2_p) values for significant main effects and interactions. All statistical analyses were conducted using JASP version 0.7.5.6 (JASP Team; software available from https://jasp-stats.org/).

RESULTS

Participant demographics are presented in Table 1. Preliminary analyses revealed expected fitness differences by age-group, such that young adults had higher $\dot{V}O_{2peak}$ than middle-age adults (43.6 ± 11.4 mL·kg^{-1}·min^{-1} vs 32.6 ± 10.2 mL·kg^{-1}·min^{-1}). No significant differences by age were found for BMI and resting HR, $P > 0.05$.

Cognitive performance data for each task are presented in Table 2. No significant main effects or interactions by fitness were found for any of the executive function dependent variables, $P > 0.05$. Consistent with the task condition effects found in the literature for behavioral performance outcomes, the expected congruency (Stroop: reaction time and accuracy), set size (Sternberg: reaction time and accuracy), and number of moves (Tower of London: planning time, total execution time, and accuracy) effects were observed, $P < 0.05$. For the composite *z*-scores for each of the executive function tasks, the 2 (condition: walking and sitting) × 2 (age: young and middle-age) ANOVAs revealed a significant main effect of age, $P < 0.05$, with impaired performance for middle-age relative to younger adults across all tasks. No significant condition or condition–age interactions were found for any of the executive function tasks, $P > 0.05$ (see Fig. 1).

Inhibition (Stroop task). For reaction time, the analyses revealed a main effect of age, $F(1,56) = 51.5$, $P < 0.001$, $\eta^2_p = 0.48$, such that young adults responded more quickly than middle-age adults. This was superseded by a congruency–age interaction, $F(1,56) = 4.2$, $P < 0.05$, $\eta^2_p = 0.07$, indicating that middle-age adults exhibited a larger congruency effect (120.2 ms) relative to young adults (85.5 ms) that was driven by slower responses on both congruent and incongruent trials. No other main effects or interactions were observed for reaction time and accuracy.

Working memory (Sternberg task). For reaction time, there was a main effect of age, $F(1,56) = 12.4$, $P < 0.001$, $\eta^2_p = 0.18$, indicating slower response speed for middle-age relative to young adults. There was also a main effect of age for accuracy, $F(1,56) = 3.8$, $P < 0.05$, $\eta^2_p = 0.07$, which was superseded by a set size–age interaction, $F(2,55) = 5.7$, $P < 0.05$, $\eta^2_p = 0.09$. The decomposition of the interaction indicated that there were larger reductions in accuracy for middle-age (−8.5%) compared with young adults (−5.2%) on the most difficult task trials (set size 7) relative to the least difficult trials (set size 3). No additional main effects or interactions were found.

Cognitive flexibility (Wisconsin card sorting test). The analyses revealed main effects of age for PE, $F(1,56) = 8.0$, $P < 0.05$, $\eta^2_p = 0.13$; NPE, $F(1,56) = 11.7$,

TABLE 2. Behavioral performance data for all executive function tasks (mean ± SD).

	Young Adults		Middle-Age Adults	
Condition	Sitting	Walking	Sitting	Walking
Stroop				
Accuracy (%)				
Congruent	96.7 ± 0.7	97.3 ± 0.7	97.0 ± 0.8	96.8 ± 0.8
Incongruent	93.6 ± 2.7	93.6 ± 2.5	88.4 ± 3.0	89.6 ± 2.7
Reaction time (ms)				
Congruent	700.1 ± 27.3	692.7 ± 25.0	960.9 ± 30.3	955.1 ± 27.7
Incongruent	782.8 ± 29.0	780.8 ± 28.8	1084.5 ± 32.2	1071.9 ± 31.9
Sternberg				
Accuracy (%)				
3-set	97.7 ± 0.3	97.5 ± 0.3	96.7 ± 1.3	96.3 ± 1.1
5-set	96.2 ± 0.5	96.1 ± 0.4	95.0 ± 1.2	95.2 ± 1.0
7-set	92.3 ± 0.6	92.5 ± 0.6	87.5 ± 2.3	88.4 ± 1.7
Reaction time (ms)				
3-set	707.6 ± 32.9	678.6 ± 32.2	895.1 ± 36.5	925.9 ± 35.7
5-set	839.5 ± 37.6	801.6 ± 32.6	991.4 ± 41.7	971.4 ± 36.1
7-set	1002.0 ± 44.5	966.7 ± 44.8	1154.6 ± 49.3	1115.7 ± 49.7
Wisconsin Card Sorting				
Accuracy (%)	83.6 ± 2.0	84.2 ± 1.8	73.1 ± 2.2	73.9 ± 2.0
PE (no.)	11.7 ± 1.1	12.9 ± 1.3	15.5 ± 1.2	16.8 ± 1.5
NPE (no.)	8.3 ± 2.7	6.3 ± 1.9	18.2 ± 3.0	16.0 ± 2.2
Tower of London				
Accuracy (%)				
4 moves	77.5 ± 3.0	68.4 ± 3.3	57.7 ± 3.4	54.8 ± 3.7
5 moves	61.9 ± 4.0	55.9 ± 4.2	39.6 ± 4.4	39.2 ± 4.7
6 moves	57.6 ± 4.5	51.0 ± 4.5	34.6 ± 5.0	33.3 ± 5.0
PT (ms)				
4 moves	8291 ± 923	8418 ± 647	11,953 ± 1024	10,477 ± 718
5 moves	14,751 ± 1296	12,216 ± 1084	12,135 ± 1438	12,276 ± 1202
6 moves	15,675 ± 1357	14,410 ± 1661	12,481 ± 1505	15,078 ± 1843
TET (ms)				
4 moves	12,566 ± 724	12,971 ± 742	20,736 ± 1752	19,951 ± 1114
5 moves	21,636 ± 1283	19,384 ± 1223	23,763 ± 2087	24,648 ± 1727
6 moves	24,161 ± 1497	23,920 ± 1563	28,399 ± 2094	30,777 ± 2801

PT, planning time; TET, total execution time.

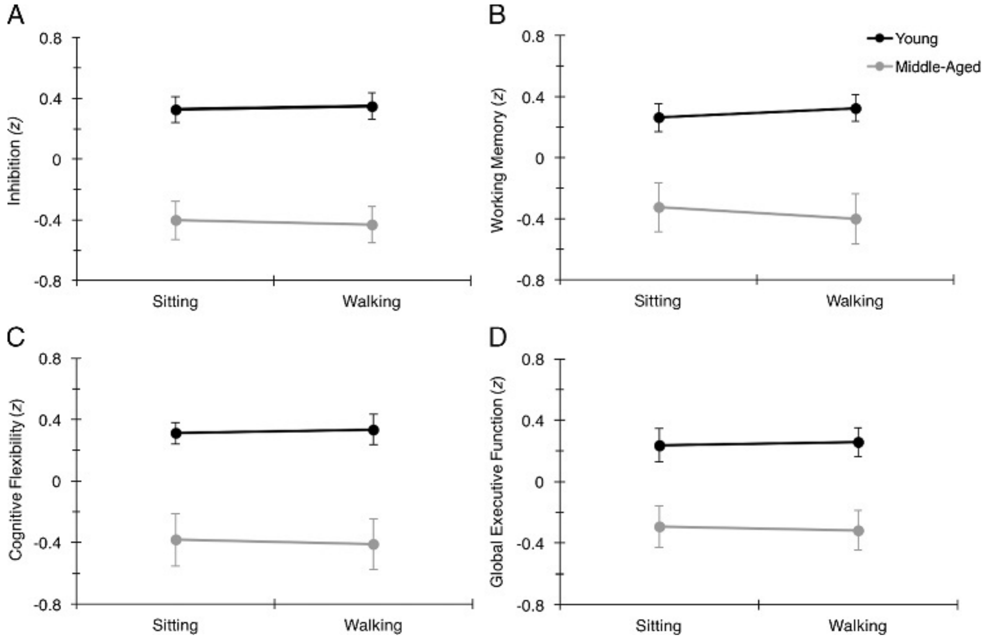

FIGURE 1—Composite *z*-scores (mean ± SD) for inhibition (A), working memory (B), cognitive flexibility (C), and global executive function (D) during sitting and walking conditions in both young and middle-age adults. Performance was significantly better among young adults relative to middle-age adults across task conditions. No effects due to treadmill walking were observed.

$P = 0.001$, $\eta^2_p = 0.17$; and accuracy, $F(1,56) = 17.0$, $P < 0.001$, $\eta^2_p = 0.23$, such that middle-age adults committed more PE and NPEs and had lower overall accuracy than young adults. No other main effects or interactions were observed for cognitive flexibility.

Global executive function (Tower of London). For accuracy, the analyses revealed a main effect of age, $F(1,56) = 20.9$, $P < 0.001$, $\eta^2_p = 0.27$, such that middle-age adults were less accurate than younger adults. There was also a main effect of condition, $F(1,56) = 4.2$, $P < 0.05$, $\eta^2_p = 0.07$, indicating impaired accuracy during walking relative to sitting. For planning time, there was a significant number of moves–age interaction, $F(2,55) = 7.4$, $P < 0.001$, $\eta^2_p = 0.12$, which was superseded by a condition × number of moves–age interaction, $F(2,55) = 4.7$, $P < 0.05$, $\eta^2_p = 0.08$. The decomposition of the interaction revealed that young adults displayed longer planning time for trials with increasing number of moves during the sitting condition, such that planning time for trials with four moves was significantly shorter than for trials with 5 moves, $t(31) = -4.3$, $P < 0.05$, and 6 moves, $t(31) = -5.0$, $P < 0.05$. There were no differences in planning time between trials requiring a different number of moves in middle-age adults during the sitting condition, $P > 0.05$. For total execution time, there was a main effect of age, $F(1,56) = 8.9$, $P < 0.05$, $\eta^2_p = 0.14$, such that middle-age adults were slower in completion of the task relative to young adults. This was superseded by number of moves–age interaction, $F(2,55) = 3.9$, $P < 0.05$, $\eta^2_p = 0.07$. The decomposition of the interaction revealed that there was an increase in total execution time as the number of moves increased from 4 to 6 particularly for young relative to middle-age adults (+11.3 s vs +9.2 s).

Exercise intensity and step count. Data regarding physical activity and step count during both experimental conditions are presented in Table 3. The average preferred treadmill speed was 1.85 ± 0.35 mph, and no difference in selected treadmill walking speed was observed by age, $F(1,56) = 2.1$, $P > 0.05$, $\eta^2_p = 0.04$. As expected, significant differences in HR were observed between conditions, $t(57) = 14.6$, $P < 0.001$, indicating higher average HR while walking relative to sitting. However, there was no significant age–condition interaction, $F(1,56) = 0.4$, $P > 0.05$, $\eta^2_p = 0.01$. Approximately 4508 ± 955 steps were accrued during the 51.4 ± 8.2-min treadmill walking session. Given the age main effects for reaction time measures, middle-age adults spent significantly more time completing the test battery (54.4 ± 1.6 min) compared with young adults (48.3 ± 1.3 min). This resulted in a significantly higher step count for middle-age (4933 ± 175 steps) relative to young adults (4164 ± 155 steps) during the walking condition, $t(57) = 3.3$, $P < 0.05$.

DISCUSSION

The purpose of this study was to investigate the concurrent effect of low-intensity walking at a treadmill workstation on executive function performance in young and

TABLE 3. Intensity and physical activity by condition (mean ± SD).

Variable	Sitting	Walking	*t*	*P*
Intensity				
HR (bpm)	78.4 ± 9.0	96.3 ± 11.1	14.6	<0.001
Physical activity				
Steps	–	4509 ± 955.5	–	–
Steps per minute	–	87.8 ± 13.8	–	–
Time (min)	51.4 ± 8.2	50.6 ± 8.7	0.9	0.365

middle-age adults. The three executive function domains of inhibition, working memory, and cognitive flexibility were assessed, along with a more complex cognitive task (Tower of London) that recruits multiple executive function domains for successful performance. The majority of studies to date have focused on college-age participants; thus, it was initially hypothesized that treadmill walking would not impair executive function in younger adults, but subtle deficits would become apparent among middle-age adults because of the simultaneous performance of walking and computerized cognitive testing. Because of the relatively small effects of exercise on executive function, this subtle influence among older adults was only expected for the more complex cognitive task (37). The primary hypothesis was partially supported in that no differences in performance for each of the three individual executive function domains were found during walking compared with sitting in either younger or middle-age adults. There was an influence of walking on the global executive function task (Tower of London), indicated by a slight impairment in accuracy for both age-groups. However, when all of the performance measures for this task were combined into a composite measure, no effect of treadmill walking was found. Aside from this finding, the results for the Stroop, Sternberg, and Wisconsin card sorting tasks replicate previous studies examining the influence of walking at a treadmill desk on cognitive control and executive control functions in younger adults (1,19) and extend the findings to middle-age adults who are often faced with modern, sedentary occupations (40). An exploratory aim of the study was to quantify the number of steps taken while treadmill walking to determine the influence of this brief intervention in meeting recommendations for physical activity and sedentary time in the workplace (7). Participants accrued approximately 4500 steps during the 50-min walking condition, supporting recent public health recommendations of 2 $\text{h}\cdot\text{d}^{-1}$ of standing and light activity in the workplace. Our findings suggest that individual domains of executive function remain relatively unaffected while walking on an active workstation in both young and middle-age adults; however, more complex tasks requiring multiple executive functions may be more susceptible to dual-task impairments, particularly among middle-age and older adults. These results also support the use of treadmill workstations as an effective approach to increase physical activity and reduce sedentary time in the workplace, while presumably resulting in minimal impairments in work-related performance.

In 2007, Levine and Miller (21) suggested that active “walk-and-work” desks could increase energy expenditure by 100 $\text{kcal}\cdot\text{h}^{-1}$ and may constitute a meaningful approach to achieve weight loss among sedentary, obese individuals. Soon after, investigators became interested in testing whether the use of active workstations would interfere with job performance (16,27,33). However, initial studies in this area mainly focused on typing performance and point-and-click tasks. Although several these studies reported impaired performance on these fine-motor skills during walking relative to sitting (16,33,36), a familiarization period was not provided; thus, the novelty of walking while working on an active workstation may have accounted for much of the variability in impaired performance. Given the influence of higher-level executive function processes on decision making, staying focused and dealing with distractions, multitasking, and overall productivity, more recent studies have examined the influence of treadmill desk walking on executive function processes (1,19). The cognitive tasks in these studies have predominantly focused on the inhibition component of executive function, and included go/no go, Stroop color-word conflict, and flanker tasks. In general, these studies have suggested that executive function performance is not meaningfully influenced by walking on a treadmill desk. However, nearly all of the studies to date have focused on college-age participants, resulting in limited generalizability to older working-age individuals. The current findings suggest that low-intensity self-selected walking, as would be implemented in a workplace, results in minimal impairment to executive function in both young and middle-age adults. However, it is possible that more complex cognitive tasks that require multiple executive functions may be impaired among older adults while working at an active workstation, and this warrants further study.

Notably, nearly all of the studies to date have assessed executive function or job-related performance while participants engage in one session of low-intensity physical activity on an active workstation (40). It remains unknown whether these findings would generalize across a typical 8-h working day. Recently, Mullane et al. (26) had nine sedentary, obese adults complete an 8-h simulated office workday that included either uninterrupted sitting, or included short active breaks of standing, cycling, or walking that accumulated to 2.5 h of standing or light activity. A computerized cognitive test battery was administered twice across the 8 h to assess psychomotor (detection test), working memory (one-back task), and shifting or cognitive flexibility (set-shifting task) domains. The authors reported that interrupting prolonged sitting resulted in an improvement in all three of the cognitive domains. However, in contrast to the cycling and walking conditions, no significant improvements were found for the cognitive flexibility task for either the standing or sitting conditions. This suggests that some level of physical activity, rather than merely a change in posture, may be needed to observe improvements in cognitive flexibility when using an active workstation across an 8-h working day. Another study determined the chronic effects (28 wk) of sit-to-stand desk use among 34 freshman high school students during the course of two semesters (23). Students who used these active workstations demonstrated improvements in executive function, and these improvements were associated with significant left frontal lobe activation during task performance assessed using functional near-infrared spectroscopy. In contrast to the current findings of minimal influence of a single session of low-intensity walking at a treadmill workstation on executive function, these studies suggest that more prolonged use may result in benefits to select aspects of executive function. Studies replicating these findings and examining multiple cognitive domains are needed to further understand the short and long-term effects of active workstation use on executive function and job-related performance. Such findings may have clinical implications for implementing active workstations into the workplace as well as in classrooms to break up prolonged sitting.

Several age-related reductions in response time and accuracy across executive function tasks were found in this study. A consistent body of evidence has shown age-related declines in cognitive performance that begin in early adulthood and are evident across different cognitive domains (14,30). Moreover, executive functioning and the prefrontal and parietal structures that support these cognitive processes may be particularly susceptible to aging (8,30); however, exercise and physical activity interventions have been shown to result in disproportionately larger benefits for executive function relative to other cognitive domains (11). Despite evidence of a consistent age-related decline in executive function abilities, slow walking on an active workstation did not affect executive functioning among middle-age relative to younger adults. There was also no difference between young and middle-age adults in preferred treadmill walking speed while performing computerized cognitive tasks. Of interest, given that middle-age adults had significantly longer reaction times for each cognitive task, they spent more time walking on the treadmill (or sitting at rest). This resulted in significantly more steps accrued for the middle-age relative to younger adults. In this study, cognitive testing also occurred after a short 5-min warm-up on the treadmill desk. Whether this brief warm-up period on the treadmill generalizes to the use of active workstations in a real-life setting remains unknown. Integrating cognitive performance testing into clinical trials of active workstations across the working or school day may help to answer whether chronic active workstation use benefits or hinders cognitive performance.

Unique to this study was the assessment of physical activity across the 50-min active workstation session. During the walking condition, participants accrued approximately 4500 steps and walked at a rate of nearly 90 steps per minute based on preferred speed. The American Heart Association has recommended that adults accumulate approximately 10,000 steps per day to be considered "active" (39). Further, recent guidelines recommend that individuals initially strive to accumulate 2 $h \cdot d^{-1}$ of standing and light activity across the workday to reduce the risk of morbidity and mortality associated with today's sedentary lifestyle (7). The current data suggest that two 50-min bouts of self-selected walking on an active workstation may be effective in meeting these recommendations. Future studies should examine whether accumulated bouts of brief interruptions in sedentary time across the 8-h workday (e.g., Mullane et al. [26]) or a fewer number of longer sessions of standing or walking, as used in this study, improve measures of physical and cognitive health. This evidence should help to advance public health guidelines for active workstation use in offices and classrooms (38).

Limitations and future directions. This study has several limitations. First, the sample consisted of individuals who have not had extensive experience using a treadmill desk, and we only incorporated one familiarization session of active workstation use before testing. Thus, the conclusions may differ for those who are actively using treadmill desks and after chronic use of an active workstation. However, the inclusion of an intensive familiarization session before the experimental sessions should have increased comfort levels with the treadmill desk and reduced possible learning effects by increasing familiarity to the cognitive tasks. We also did not standardize walking speed and instead allowed participants to choose their preferred speed while performing computer-based tasks. Despite the possible threat to internal validity, allowing for choice in treadmill speed increases the generalizability of the findings to the workplace where users can self-select from a range of speeds.

A possible significant limitation relates to the specific cognitive tasks chosen to assess executive function. Previous studies examining the effects of exercise on executive function in general (see [10]) as well as the specific influence of walking on a treadmill desk (1,19) have used one or two cognitive tasks to assess executive function. This limitation may be exacerbated by the task impurity issue, which renders it difficult to assess each domain of executive function separately because other cognitive processes are also involved in successful performance on these tasks (24). In line with previous recommendations (13,24), four well-established neuropsychological tasks were used in this study to examine global executive function and its three constituent domains. However, most of the cognitive tasks used here and elsewhere also include multiple outcome measures (e.g., reaction time, accuracy), which may increase the probability of committing a type I error. To help guard against this, composite measures for each task (*z*-scores) were created and analyzed in addition to the traditional outcomes. Future research is needed to best address several issues that arise when assessing "executive function," including the use of a guiding theoretical rationale and appropriate justification for selecting cognitive tasks based on the effects and population of interest (13).

Lastly, the use of behavioral performance measures (i.e., reaction time and accuracy) are limited in that they represent end-state processes that result from a combination of neuropsychological processes, including early sensory processing, engagement of cognitive control, and motor response execution. These end-state measures make it challenging to draw conclusions about precisely how in-task processing may be affected. Future study designs should consider incorporating advanced psychophysiological techniques, such as mobile EEG and functional near-infrared spectroscopy, to better understand the underlying processes during active workstation use. Although previous research, including the present study, has assessed the effects of slow walking on a treadmill desk on executive function performance using standard neuropsychological tasks, future research should also address how executive function relates to metacognition (i.e., an individual's understanding of his or her knowledge and how to apply it to regulate and influence behavior [5]) to connect to real-world job performance.

CONCLUSIONS

In sum, our findings suggest that global executive function performance remains relatively unaffected while walking on an active workstation, further supporting the use of treadmill workstations as an effective approach to increase physical activity and reduce sedentary time in the workplace. It remains to be determined whether other cognitive domains or work-related tasks are affected by slow treadmill walking and whether more chronic use of these workstations may result in improvements to select aspects of executive function. Given the accumulation of daily activity, our findings suggest that active workstations may be an effective way to reduce the public health threat of sedentary behavior without negatively affecting executive function.

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

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