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ORIGINAL RESEARCH

Cognitive Function During Low-Intensity Walking: A Test of the Treadmill Workstation

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***Background*:** The purpose of this study was to examine the effects of walking at self-selected speed on an active workstation on cognitive performance. ***Methods*:** Sixty-six participants (n = 27 males, 39 females; mean age = 21.06 ± 1.6 years) completed a treadmill-desk walking and a seated control condition, separated by 48 hours. During each condition, participants completed computerized versions of the Stroop test, a modified flanker task, and a test of reading comprehension. ***Results*:** No significant differences in response speed or accuracy were found between walking and sitting conditions for any the cognitive tests. ***Conclusions*:** These findings reveal that performance on cognitive tasks, including executive control processes, are not impaired by walking on an active workstation. Implementing active workstations into offices and classrooms may help to decrease sedentariness without impairing task performance.

***Keywords*:** treadmill desk, low-intensity exercise, executive function, interference, Stroop task

Approximately two-thirds of the U.S. adult population are considered overweight or obese, and in roughly 15 years, these numbers are projected to increase to nearly 80% of all adults.[1] This upward trend in overweight and obesity can be partially attributed to insufficient levels of physical activity (PA). Of equal concern is the increasingly high number of waking hours adults are spending in sedentary behaviors such as sitting or in light-intensity activities such as standing with some gentle ambulation.[2] Recent evidence also suggests that distinct physiological consequences may distinguish between sedentary time and insufficient PA[3] and that a wide array of adverse health effects may accompany sedentary behaviors.[4] The decline in PA and increase in sedentary pursuits has been exacerbated by the ergonomics of the present day home and work environment. The technological revolution has been accompanied with labor saving devices (eg, computers), increased use of automobiles for transport, and a decline in labor-intensive occupations.[5,6] For instance, with the implementation of computers into the workplace, a large portion of adults are also confined to a desk throughout the majority of their workday.[7,8] Thus, in addition to the emphasis on interventions aimed at improving the adoption and maintenance of exercise and PA behaviors, both research and practical approaches addressing this "too much sitting" phenomenon are warranted.[2] In a creative attempt to address today's increasingly sedentary lifestyle, Levine and Miller[8] reintroduced the concept of an active workstation consisting of a treadmill and an adjustable sit-to-stand desk. Incorporating treadmill workstations into classrooms and offices may serve as an effective means to break up long stretches of sedentary time, as well as increase energy expenditure, throughout the workday. However, some may be hesitant to implement the workstations because of the possible impairment they could pose to job performance. An individual working on an active workstation may be forced to consciously or unconsciously divide limited attentional or cognitive resources between walking (or cycling) and job-related work activities, which may compromise work performance and productivity.

Straker and colleagues[6] conducted a study to examine the effects of standing, walking, and cycling while using an active workstation on accuracy and speed of typing, a mouse pointing task, and a combined keyboard and mouse task. Evidence for impaired speed and accuracy on all computer-based tasks was found; however, impairment was slightly larger for the mouse task compared with the typing task. The impairment of typing performance resulted in a shift from 54.4 wpm while sitting to 50 and 49.6 wpm when walking at 1 and 2 mph, respectively. In the context of most workers' daily tasks, this statistical difference may not result in a meaningful change in overall work performance. However, occupations requiring intensive hours at the keyboard where work performance is based on precision in using the mouse or keyboard, may be impacted to a greater extent than jobs requiring less time on these fine-motor tasks. For instance, Thompson and Levine[9] recently trained 11 experienced medical transcriptionists in the use of a treadmill desk and although the accuracy of transcription across 8 hours did not differ between sitting and walking conditions, the speed of transcription was 16% slower when walking. Notably, the transcriptionists in their study expended 100 calories per hour more in the walking condition relative to sitting. Based on a cost-benefit rationale including improved metabolic and musculoskeletal health, it has been suggested that active workstations might be successfully used for a few hours each day during periods when the use of a keyboard and mouse is not necessary. However, the effects of low-intensity walking on other types of performance-based cognitive tasks involved in the typical workday are warranted before definitive statements can be made regarding the efficacy of implementing active workstations in the workplace environment. For instance, qualitative reports from the participants in the Straker et al[6] study indicated potential cognitive benefits from using the treadmill desk intermittently to break the monotony of daily office work, but also the possibility of detriments to performance during cycling as a result of the increased cognitive load associated with dual tasking. It is also important to determine whether the use of an active workstation facilitates or impairs specific types of cognitive processes. Various cognitive performance-based

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tasks have been employed in the exercise and cognitive functioning literature and range from simple tasks involving speed of responding (eg, reaction time) to more complex cognitive tasks involving working memory and executive function, including decision-making, task switching, and inhibition.[10] Executive functioning refers to a subset of processes associated with the selection, scheduling, and coordination of computational processes that are responsible for perception, memory, and action[11] and involve situations such as planning, problem solving, task switching, and inhibition. It has been suggested that executive control, relative to other cognitive processes, may be more selectively impacted by exercise.[12,13]

John et al[7] performed a study to examine the effect of treadmill walking at 1 mph on both simulated office-related computer tasks and executive control. The performance measures included typing and mouse proficiency as simulated office-related computer tasks, the paper-based version of the Stroop color-word test as a measure of information processing and task interference, and written versions of the graduate record examination (GRE) math and reading comprehension sections as measures of information analysis, evaluation, and synthesis. Their findings revealed impaired performance on typing, mouse proficiency, and GRE math tasks, but no significant influence of walking on the reading comprehension or Stroop tests. Thus, although impairment was noted for the more simple cognitive tasks involving reaction time and coordinated movement, effects on higher-level executive control were limited. It is possible that the relationship between exercise and task performance may vary based on the particular subset of cognitive processes engaged in during task execution. Further, a minimum exercise intensity threshold might have to be achieved before the coordination and control of gross bodily movements and accompanying physiological responses places such a demand on the information processing system as to impair cognitive processing.[14] Additionally, the participants in the John et al study were only afforded a few minutes to acclimate to the treadmill and were not allowed to self-select their preferred walking speed, both of which may have affected performance on the computer-based and cognitive tasks.

A growing body of research has examined acute exercise effects on cognition[10] and the literature is mixed with some studies indicating a facilitation of cognitive performance,[15,16] while others have observed an impairment of specific cognitive processes, including executive control.[14,17] Further, cognitive testing in the majority of the extant literature has been administered *at least* 10 to 15 minutes after exercise in an attempt to control for physiological arousal accompanying the exercise bout. Relatively less research has examined cognitive performance *during* exercise and the studies that have been conducted have used exercise intensities that are well above treadmill workstation recommendations. For instance, Del Giorno, Hall, O'Leary, Bixby, and Miller[18] performed a study to determine if executive control processes would be impaired during 30 minutes of exercise at 2 different intensities: at ventilatory threshold (VT) or at 75% of VT. They found that cognitive performance decreased during both intensities of exercise with a longer lasting impairment in the higher intensity condition (ie, at VT). Pontifex and Hillman[14] observed that exercise at 60% of maximal HR resulted in reduced response accuracy for incongruent trials of a modified Flanker task but did not impair performance on congruent trials. Neuroelectric measures of event related brain potentials (ERPs) in their study suggested that the need to allocate attentional resources toward the large-scale bodily movements inherent in exercise resulted in decreased interference control during the more difficult version of the Flanker test. Similarly, Dietrich and Sparling[17] reported that moderate-intensity exercise impairs prefrontally mediated cognitive tasks, which include measures of executive function, while cognitive processes requiring little prefrontal activity were unaffected. Such findings have lent support for Dietrich's[19,20] transient hypofrontality hypothesis and more recently, the reticular-activating hypofrontality model.[21] According to this model, the brain operates on a fixed amount of metabolic resources and certain events, such as engaging in exercise, may lead to a reduction or deregulation in attentional resources, particularly for tasks requiring more extensive amounts of executive control. Because the motor and prefrontal cortices are activated during exercise, a temporary deregulation in tasks (eg, certain types of cognitive function) requiring those neural circuits are hypothesized to occur. Once exercise ends, the metabolic resources in the brain are restored and the decrements in those tasks would cease. Although several studies to date have found impaired frontally mediated executive performance during exercise, they have all relied on moderate-to-vigorous intensities of exercise.[14,17,18] It is important to determine if the transient hypofrontality hypothesis or reticular-activating model holds for lower intensities of exercise as well. As mentioned, it is possible that exercise must meet a certain intensity threshold before higher level cognitive functions are impaired. However, if low-intensity exercise also disrupts cognitive functioning, particularly executive control processes, support for the use of active treadmill workstations would be limited.

Few studies have examined cognitive performance during exercise and little is known about the effects of low-intensity treadmill walking, particularly on prefrontally-mediated executive functioning tasks. Therefore, the purpose of this study was to examine performance on executive control tasks during low-intensity treadmill walking. Specific measures of executive function included response speed and response accuracy on the Stroop and Eriksen flanker tests, both of which have been widely accepted as measures of executive function.[7,22–24] The Stroop test[25] is a frequently used measure of cognitive performance. Several versions of the Stroop have been used and are believed to tap into speed of processing using more simplified versions of the task (*word or congruent condition*), while the color-word conditions (*interference or incongruent*), where the stimulus is presented as a color name (eg, 'blue') printed in a different ink color (eg, red) and individuals are asked to respond to either the color or ink name, have been used as a measure of executive control. The Ericksen flanker task[26] is a paradigm used to manipulate interference control or response inhibition, one important aspect of executive control. Variable amounts of interference control are required to successfully negotiate the task based on the compatibility of a central target and flanking letters around the target. The congruent condition (eg, HHHHH) results in faster and more accurate responses than the incongruent condition (eg, HHSHH) since the incongruent condition results in greater response competition between the target and flanking letters.[14] Response speed and accuracy were also assessed on a reading comprehension test, which has previously been used as a measure of working memory and executive function.[27] Based on the initial tenets of the transient hypofrontality theory and the reticular-activating model, along with previous research, it was hypothesized that performance on the executive control tasks would be impaired during low-intensity treadmill walking at a self-selected speed.

Methods

Participants

Sixty-six healthy undergraduate students (27 male, 39 female, mean age = 21.06 ± 1.6 years) were recruited to participate in this study. Recruitment took place through the use of flyers and advertisements posted around campus and in the school newspaper. Interested participants were prescreened for any neurological and/or health conditions that might have impacted our results, including attention deficit hyperactivity disorder (ADHD) and current use of stimulants. Those who reported use of stimulants were excluded from participating. Subjects were also asked not to exercise on test day and to not eat or consume caffeinated beverages for at least 3 hours before reporting to the laboratory. All participants provided written informed consent and the research protocol was approved by a university committee for institutional review. See Table 1 for participants' descriptive information.

Procedures

Participants visited the laboratory for 2 separate sessions conducted 48 hours apart at the same time of day. The 2 sessions (seated control, self-selected intensity treadmill walking) were counterbalanced to minimize any potential practice effects. At the start of both testing sessions, participants were fitted with a Polar HR monitor and transmitter and asked to sit quietly and relax for 10 minutes in a comfortable chair while HR was assessed. During this time, soft music was played and participants were offered prescreened magazines to read. Following the rest period, participants were asked to move to a seated (control) or standing position on a treadmill at a desk. At the start of the walking condition, participants were instructed to self-select a speed between 0.5 mph and 2.5 mph where they felt most comfortable performing computer-based tasks. To aid in determining an appropriate walking speed while working, participants in both conditions were instructed to type for approximately 15 minutes about something meaningful that recently happened in their life (session 1) or someone in their life that is close to them (session 2). This 15-minute preparatory period was used to ensure that participants felt comfortable typing while in the seated or walking (treadmill) position.[8]

Next, participants were given written and verbal instructions on how to complete the cognitive tasks and completed several practice tests to acclimate themselves with testing protocol. Computerized and verbal feedback, including accuracy and speed data were given following a response during the practice trials. During the treadmill walking condition, participants were allowed to continually adjust the walking speed between 0.5 and 2.5 mph until the end of the practice test, at which time the speed would then be maintained for the remainder of the testing session. Response time, response accuracy, and heart rate (HR) were collected throughout the cognitive testing. Guidance and computer-based feedback were not provided during the data recording period. Upon completion of the cognitive performance tasks on the second testing day, participants were debriefed on the purpose of the experiment.

Measures

Demographics. Age was assessed by self-report. Height and weight were measured without shoes to the nearest 0.5 cm and 0.1 kg, respectively, using a digital stadiometer and scale. Body mass index (BMI) was computed by dividing weight by the square of height (kg/m^2).

Heart Rate (HR). HR was assessed at baseline and at 5-minute intervals throughout each testing session using a Polar RS800 HR monitor and transmitter (Polar, Kempele, Finland). Baseline HR was established and recorded following a 10-minute baseline resting period. Average HR was calculated for the entire session and represents the average HR across treatment conditions.[28,29]

Cognitive Performance Tests

Stroop Test. The Stroop test,[25] also called the color naming task, was used to assess information processing speed, executive abilities, selective attention, and the ability to inhibit habitual responses.[30,31] Three different trials of the Stroop test were presented to participants in random order, each separated by a 30-second rest period. Preceding each trial was a set of instructions that explained which keys corresponded to which color. Following the directions, stimuli were presented after visual fixations (+) lasting for 1000 ms. Participants were tested on the speed and accuracy of their keyed responses after presentation of the stimulus.

The *neutral trials* consisted of a string of Xs that appeared on the computer screen in red, yellow, blue, or green ink. Participants were instructed to press the key that corresponded to the color of ink that appeared on the screen. The remaining 2 trials were continuations of the Stroop test, which have previously been used to manipulate interference and goal maintenance.[24] One of the *interference trials* presented color word stimuli, including the words 'red,' 'yellow,' 'blue,' or 'green,' presented in a randomly selected ink color of red, yellow, blue, or green. Participants were asked to identify the word using the computer keys (*interference word*). The final trial was constructed in the same way, but asked participants to identify the color of the ink the word was presented in, inhibiting the meaning of the word itself (*interference color*). Each block of trials lasted approximately 2.5 minutes.

Flanker Task. A modified version of the Eriksen flanker task[26] was used to manipulate interference control.[14,23] Two blocks of 100 trials were presented, each separated by 30 seconds. A set of instructions preceded the first trial that explained which keys would be used to indicate the direction of the central or target arrow. Participants performed a button press with their left thumb

Table 1 Participant Characteristics (M ± SD) Overall and by Gender

Measure	Males	Females	Total
Sample size	27	39	66
Age (years)	21.63 ± 1.94	20.67 ± 1.13	21.06 ± 1.58
Age range (years)	19–25	18–22	18–25
Height (cm)	173.78 ± 7.17	161.71 ± 7.28	168.18 ± 9.38
Weight (kg)	77.29 ± 9.19	62.40 ± 19.84	70.39 ± 16.67
BMI (kg/m^2)	25.61 ± 2.81	23.68 ± 6.61	24.71 ± 4.97
$HR_{resting}$ (beats/min)	74.0 ± 10.49	74.28 ± 12.71	74.17 ± 11.77
Ave walking speed (mph)	1.65 ± 0.37	1.53 ± 0.43	1.58 ± 0.41

when the target arrow, or 3rd arrow from the left, pointed to the left (<) and a button press with their right thumb when the target arrow pointed to the right (>). Each block consisted of 100 trials of congruent and incongruent stimuli presented in random order. The congruent trials consisted of the target arrow being flanked by arrows facing the same direction (ie, presented as <<<<< or >>>>>) while incongruent trials involved the target arrow being flanked by arrows facing the opposite direction (ie, presented as <<><< or >><>>). The stimuli were 7 cm tall black arrows centered focally on a white background for 100 ms with a response window of 1500 ms. A random interstimulus interval of 1100, 1300, or 1500 ms was used for the time between each visual fixation (+) and the stimulus[14,23] to increase task difficulty. Total task duration for each block was approximately 5.5 minutes.

Reading Comprehension. Four SAT equivalent reading comprehension tests were used for the assessment of working memory.[7,27] The reading comprehension part of the SAT is designed to measure the ability to analyze, evaluate, and synthesize information and has been used successfully in other studies measuring cognition.[7] Two of the four reading comprehension tests were randomly administered for each session and separated by a 30-second period. Each test included a 2-slide passage to read followed by 9 true-or-false questions. A set of instructions was given before each passage indicating which keys to press for "true" or "false" answers. Upon completion of reading the passage, participants were presented with the series of true-or-false questions. Each trial was approximately 2.5 minutes long. Speed and accuracy for responses averaged across both reading comprehension tests per testing session were calculated and used in the analysis.

Data Analysis

Statistical analyses were conducted using SPSS version 19 for windows (SPSS, Chicago, IL). Descriptive statistics were calculated and an independent samples *t* test was conducted to examine potential gender differences for age, height, weight, BMI, and resting HR. The independent variable in this study was the workstation condition (seated vs. treadmill walking). The dependent variables were response speed and accuracy for each of the following cognitive tasks: the Stroop task (3 versions), congruent and incongruent versions of the Flanker test, and the SAT equivalent reading comprehension test. Average response speed and accuracy across each of the cognitive tests was conducted and test results are presented as means ± standard deviations in Table 2. Average HR across the treatment conditions was also determined for each participant. Preliminary analyses were performed to determine whether testing order, which was counterbalanced across participants, had any effect on the dependent variables. Response time (RT) and accuracy values for the Stroop task across each participant were submitted to a 2 (Condition: Walking, Sitting) × 3 (Task: Stroop, Flanker, Reading Comprehension) repeated measures MANOVA. A 2 (Condition: Walking, Sitting) × 2 (Congruency: Congruent, Incongruent) repeated measures MANOVA were also performed for RT and accuracy scores for the Flanker task. A 1-way repeated measures MANOVA was conducted for RT and accuracy for the test of reading comprehension by condition. Paired samples *t* tests were used to examine differences on the cognitive performance measures and HR between treatment conditions. Statistical significance for all analyses was set at $P < .05$ and effect size estimates (ES) were calculated for ANOVAs and pairwise comparisons by using partial η^2 (η_p^2) and Hedges' g statistic,[32] respectively.

Results

Means and standard deviations for participant demographic information are presented in Table 1. As a manipulation check of intensity, a *t* test was conducted for average HR between conditions. There was a significant difference in HR, $t(63) = 13.93$, $P < .001$, ES = 1.6 with greater average HR values during the treadmill walking (91.4 ± 12.4 beats/min) than during the seated condition (73.2 ± 10.5 beats/min). Independent *t* tests revealed no significant gender differences in preferred treadmill walking speed, resting HR, or BMI. However, men were significantly older, $t(64) = 2.54$, $P < .05$, ES = .84, taller, $t(64) = 5.34$, $P < .001$, ES = 1.6, and heavier, $t(64) = 3.16$, $P < .01$, ES = .90, relative to women. Preferred walking speeds ranged from 0.8 to 2.5 mph (mean = 1.58 ± .41 mph).

Table 2 Descriptive Data and Effect Size Measures for All Cognitive Tests Between Conditions

Measure	Treadmill walking	Seated control	Effect size
Mean RT (ms)			
Congruent Flanker	318.39 ± 59.31	322.10 ± 69.31	–0.06
Incongruent Flanker	380.40 ± 60.16	390.63 ± 76.13	–0.15
Stroop 1	672.19 ± 115.84	663.34 ± 111.39	0.08
Stroop 2	808.26 ± 195.11	815.88 ± 213.17	–0.04
Stroop 3	932.56 ± 215.98	892.84 ± 189.98	0.19
Reading Comp.	3310.85 ± 757.89	3452.12 ± 849.13	–0.18
Response accuracy (%)			
Congruent Flanker	98.73 ± 2.82	97.58 ± 6.76	0.24
Incongruent Flanker	93.29 ± 5.63	93.13 ± 8.14	0.02
Stroop 1	95.14 ± 5.43	95.97 ± 4.03	–0.17
Stroop 2	94.08 ± 10.84	92.91 ± 13.91	0.09
Stroop 3	83.60 ± 23.57	90.96 ± 16.00	–0.36
Reading Comp.	76.72 ± 14.18	75.22 ± 11.92	0.11

Stroop Test

The omnibus analyses for RT revealed a main effect of Stroop Type, $F_{2,64} = 125.3$, $P < .001$, $\eta_p^2 = .80$, with shorter RT latency for the neutral trials (mean = 667.8, SE = 11.7) relative to interference word (mean = 812.1, SE = 19.8) or interference color (mean = 912.7, SE = 20.7) trials. The interference word trials were also shown to result in shorter RT latency than interference color trials, $P < .001$. No Condition main effect, $F_{1,65} = .53$, $P = .47$, $\eta_p^2 = .01$ or Condition × Stroop Type interaction was found, $F_{2,64} = 1.0$, $P = .36$, $\eta_p^2 = .03$. Analyses for response accuracy revealed a main effect of Stroop Type, $F_{2,64} = 15.4$, $P < .001$, $\eta_p^2 = .33$, with a significant decrease in response accuracy for the interference color trials (.87) compared with neutral (.96) or interference word (.94) trials. The neutral and interference word trials did not significantly differ from one another, $P = .15$. No Condition main effect, $F_{1,65} = 2.3$, $P = .13$, $\eta_p^2 = .03$ or Condition × Stroop Type interaction, $F_{1,65} = 2.2$, $P = .12$, $\eta_p^2 = .07$, for response accuracy was observed.

Flanker Task

The RT analyses revealed a main effect of Task Congruency, $F_{1,65} = 336.1$, $P < .001$, $\eta_p^2 = .84$, with shorter RT latency for congruent (mean = 320.2, SE = 7.3) relative to incongruent (mean = 385.5, SE = 7.7) trials. No Condition main effect was found, $F_{1,65} = 1.3$, $P = .27$, $\eta_p^2 = .02$; however, a 2-way interaction of Condition × Task Congruency was found, $F_{1,65} = 6.9$, $P < .05$, $\eta_p^2 = .10$. However, post hoc Bonferroni corrected *t* tests of Task Congruency within each Condition found no significant effects, $t(65) \leq 1.5$, $P = .13$. Analyses for response accuracy during the Flanker revealed a main effect of Task Congruency, $F_{1,65} = 85.8$, $P < .001$, $\eta_p^2 = .57$, with a significant decrease in response accuracy for incongruent (.93) compared with congruent (.98) trials. No Condition main effect, $F_{1,65} = 0.66$, $P = .42$, $\eta_p^2 = .01$ or Condition × Congruency interaction, $F_{1,65} = 1.84$, $P = .18$, $\eta_p^2 = .03$, was observed.

Reading Comprehension

No effect of Condition was found for either RT, $F_{1,62} = 1.9$, $P = .18$, $\eta_p^2 = .03$ or response accuracy, $F_{1,62} = 0.40$, $P = .53$, $\eta_p^2 = .01$.

Discussion

The purpose of the current study was to examine performance on executive control tasks during low-intensity treadmill walking. Specific measures of executive function included response speed and accuracy on the Stroop and Eriksen flanker tests, as well as a measure of reading comprehension that has previously been used as a measure of working memory.[27] The main findings revealed longer response times and decreased accuracy for the more challenging trials of the Stroop and flanker tasks. These results are in line with previous research[14,33,34] and support that the incongruent or interference trials of these tasks place additional demand on the information processing system, including executive control, thereby resulting in increased RT and decreased accuracy. Importantly, no such effect was observed for any of the cognitive tests between conditions. These findings indicated that walking at a self-selected intensity does not decrease efficiency of the information processing system and does not impair task performance.

Levine and Miller[8] have established that low-intensity walking on a treadmill desk results in a significant increase in energy expenditure. Therefore, implementation of active workstations into offices and classrooms remains part of a plausible attempt to address the rising obesity and sedentary lifestyle crises. With scant research addressing the effects of using a treadmill desk on job performance and productivity, school and business owners may be hesitant to implement active workstations on the basis of health benefits alone. Although previous research has indicated impairments in physical work-related tasks (ie, typing and mouse proficiency) while using an active treadmill workstation,[6,7] higher level cognitive processing may be considered a more important factor in judging work performance, as many of the tasks and decisions performed throughout a workday largely depend on executive function. We did not observe any decrement in RT or accuracy on any of the cognitive tasks during low-intensity walking. Our findings thus provide preliminary support for implementing treadmill desks into the workplace based on job performance and productivity.

Specifically, no significant differences in RT or accuracy were found for reading comprehension, Eriksen flanker, or Stroop tasks between the treatment conditions. Collectively, our findings are in line with previous research that has analyzed effects of low-intensity walking on cognitive performance. John et al[7] found that walking while working decreased scores on tests of typing and mouse proficiency, as well as math problem solving ability by approximately 6 to 11%. However, unlike the fine motor tasks and mental arithmetic used, performance on the Stroop and reading comprehension tests were not significantly different between walking and sitting. Similarly, in a study of participants who were significantly older (*M*age = 43.2 ± 9.3 yrs) than those in the current study, Ohlinger, Horn, Berg, and Cox[35] reported that walking at 1.6 km/h on an active workstation resulted in impaired performance on a finger tapping task while tasks that require more cognitive or attentional resources (ie, the Stroop and an auditory verbal memory task) were not altered by walking. It is possible that low-intensity walking on a treadmill desk would impair simultaneous fine motor tasks, particularly as one becomes accustomed to working while walking. For instance, in the Thompson and Levine[9] study, 11 experienced medical transcriptionists demonstrated 16% slower typing speed but no change in accuracy in a treadmill desk walking condition across 8 hours of transcription. Although the amount of time participants had to become familiarized to the treadmill workstation was limited in our study, they were afforded approximately 15 to 20 minutes to establish their preferred walking speed while conducting a simple typing task. It is likely that participants felt more comfortable with the active workstation in the current study relative to previous studies[7,35] due to the acclimation period along with the use of self-selected walking speed, 2 variables which theoretically could impact performance on both fine motor and higher level cognitive-based tasks due to dual-tasking. Future research should be conducted to establish whether and how long it takes for individuals to become comfortable with active workstations and whether other task performance measures are impacted through walking while working. Future work should incorporate a variety of tasks that engage different aspects of cognitive functioning.

Our findings add to the emerging body of evidence that low-intensity walking does not impair executive controlled processing. Considering that there were no differences in RT or accuracy between conditions on any of the cognitive tests, the results suggest that dividing attentional resources during low-intensity arousal, induced by walking, does not cause a deregulation in higher order thinking. In accord with Dietrich's[19,20] hypofrontality theory, and more recently the reticular-activating hypofrontality model,[21] prefrontally mediated executive function is likely only impaired or deregulated during moderate-to-vigorous intensities of exercise and the dose of activity typically performed on an active workstation would not impair cognitive performance. Further study of the dose-response relationship of exercise on cognitive performance *during* the activity warrants attention.

Previous research is conflicting on the effects of exercise on fine motor tasks with some studies reporting an improvement[16,22,36] while others have reported impairment.[7,35] Although no significant differences were found for reaction time on any of the cognitive tests in the current study, there were also no impairments found in RT in the walking condition. It has been suggested that exercise may enhance the efficiency of peripheral motor skills,[16] which may be associated with a decrease in RT. However, others have contended that dual-task protocols and the extent of attentional resources allocated to the exercise condition may impact performance.[14] Future research should attempt to address whether ergonomic factors associated with active workstations are facilitated or impaired by low-intensity walking or cycling or if acclimatization to the activity itself will result in ameliorating the performance decrements in motor tasks observed to date.[35]

Limitations of the Study

The study focused on cognitive performance during an acute bout of low-intensity walking on an active workstation, lasting approximately 50 minutes. Investigating the effects of the treadmill desk on work performance at a minimum of 2 hours during a typical or simulated 8-hour workday (similar to the Thompson and Levine study[9]) is warranted. The 8-hour simulated workday would help to better understand the temporal dynamics of cognitive performance during low-intensity exercise and the overall practicality of using an active workstation at various times throughout the workday. Metabolic changes during an 8-hour period would also be an important measure to obtain to provide further understanding of changes in energy that would accompany use in a typical workday.

Although not directly studied with using a treadmill desk, previous research has found that exercise results in enhanced cognitive functioning 15 to 30 minutes following exercise cessation.[10,37] We only assessed cognitive performance during in-task low-intensity walking. Given that use of active workstations may provide cognitive benefits following as opposed to during activity, future research should employ pre-post designs in addition to assessing in-task performance. We also did not include fine motor tasks and limited this study to higher-level cognitive performance. Since previous studies have found impaired performance on typing and mouse use,[7] future studies should aim to determine how these impairments may be ameliorated during use of active workstations. Participants in this study were young and relatively homogeneous college students. Therefore, generalizability to diverse subject populations including older adults may be limited. There are also individual latent variables related to learning, cognition, and intelligence (among others) that could have influenced cognitive performance in this study. However, subjects were of the same relative age and education status and random assignment to experimental treatment conditions was ensured. Finally, it is possible that other important psychological variables that connected to work performance are affected by low-intensity walking (eg, concentration, stress, mood state) and these also deserve study.

Conclusions

Active workstations are associated with several short-term health benefits (eg, increased energy expenditure) and may be part of an overall strategy to reduce sedentary time.[8] The results of this study support the hypothesis that low-intensity walking on an active workstation do not impair cognitive performance tasks. Our findings, along with emerging evidence[7,35] suggest that active workstations may have limited or no effects on work productivity. Although other investigators have reported that active workstations may impair performance on fine motor tasks (eg, typing), future research needs to determine if such performance decrements remain after a period of acclimation to the active workstation. Overall, our results support the implementation of treadmill desks into offices and provide a basis for further study, including analysis of incorporating the treadmill desk into an 8-hour simulated workday period.[9] The treadmill desk may serve as an effective way for workers to break up the normal sedentary workday.

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