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ORIGINAL RESEARCH

Effect of Active Workstations on Neurocognitive Performance and Typing Skills: A Randomized Clinical Trial

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BACKGROUND: Extended sedentary behavior is a risk factor for chronic disease and mortality, even among those who exercise regularly. Given the time constraints of incorporating physical activity into daily schedules, and the high likelihood of sitting during office work, this environment may serve as a potentially feasible setting for interventions to reduce sedentary behavior.

METHODS AND RESULTS: A randomized cross-over clinical trial was conducted at an employee wellness center. Four office settings were evaluated on 4 consecutive days: stationary or sitting station on day 1 (referent), and 3 subsequent active workstations (standing, walking, or stepper) in randomized order. Neurocognitive function (Selective Attention, Grammatical Reasoning, Odd One Out, Object Reasoning, Visuospatial Intelligence, Limited-Hold Memory, Paired Associates Learning, and Digit Span) and fine motor skills (typing speed and accuracy) were tested using validated tools. Average scores were compared among stations using linear regression with generalized estimating equations to adjust standard errors. Bonferroni method adjusted for multiple comparisons. Healthy subjects were enrolled (n=44), 28 (64%) women, mean±SD age 35±11 years, weight 75.5±17.1 kg, height 168.5±10.0 cm, and body mass index 26.5±5.2 kg/m^2. When comparing active stations to sitting, neurocognitive test either improved or remained unchanged, while typing speed decreased without affecting typing errors. Overall results improved after day 1, suggesting habituation. We observed no major differences across active stations, except decrease in average typing speed 42.5 versus 39.7 words per minute with standing versus stepping (*P*=0.003).

CONCLUSIONS: Active workstations improved cognitive performance, suggesting that these workstations can help decrease sedentary time without work performance impairment.

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Key Words: cardiovascular diseases ■ neurocognitive test ■ office ■ physical activity ■ sedentary time ■ typing

Extended sedentary behavior has emerged as an independent risk factor for cardiovascular disease (CVD), adverse health outcomes, and premature mortality, even among those who engage in regular moderate-to-vigorous physical activity (PA).[1,2] With the increase of PA, ≈8% of CVD and ≈3.9 million premature deaths could be prevented globally.[3] Over a quarter of the global population fails to meet the recommended levels of PA. This poses a risk for preventable chronic diseases to ≈1.4 billion individuals worldwide, and ≈25.4% of adults in the United States do not engage in sufficient leisure-time PA.[3,4]

Office employees work an average of 8.8 hours per day, and ≈89% of this time is spent sitting, putting them at increased risk of metabolic CVD.[5] The detrimental consequences of sitting are further exacerbated by

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CLINICAL PERSPECTIVE

What Is New?

- In this randomized trial, we demonstrated that when compared with sitting, the use of active workstations (walking, standing, or stepping) did not affect typing and neurocognitive skills.
- Moreover, neurocognitive and typing skills improved with additional exposure to active workstations.

What Are the Clinical Implications?

- Office workers or people working from home might benefit from integrating active workstations in different settings without substantial changes in work performance.
- Implementation of active workstations could help increase physical activity and daily energy expenditure, thereby helping to achieve preventive goals and improving office workers' overall health.

reports of reduced productivity in office workers who spend most of their time sitting.[6] Those with obesity appear to exhibit a tendency to be seated for 2.5 hours per day more than their sedentary lean counterparts.[7] Considering the time constraints of incorporating PA into one's daily schedule, office environments serve as potentially important settings for interventions aimed at reducing sedentary behavior. Strategies have been developed to increase nonexercise PA during work hours (eg, brief periods of PA such as walking, standing, and using a stepper), which have shown benefits toward improving CVD risk, metabolic profile, well-being, and productivity.[8,9] Restricting the amount of time sitting and switching from sedentary to active behaviors has been shown to improve cardiometabolic health risk anthropometric measurements (weight, body fat, waist circumference, body mass index, waist-to-hip ratio) and biomarkers (blood pressure, fasting glucose, triglycerides, and cholesterol levels) with an inverse relationship between incident CVD and daily step count (–10% for every increase by 2000 daily steps).[8,10,11]

Active workstations, which generally require redesign of the workspace by incorporating a treadmill, bike, stepper, and/or standing desk, have been demonstrated as successful strategies to reduce sedentary time.[7,12,13] A reasonable concern is that these interventions might compromise work performance. The impact of these workstations has been partially evaluated in the literature with mixed results.[7,9,12–14] However, the effect of different active workstations on neurocognitive and fine motor skills has not been extensively studied in randomized controlled trials. Thus, we aimed to evaluate whether these workstations affected neurocognitive function through reasoning, memory, and evaluation of concentration and fine motor skills in a controlled office-based environment. We hypothesized that those who use an active workstation during low-intensity PA while performing office activities will perform similarly to those who work in a sitting position.

METHODS

In consideration of patient privacy, the study data and analytic methods could be shared if there is a reasonable request to the corresponding author and methods to safeguard privacy of participants can be guaranteed. The study protocol was approved by the Institutional Review Board at Mayo Clinic and signed informed consent was obtained from all participants. Clinicaltrial.gov identifier is NCT06240286.

Study Design

We conducted a randomized cross-over clinical trial at the Dan Abraham Healthy Living Center at Mayo Clinic in Rochester, Minnesota, to test the effect of standing, stepping, or walking, versus sitting on neurocognitive function (reasoning, memory, concentration) and fine motor skills through the typing test (typing speed, number of errors, and adjusted participant speed). Participants attended the Active Wellness Office for 4 consecutive days at the same time of the day (morning, afternoon, or evening). On day 1, all subjects performed neurocognitive and fine motor skills tests while seated, which served as control. Over the course of the next 3 days, 3 distinct active workstations (standing, stepping, or walking stations) were randomly assigned (Figure).

Participants

Forty-four volunteers 18 years or older were recruited by word of mouth. The exclusion criteria were inability to stand up, walk on a treadmill or use a stepper, diagnosis of Alzheimer disease, other types of dementia or any memory impairment, conditions affecting fine motor skills such as Parkinson disease, unwillingness to use a standing desk, stepper, or treadmill, or currently using a treadmill desk or stepper desk at home or work. Monetary compensation was provided.

Workstations

The Active Wellness Office testing environment, which measures 11.9 m^2 (Figure S1), comprises 4 office workstations, organized around 2 large height-adjustable desks (Steelcase Inc., Grand Rapids, MI), with 2 office treadmills (TRUE Fitness technology, Inc., O′ Fallon, MO). Each station had room for standing/

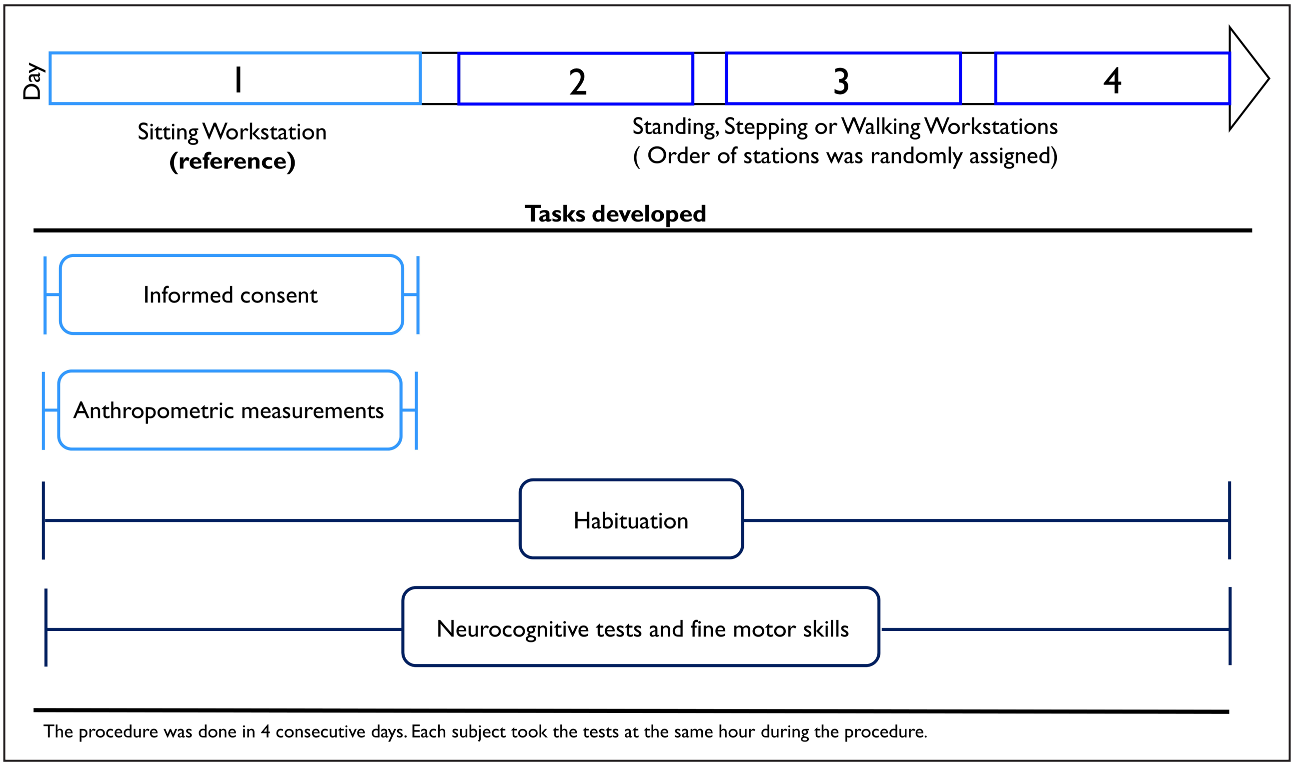

Figure. Experimental study design.
Four workstations were used: 1 stationary and 3 active workstations tested on 4 consecutive days. Informed consent was obtained before day 1, and individuals were tested on the sitting workstation as reference. The subsequent workstations were randomized on days 2 to 4 either to standing, stepping, or walking. Every day patients had a 10-minute habituation period before starting; work at each station lasted 45 to 55 minutes. Neurocognitive and fine motor skills were tested using validated tools.

sitting a commercial portable stepper (Xiser Industries, Fort Collins, CO), or a treadmill. Noise-canceling headphones (3M, St. Paul, MN) were provided to all participants. The room was equipped with a temperature- and illumination-controlled system.

Measurements

A summary of test methodology is provided in (Table S1). Briefly, using an online platform from Creyos (Toronto, Canada), we applied a battery of 11 extensively validated neurocognitive assessments based on classical paradigms of psychology and neuroscience that evaluate reasoning (Double Trouble Task, Grammatical Reasoning Test, Odd One Out Test, Object Reasoning Task), memory (Spatial Span Task, Monkey Ladder Task, Digit Span Task, and Paired Associated Task), and concentration (Rotation Task, Feature Match Task, and Polygon Task) (Figure S2).[15] Fine motor skills were assessed using the Split Screen Typing Program (Typing Master Inc., Helsinki, Finland) available online.[16] Individuals were asked to wear an accelerometer device ActiGraph model GT9X Link (ActiGraph, LLC., Pensacola, FL) comfortably at their waist level but taking into consideration that the device should not rotate. Measurement staff ensured proper positioning of the device in order to accurately record step count at walking and stepping active stations, because wrist placement will not accurately capture steps while typing.[17]

Procedure

After providing informed consent, participants received a detailed explanation of activities and instructions for maintaining a comfortable and adequate position during tasks according to the US Occupational Safety and Health Administration. Baseline weight, height, hip circumference, waist circumference, waist-to-hip ratio, and body mass index were obtained using standard methods.[18] After tasks were completed on the sitting station, stations were randomly assigned to either standing, using the stepper, or walking. A 10-minute habituation time was given before starting each station. Subjects were advised to exercise at a comfortable speed when using the active stations. When using the walking treadmill, we recorded the speed velocity in miles per hour (mph); a velocity between 1 and 2 mph was recommended, but we allowed subjects to choose a comfortable speed and increase the velocity if needed (velocity changes were recorded). When using the stepper, participants were advised to make proper steps of >20 cm for the ActiGraph to capture step data properly.[17] Each station lasted 45 to 55 minutes. We administered a pre- and postsurvey in each station; the presurvey consists of questions from both the International Physical Activity Questionnaire and the Last-7-Day Sedentary Time Questionnaire which assesses specific baseline sedentary.

Statistical Analysis

The sample size calculations for this study were determined based on a target accrual of 45 participants. With this number of participants, we would have 80% power to detect an effect size of 0.43 (effect size=difference in average score from reference divided by reference standard deviation), with a paired *t* test and 2-sided 5% type I error rate.

The continuous variables were presented as mean±SD along with medians and interquartile range (25th and 75th percentiles). Nominal variables were presented as number and percentage (Table 1). We compared average test scores of 44 participants using linear mixed-effects regression models, including a random effect for participants (nested within workstation sequence) to account for repeated data. For each outcome, 2 models were created to compare scores: Model 1 assessed the effect of period and sequence; this included the day of study (period) and workstation sequence (considering a separate model to test for the interaction between day and sequence), and Model 2 included workstation used while adjusting for sequence. For the fine motor skills domain, the typing errors outcome had a positively skewed distribution; therefore, log transformation was used, after adding a 0.1 constant to handle observations with zero errors; this transformation resulted in a symmetric distribution. Assessment scores at each time point or workstation are summarized in Tables 2 and 3 along with *P* values from comparisons to the reference (footnotes detail additional findings for comparisons among days 2 to 4 or among the active workstations). To preserve an overall 5% type I error rate for each assessment score (for comparisons by day or comparisons by workstation), we corrected for multiple comparisons. There are 6 possible comparisons between the 4 days or between the 4 workstations for each assessment; therefore, statistical significance was set to a *P* value <0.008 using the Bonferroni method (0.05/6=0.008). The significance level for assessing the effects of sequence or sequence-by-day interaction was set at 0.05. All analyses were performed using SAS version 9.4 (SAS Institute Inc., Cary, NC).

Table 1. Characteristics of the Participants

Patient characteristics	Total (N=44)
Sex, n (%)	
Female	28 (63.6%)
Male	16 (36.4%)
Age, y	
Mean±SD	35 (11)
Weight, kg	
Mean±SD	75.5 (17.1)
Height, cm	
Mean±SD	168.5 (10.0)
BMI, kg/m^2	
Mean±SD	26.5 (5.2)
Obesity defined by BMI, n (%)	11 (25%)
Waist, cm	
Mean±SD	90.2 (13.5)
Hip, cm	
Mean (SD)	104.6 (11.4)
Waist-to-hip ratio	
Mean±SD	0.86 (0.07)
Obesity by waist-to-hip ratio, n (%)	22 (12.5%)

BMI indicates body mass index (calculated as weight in kilograms divided by the square of height in meters). Obesity was defined by BMI (BMI ≥30 kg/m^2). Obesity was defined by waist-to-hip ratio (female, waist-to-hip ratio≥0.85; male, waist-to-hip ratio ≥0.90).

RESULTS

We enrolled 44 healthy subjects, 28 (63.6%) women, mean±SD age of 35±11 years, mean weight 75.5±17.1 kg, mean height 168.5±10.0 cm, body mass index 26.5±5.2 kg/m^2, with 25% classified as obese based on their body mass index, mean waist circumference 90.2±13.5 cm, mean hip circumference 104.6±11.4 cm, and waist-to-hip ratio 0.86±0.07. Central obesity was observed in 13% of the participants (Table 1). Treadmill velocity had a mean velocity of 1.48±0.45 mph; accelerometers recorded 2130.6±1232.8 steps when subjects were on the walking station compared with 414±722.7 on the stepper. Sedentary time could not be calculated due to missing survey information.

When comparing sitting to randomized active stations (differences by day; Model 1), most neurocognitive assessment scores improved or remained unchanged after day 1. In contrast, fine motor skills assessed using typing speed as a raw value slightly decreased, without a significant effect on typing errors across all stations and study days (Table 2). Moreover, when comparing study outcomes beyond day 1, only the Double Trouble Task continued to improve, with day 4 having significantly higher scores as compared with days 2 and 3 (*P*≤0.005; Table 2).

Comparisons among active workstations (difference by sequence [ie, standing, walking, and stepper; Model 2]) were not statistically significantly different from each other, except decrease in average typing speed 42.5

Table 2. Comparison of Neurocognitive and Fine Motor Skills Assessments Between Sitting and Randomized Active Workstations Stations

	Day 1 (sitting)	Day 2	Day 3	Day 4	Period *P* value*	Sequence *P* value*
Reasoning assessment						
Double Trouble Task, points						
Mean (SD)	13.5 (13.6)	24.9 (18.7)	28.8 (20.5)	34.4 (21.0)	<0.001	0.28
Median (Q1, Q3)	17.0 (0.0, 25.0)	33.5 (7.8, 40.2)	33.5 (10.0, 45.2)	42.0 (18.0, 49.5)		
P value†	[Reference]	<0.0001§	<0.0001§	<0.0001§		
Grammatical Reasoning Test, points						
Mean (SD)	14.0 (5.1)	14.8 (6.1)	15.7 (5.4)	16.1 (5.4)	0.01	0.36
Median (Q1, Q3)	15.0 (11.0, 17.0)	17.0 (13.5, 18.2)	16.0 (13.8, 20.0)	17.0 (13.8, 19.0)		
P value†	[Reference]	0.23	0.01	0.002§		
Object Reasoning Task, points						
Mean (SD)	9.7 (10.6)	13.2 (13.1)	17.1 (12.4)	15.3 (15.3)	0.008	0.20
Median (Q1, Q3)	7.5 (3.8, 14.8)	13.5 (5.0, 17.0)	15.5 (11.0, 25.8)	14.0 (6.0, 23.2)		
P value†	[Reference]	0.12	0.001§	0.01		
Odd One Out Test, points						
Mean (SD)	11.0 (3.2)	11.2 (2.9)	11.1 (3.1)	10.9 (3.3)	0.95	0.48
Median (Q1, Q3)	12.0 (9.0, 13.0)	11.0 (10.0, 13.0)	11.5 (9.0, 13.2)	11.0 (9.0, 12.2)		
P value†	[Reference]	0.80	0.93	0.76		
Memory assessment						
Spatial Span Task, points						
Mean (SD)	5.3 (1.4)	6.0 (1.0)	5.8 (0.9)	5.8 (1.1)	0.003	0.24
Median (Q1, Q3)	6.0 (5.0, 6.0)	6.0 (5.0, 6.0)	6.0 (5.0, 6.0)	6.0 (5.0, 6.0)		
P value†	[Reference]	0.0005§	0.01	0.005§		
Monkey Ladder Task, points						
Mean (SD)	7.3 (0.9)	7.7 (1.2)	7.5 (1.0)	7.7 (1.0)	0.18	0.15
Median (Q1, Q3)	7.0 (7.0, 8.0)	8.0 (7.0, 8.0)	7.5 (7.0, 8.0)	8.0 (7.0, 8.0)		
P value†	[Reference]	0.07	0.22	0.05		
Digit Span Task, points						
Mean (SD)	6.0 (1.3)	6.3 (1.1)	6.8 (1.3)	6.5 (1.5)	0.003	0.98
Median (Q1, Q3)	6.0 (5.0, 7.0)	6.0 (6.0, 7.0)	7.0 (6.0, 8.0)	6.5 (6.0, 7.0)		
P value†	[Reference]	0.10	0.0002§	0.02		
Paired Associates Task, points						
Mean (SD)	4.9 (0.9)	5.0 (1.0)	5.2 (1.0)	4.8 (1.7)	0.23	0.99
Median (Q1, Q3)	5.0 (4.0, 5.2)	5.0 (4.0, 6.0)	5.0 (5.0, 6.0)	5.0 (4.0, 6.0)		
P value†	[Reference]	0.40	0.12	0.75		
Concentration assessment						
Rotations Task, points						
Mean (SD)	65.2 (32.9)	94.6 (35.6)	93.6 (38.0)	93.7 (34.3)	<0.001	0.16
Median (Q1, Q3)	69.0 (42.8, 88.0)	91.0 (72.0, 109.8)	88.0 (73.0, 120.0)	98.0 (76.0, 109.0)		
P value†	[Reference]	<0.0001§	<0.0001§	<0.0001§		
Feature Match Task, points						
Mean (SD)	109.9 (28.3)	122.3 (36.1)	123.4 (34.6)	124.4 (35.5)	0.04	0.008
Median (Q1, Q3)	110.0 (93.8, 131.2)	121.5 (106.0, 144.0)	121.0 (99.8, 156.0)	132.0 (93.5, 144.5)		
P value†	[Reference]	0.03	0.02	0.01		
Polygons Task, points						
Mean (SD)	31.3 (19.0)	43.3 (23.2)	50.4 (34.2)	52.3 (26.8)	<0.001	0.02

(Continued)

Table 2. Continued

	Day 1 (sitting)	Day 2	Day 3	Day 4	Period *P* value*	Sequence *P* value*
Median (Q1, Q3)	33.0 (16.8, 42.2)	39.5 (26.5, 60.2)	43.0 (27.8, 70.2)	50.0 (35.8, 70.0)		
P value†	[Reference]	0.01	0.0001§	<0.0001§		
Fine motor skills						
Typing speed, words per min						
Mean (SD)	44.6 (15.6)	41.2 (13.4)	40.1 (14.4)	41.5 (14.2)	<0.001	0.05
Median (Q1, Q3)	45.0 (31.2, 57.2)	39.0 (29.0, 52.0)	40.0 (30.0, 49.2)	39.5 (31.5, 51.0)		
P value†	[Reference]	0.0004§	<0.0001§	0.001§		
Typing errors, number of errors						
Mean (SD)	13.9 (24.8)	12.4 (13.0)	21.9 (35.2)	9.9 (9.0)	0.33	0.14
Median (Q1, Q3)	7.0 (3.0, 12.0)	7.0 (3.8, 18.5)	7.5 (5.0, 12.8)	6.0 (4.0, 15.0)		
P value†,‡	[Reference]	0.49	0.15	0.82		
Adjusted typing speed, words per min						
Mean (SD)	39.2 (18.0)	37.1 (14.2)	33.0 (17.2)	38.1 (14.9)	0.009	0.30
Median (Q1, Q3)	41.0 (26.0, 50.5)	36.5 (26.0, 47.0)	32.0 (20.8, 44.5)	37.0 (27.8, 46.5)		
P value†	[Reference]	0.27	0.001§	0.56		

Q1 indicates 25th percentile; and Q3, 75th percentile.

*Period (days 1–4) and sequence (6 possible sequences for the active workstations) effects assessed with linear mixed models including terms for period along with sequence. Interaction between period and sequence were assessed in separate models. Significant period-by-sequence interaction found for the Monkey Ladder Task (P=0.048). This interaction remained significant even when focusing just on days 2–4 (P=0.006).

†Pairwise *P* values comparing each subsequent day with day 1 (sitting), adjusted for sequence. Days 2–4 were not significantly different ($P \geq 0.008$) from each other with exception of the Double Trouble task ($P<0.0001$ day 4 vs 2; P=0.005 day 4 vs 3).

‡Due to high positive skew, typing errors was modeled after log transformation (after adding 0.1 constant to all observations to handle values of zero). Reported means, SD, median, and quartiles are based on the nontransformed scale.

§Statistical significance was set at $P<0.008$ for pairwise comparisons according to the Bonferroni correction method to account for 6 pairwise comparisons within each measurement.

versus 39.7 words per minute (P=0.003 comparing standing versus stepping; Table 3). Interaction testing details are outlined in the footnotes of Tables 2 and 3.

DISCUSSION

The effects on neurocognitive and fine motor skills with the implementation of active office workstations have been debated. Our study assessed such effects in 3 types of active office workstations using validated neurocognitive and motor skills tests. Our findings show that using an active workstation does not lower essential neurocognitive functions (reasoning, memory, concentration) or accuracy of fine motor skills (typing) for office work, except for typing speed, which was slightly better while sitting compared with any active workstation.

The results of this study are novel yet in line with previous studies on the effect of exercise on cognitive function as well as fine motor skills (ie, cognitive function was nonsignificantly affected, whereas fine motor skills had a significant increase in typing time).[9,14,19–21] Several studies showed that active workstations do not negatively affect reasoning, memory, and concentration.[14,19,22–25] However, our study revealed improved reasoning scores when standing, stepping, and walking when compared with sitting using a crossover randomized trial design.

Improved dose–response cognitive processes, working memory, and executive function have been demonstrated in functional near-infrared spectroscopy magnetic resonance imaging studies of the prefrontal and frontal lobes, during an acute bout of activity while using active workstations.[26] In this sense, Russel et al found that when using only sitting versus standing workstations, there was no difference in cognitive performance represented by attention, information processing speed, and memory,[25] as evident in other randomized control trials.[14,22,23] Likewise, John et al found that treadmill walking caused a 6% to 11% decrease in performance of fine motor skills (eg, drag-and-drop, mouse clicking, and typing speed) and math problem solving, but did not affect selective attention and processing speed or reading comprehension.[20]

As in our study, Thompson et al assessed fine motor skills by transcribing tapes, noting that the accuracy of transcription did not differ between sitting and walking; in contrast, the speed was 16% slower while walking than while sitting.[27] Funk et al demonstrated that typing performance while walking at 2.25 km/h. was not different from seated typing performance,[14] and Husemann et al described a slight but nonsignificant loss of efficiency in data entry,[14] in line with Kang et al

Table 3. Comparison of Neurocognitive and Fine Motor Skills Assessments Between Sitting and Individual Active Workstation Stations

	Sitting	Standing	Walking	Stepping
Reasoning assessment				
Double Trouble Task, points				
Mean (SD)	13.5 (13.6)	30.5 (19.9)	27.3 (21.4)	30.2 (19.9)
Median (Q1, Q3)	17.0 (0.0, 25.0)	35.5 (10.8, 45.2)	34.0 (6.5, 43.2)	37.5 (14.8, 44.2)
P value*	[Reference]	<0.0001†	<0.0001†	<0.0001†
Grammatical Reasoning Test, points				
Mean (SD)	14.0 (5.1)	15.1 (6.0)	15.9 (5.3)	15.5 (5.6)
Median (Q1, Q3)	15.0 (11.0, 17.0)	17.0 (13.0, 19.0)	17.0 (14.0, 19.0)	16.0 (12.8, 20.0)
P value*	[Reference]	0.10	0.005†	0.02
Object Reasoning Task, points				
Mean (SD)	9.7 (10.6)	16.6 (14.0)	15.2 (13.5)	13.9 (13.7)
Median (Q1, Q3)	7.5 (3.8, 14.8)	15.5 (9.5, 23.2)	13.5 (6.8, 24.0)	13.0 (5.8, 19.0)
P value*	[Reference]	0.003†	0.02	0.07
Odd One Out Test, points				
Mean (SD)	11.0 (3.2)	11.5 (2.9)	10.9 (2.8)	10.8 (3.5)
Median (Q1, Q3)	12.0 (9.0, 13.0)	11.0 (10.0, 14.0)	11.0 (9.0, 13.0)	11.5 (9.0, 13.0)
P value*	[Reference]	0.39	0.79	0.57
Memory assessment				
Spatial Span Task, points				
Mean (SD)	5.3 (1.4)	5.9 (1.2)	6.0 (0.9)	5.7 (0.9)
Median (Q1, Q3)	6.0 (5.0, 6.0)	6.0 (5.0, 6.0)	6.0 (5.8, 6.0)	6.0 (5.0, 6.0)
P value*	[Reference]	0.002†	0.0002†	0.05
Monkey Ladder Task, points				
Mean (SD)	7.3 (0.9)	7.7 (1.1)	7.7 (1.2)	7.5 (0.9)
Median (Q1, Q3)	7.0 (7.0, 8.0)	8.0 (7.0, 8.0)	8.0 (7.0, 8.0)	8.0 (7.0, 8.0)
P value*	[Reference]	0.03	0.06	0.32
Digit Span Task, points				
Mean (SD)	6.0 (1.3)	6.6 (1.3)	6.5 (1.4)	6.5 (1.3)
Median (Q1, Q3)	6.0 (5.0, 7.0)	7.0 (6.0, 8.0)	6.0 (6.0, 7.0)	6.0 (6.0, 7.0)
P value*	[Reference]	0.005†	0.01	0.02
Paired Associates Task, points				
Mean (SD)	4.9 (0.9)	5.0 (1.8)	5.1 (1.0)	5.0 (0.9)
Median (Q1, Q3)	5.0 (4.0, 5.2)	5.0 (4.0, 6.0)	5.0 (4.0, 5.2)	5.0 (4.0, 6.0)
P value*	[Reference]	0.54	0.35	0.61
Concentration assessment				
Rotations Task, points				
Mean (SD)	65.2 (32.9)	86.8 (36.1)	98.5 (33.4)	96.7 (37.2)
Median (Q1, Q3)	69.0 (42.8, 88.0)	86.5 (62.0, 109.0)	98.0 (80.8, 115.5)	93.5 (69.5, 120.0)
P value*	[Reference]	0.0005†	<0.0001†	<0.0001†
Feature Match Task, points				
Mean (SD)	109.9 (28.3)	123.0 (33.4)	120.1 (39.9)	127.1 (32.1)
Median (Q1, Q3)	110.0 (93.8, 131.2)	121.5 (92.8, 145.0)	121.5 (98.0, 145.2)	132.0 (102.2, 147.0)
P value*	[Reference]	0.02	0.07	0.003
Polygons Task, points				
Mean (SD)	31.3 (19.0)	46.1 (29.7)	48.3 (27.0)	51.7 (29.0)
Median (Q1, Q3)	33.0 (16.8, 42.2)	41.5 (28.5, 56.0)	47.0 (26.5, 71.0)	49.0 (34.0, 64.0)
P value*	[Reference]	0.003†	0.0007†	<0.0001†

(Continued)

Table 3. Continued

	Sitting	Standing	Walking	Stepping
Fine motor skills				
Typing speed, words per min				
Mean (SD)	44.6 (15.6)	42.5 (14.6)	40.5 (13.6)	39.7 (13.7)
Median (Q1, Q3)	45.0 (31.2, 57.2)	40.5 (30.5, 54.2)	39.0 (29.8, 49.8)	38.0 (30.5, 50.0)
P value*	[Reference]	0.02	<0.0001†	<0.0001†
Typing errors, number of errors				
Mean (SD)	13.9 (24.8)	19.6 (32.3)	12.9 (18.7)	11.7 (11.6)
Median (Q1, Q3)	7.0 (3.0, 12.0)	6.0 (4.8, 20.2)	6.0 (3.0, 13.8)	8.0 (5.0, 15.0)
P value*,‡	[Reference]	0.33	1.0	0.35
Adjusted typing speed, words per min				
Mean (SD)	39.2 (18.0)	36.2 (17.1)	36.1 (15.5)	35.8 (14.2)
Median (Q1, Q3)	41.0 (26.0, 50.5)	37.0 (25.5, 49.5)	35.0 (23.8, 47.2)	36.5 (25.8, 44.2)
P value*	[Reference]	0.13	0.12	0.09

Q1 indicates 25th percentile, and Q3, 75th percentile.

*Pairwise *P* values comparing each active workstation with sitting (day 1), adjusted for sequence. Pairwise comparisons between the 3 active workstations were not significantly different ($P \geq 0.008$) from each other for most of the assessments with exception of typing speed ($P=0.003$ standing vs stepping). For outcomes in which a significant sequence effect was found when comparing by day (via Table 2: feature match, polygons), no significant sequence-by-station interaction was detected.

†Statistical significance was set at $P<0.008$ for pairwise comparisons according to the Bonferroni correction method to account for 6 pairwise comparisons within each measurement.

‡Due to high positive skew, typing errors was modeled after log transformation (after adding 0.1 constant to all observations to handle values of zero). Reported means, SD, median, and quartiles are based on the nontransformed scale.

who reported decreased concentration and fine motor skills while standing versus sitting.[28]

Other types of active workstations, such as bike-desk workstations, have also been studied, showing that implementing cycling workstations may decrease productivity and may be associated with reduced satisfaction among workers.[14,29–31] Similarly, other studies had shown that pedaling had no significant effect on cognitive tasks but had a significantly decreased impact on typing performance,[32,33] while some studies also found that mouse precision was impaired.[9,29] Some studies have shown a reduced performance in fine motor skills with the use of active workstations as seen in our study, which frequently demonstrated a difference in typing speed; such an effect on performance may be explained in part by the pattern of the allocation of attention and consciousness toward different cognitive and physical activities across workstations,[32] Funk et al have shown that practicing typing while using a walking workstation can improve typing speeds[19] as suggested in our study. Whether this can impact workers' productivity is yet to be determined.

In a systematic review and meta-analysis, Cao et al stated that energy expenditure was significantly increased by using active workstations. Its utilization did not affect selective attention, processing speed, speech quality, reading comprehension, interpretation, and accuracy of transcription, but it could decrease the efficiency of typing speed and mouse clicking.[19]

These observations may be explainable by reviewing the differences in the methodology of the studies. In the study by Koren et al, the number of participants was smaller,[21] which will affect the generalizability of the results, and the entire study was done in 1 day where using a retyping test modality did not affect the number of errors, which raises the question of how boredom and fatigue may affect cognitive function. Studies by Ohlinger et al, Commissaris et al, and Larson et al used only a small number of cognitive tests, which could limit the accuracy and reliability of their results.[9,14,34]

Our findings show a significant improvement of neurocognitive test results after the first day when comparing results by day, except for typing speed, which was slightly faster on day 1. One explanation for this is a certain level of habituation and learning; an alternative could be the one proposed in another study in which individuals self-reported feeling more energetic, sharper, and alert after several days of using an active office setting.[27]

Active workstations have been linked to increased work-time PA without impacting overall PA.[35] Also, using walking or cycling stations may compensate for a major part of the daily bodily need for PA for those whose profession leads to sedentary behavior.[36,37] We utilized accelerometers to record average steps with results of 2130 and 414 steps while using walking and stepping workstations for 45 to 55 minutes, respectively. Although this only constituted a small proportion of the workday, these findings have significant primary prevention implications and could significantly decrease overall sedentary time by increasing the total number of daily steps, which has been related to a decrease in risk of all-cause and CVD morbidity and mortality.[8]

The present study used 11 different cognitive tests to evaluate executive function and cognition of the participants during the study. This increases the precision and accuracy of the results. On the other hand, conducting the study on several days will reduce the effect of fatigue on participants' performance.[27,31,38] Using different stations including sitting, standing, stepping, and walking in a cross-over random manner is another relatively unique advantage of our study.

Along with the strengths of the present study, some limitations deserve to be mentioned. The study was conducted in a very short period and evaluated the acute effect of using active workstations on cognition and motor skills in a small number of participants. Hence, we are unable to properly assess carryover or learning effects from repeated testing with the current study design. It is possible that extended exposure, either from repeated testing within our study or even prolonged exposure in a nonresearch setting, may impact the outcomes; also our population was relatively young and our results may not be readily extrapolated to older populations in comparable office settings.[39] Missing data limited the calculation of self-reported baseline sedentary time, limiting the interpretation of our findings. Moreover, the study was conducted at the Active Wellness Office, which is an office-based, research-controlled environment that limits the external validity of our results. Therefore, future research is required to determine the effect of the use of active workstations in real-world settings. Lastly, the duties of an average workday were not able to be replicated. Additionally, there are numerous office-based activities that require testing the effect of active workstations in the future.

Clinically, the benefits of using active workstations extend beyond their effects on cognition. Even assuming no positive effects on cognitive function, the active workstations would benefit office workers by decreasing sedentary time with a reduced risk for several chronic noncommunicable diseases such as CVD or type 2 diabetes[14,40,41] while increasing the daily energy expenditure that is related to a lower risk of obesity and CVD.[2,42] Data from a recent systematic review and meta-analysis showed limited but statistically significant decreases in fasting blood glucose levels and body fat mass after replacing an average of 1.33 hours of sitting time with standing for an average of 4 months (2.53 [95% CI, 4.27–0.79] mg/dL and 0.75 [95% CI, 0.91–0.59] kg, respectively), suggesting that standing can help reduce the burden of cardiovascular risk factors.[2]

In conclusion, our results indicate that cognitive performance was not impaired but rather improved with the short-term use of active workstations. Office workers can benefit from the implementation of active workstations in different settings without decrease in office work performance and with even better cognition, increasing PA and daily energy expenditure and decreasing sedentary time, which is related to several cardiometabolic conditions, thereby improving office workers' overall health. Exceptions could be made for work offices where fine motor skills, such as data entry and precision outlines, are a significant part of the job, for office workers with comorbidities, or where the use of these active workstations would not be well tolerated. Future research should include the evaluation of the long-term benefits and adverse effects of using active workstations in the general population.

ARTICLE INFORMATION

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JRMI, MAGI, VS, and FLJ were responsible for study conception and design. JRMI, MAGI, MS, and LJ carried out the study. BMI, VS, JRMI, LJ, SJ, and FLJ interpreted the data, and SJ completed statistical analyses. JRMI, BJMI, and NPS were responsible for drafting the manuscript. JRMI, MAGI, BMI, MS, SJ, LJ, NPS, AB, VS, and FLJ edited the manuscript, and BJMI incorporated edits. All authors have approved the final version of the manuscript.

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None.

Supplemental Material

Table S1.
Figures S1–S2.

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