Metabolic Rate during a Cognitive Vigilance Challenge at Alternative Workstations

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Objective: The aim of this study was to compare energy expenditure (EE, kcal/min) at three workstations during an attention-demanding cognitive function task (Test of Variables of Attention or TOVA). Workstations included the seated desk (SIT), standing desk (STAND), and seated workstation designed to promote spontaneous movement (SWING). **Methods:** Adult males ($n = 11$) and females ($n = 13$) were assessed for EE using VO_2 and VCO_2 per quarter of the 22-min TOVA. **Results:** Average EE were 1.39 ± 0.06 (SIT), 1.55 ± 0.08 (SWING), and 1.44 ± 0.08 (STAND). Main effects ($P < 0.05$) were seen for workstation (SWING, STAND > SIT), and quarter of TOVA (Q2 < Q1,Q3,Q4). TOVA errors and response times were not different for workstations but increased for Q3 and Q4. **Conclusion:** Spontaneous movement at an alternative workstation elevated EE 10% to 11% compared with sitting and could increase daily nonexercise activity thermogenesis without diminishing mental attention to desk work.

Keywords: attention, NEAT, nonexercise activity thermogenesis, sedentary, sitting, TOVA

Excessive daily sitting is a known a risk factor for various diseases and premature mortality. Cardiometabolic diseases, such as Type II Diabetes, heart disease, and stroke, are strongly linked to prolonged sitting.[1,2] An epidemiological study on Australians indicated that prolonged sitting could account for ~7% of deaths independent of existing disease and that weekly exercise at recommended levels for moderate intensity might not confer a protective effect from mortality.[3] Brief and very modest-intensity physical activity, such as fidgeting, aimed at disrupting motionless while sitting at a desk has been associated with reduced risk factors, such as large waist circumference, high body mass index (BMI), elevated serum triglycerides, and elevated postprandial plasma glucose concentration.[4] The activity does not need to be traditional exercise to promote movement and nonexercise activity thermogenesis (NEAT). NEAT appears to be a critical component of total daily energy expenditure by helping to offset the consequences of being otherwise sedentary.[5] Spontaneous movement such as fidgeting may offer resistance to weight gain over a span of years.[6,7] In addition to raising NEAT, fidgeting-type movement might also reduce the endothelial dysfunction that links motionless to vascular disease.[8]

The ill effects of workstation inactivity have prompted the development of strategies and technologies to help increase movement and NEAT while at a desk. The typical options for increasing NEAT for workers include static stations, such as sitting on a stability ball or standing, and active workstations that include walking treadmills or pedaling devices.[9] The magnitude of effects of alternative workstations clearly varies based on the metabolic demand elicited by the movement. Dynamic workstations stimulate greater physiological demands and seem to do more to reduce risk factors for obesity, vascular diseases, and Type 2 diabetes than do the effects of static workstations.[9] Alternative workstations are not universally accepted as a replacement for planned exercise time. Yet, recent experimental research suggests that intermittent standing that breaks up 9 hours of desk sitting reduces postprandial glucose response more so than the effect of a planned 30-minute session of moderate level exercise.[10]

One concern about alternative workstations is whether the movement detracts from desk work productivity.[9,11,12] Effects on true work productivity are unclear, but proxies for productivity, that is, cognitive function tests, have been studied with a variety of cognitive tests applied. Generally, when precision and hand-eye coordination are required, the active workstations show a greater decrement in performance based on error rates or speed to complete the tasks.[9,13] Direct comparisons of computer task performance, for example, reveal reduced cognitive performance when walking or cycling compared with performance while sitting in a chair, but seated cycling had a lesser impact than did walking.[14] Therefore, mental attention as well as fine-motor skills could suffer in association with the degree of movement induced by the station.

Recent research indicates a swing-like device for the legs can promote spontaneous movement while performing desk work. Metabolic rate increased by 17% and 7% compared with that of sitting and of standing, respectively ($P < 0.05$)[15] and in another study, by 18% to 19% compared with sitting.[16] In the former study, cognitive function was tested at the end of the metabolic assessment due to the task requiring verbal responses that would be impossible while wearing a mouthpiece for quantifying oxygen consumption. A pattern of significant improvement in cognitive scores was observed, most likely due to an order effect, not the workstation, based on the study design. It was not clear whether leg movement was sustained and continued to promote an elevated metabolism when the subject's attention was redirected to the cognitive task. A valid comparison devoid of a warm-up effect is required to test whether the subtle activity of leg swinging while seated affects mental function.

The purpose of the present study was to compare metabolic rate and outcomes for a cognitive attention-demanding task while subjects performed at a seated desk, a standing desk, and a workstation designed to elevate NEAT by promoting spontaneous motion of leg swinging (Hovr®). The hypothesis was that NEAT would be induced by the novel alternative workstation and that cognitive function would not differ between the three workstations.

MATERIALS AND METHODS

Subjects

Twenty-four healthy individuals (11 male, 13 female) between the ages of 18 and 50 years (mean ± SD: age, 23.4 ± 5.9 years; height 170.6 ± 10.4 cm; weight, 73.9 ± 19.3 kg; BMI, 25.0 ± 4.5) were recruited from university staff, faculty, and student populations. The exclusion criteria other than age were that subjects did not have orthopedic issues that might be aggravated by the desk swing or standing for ~30 minutes, and that they did not have problems such as eye strain or headaches that could be induced staring at a computer screen for that same duration. The participants

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provided written informed consent after having the study described to them. The study and consent form were approved by Institutional Review Board within the institution's Office of Protection of Research Subjects.

Experimental Protocol

A crossover design with randomized assignment of the order of workstations treatment was employed. The order was also balanced such that all six combinations of order were experienced by four subjects. The study participants attended a total of four sessions. The purpose of the first session was to obtain informed consent as well as familiarize subjects to the testing. Participants were introduced to the facemask used for measuring respiratory gasses, the HOVR device (the leg swing workstation), and performance of the test of variables of attention (TOVA) for cognitive function.

The remaining three visits were used for data collection in each of the three modes, including using a sitting workstation, a standing workstation, and a sitting workstation while using the HOVR. These three workstations were selected as a part of more rigorous testing than what had previously been done for shorter durations and nonrandomized order.[15,16] The desk swing remains a fairly novel device to induce fidgeting, while sitting and standing desks have been researched considerably more and provide reasonable standards for comparison.[9,13] Each experimental session began with participants completing a survey to record wellbeing, restfulness, timing of last meal, and physical characteristics to allow for consistency at each visit. Participants then rested in the designated workstation mode for 5 minutes before the beginning of data collection. They were then fitted with a facemask to begin metabolic data collection. After a 5-minute period to wash out room air and achieve steady state metabolism, the participants began the TOVA test, which lasted approximately 22 minutes. Heart rate and blood pressure was measured every 5 minutes throughout the collection period.

Instrumentation and Analyses

The TOVA was used to challenge the cognitive abilities of the participants.[17] This test is used in clinical psychology to identify disorders influencing attention. Briefly, the test uses a computerized system in which participants observe the computer screen and are prompted visually for a response. For the correct prompting, the participant depresses a switch held in his/her hand as quickly as possible. The response time is quantified. If the participant reacts and presses the button for an inappropriate prompting, the response is scored as a commission error. If the participant does not react appropriately before the correct prompting disappears from the screen, the response is scored as an omission error. The type of prompting is random, but the rate at which the prompts appear increases over the assessment period. The variability in response is the fourth variable measured during the test. By design, TOVA is a continuous test for which results of each outcome variable is compartmentalized into four equal time segments, or quarters according to the designer's nomenclature. The quarters allow the evaluation of change in the subject's performance, as the prompts are varied to further stress the cognitive vigilance.

Rate of energy expenditure was determined using respiratory gasses measured with a metabolic cart (Parvo Medics TrueOne 2400; Sandy, Utah). The VO_2 and VCO_2 values were converted to kilocalories per minute using the following equation:

$$\text{Energy Expenditure in kcal/min} = (3.9 \times \text{VO}_2 \text{ in L/min}) + (1.1 \times \text{VCO}_2 \text{ in L/min})^{18}$$

In addition to energy expenditure, METS was also calculated using 3.5 mL/kg/min as one MET. Heart rate was measured using a finger pulse oximeter on the hand free of the TOVA switch (Diagnostix 2100; American Diagnostic Corp, Hauppage, NY). Blood pressure was measured using an automated system (OSCILLA Automated Blood Pressure Monitor; MDF Instruments, Agoura Hills, California).

Statistical Analysis

Statistical analyses were done using IBM SPSS® Statistics version 24. Mean and standard deviation were determined to summarize the data. Dependent variables included energy expenditure (kcal/min), MET level, the raw scores for the four variables measured by TOVA, heart rate (HR), and systolic and diastolic blood pressure. Two-way analysis of variance (ANOVA) adjusted for repeated measures was used to examine interactions between time (quarter or Q) by workstation (seated, seated with leg movement using HOVR, and standing). In the event that Mauchy test of sphericity was statistically significant ($P < 0.05$), the Greenhouse–Geisser correction was applied. If an ANOVA showed a statistically significant difference between the means, multiple comparison tests were done using least significant difference to compare specific means. Effect size was also calculated for differences between the workstations when tendencies for statistical differences were observed. Finally, the association between body size and metabolic rate (BMI or body mass vs METs or difference in METs for standing, HOVR, and sitting) was examined using Pearson correlation coefficients. A probability level of 0.05 was selected to establish statistical significance.

RESULTS

Figure 1 displays the pattern of energy expenditure in kcal/min across the quarters. A trend for an interaction was observed ($P = 0.057$). The effect size for a difference between EE for the HOVR and sitting ranged from 0.52 in Q1 to ~0.4 for the remaining quarters. The effect size for a difference between HOVR and standing was 0.39 in Q1 and decreased to ~0.24 for the remaining quarters. A main effect was found for workstation ($P = 0.03$) and time ($P = 0.02$). Average expenditure (kcal/min) for the entire observation period for each workstation was sitting, 1.39 ± 0.06; use of HOVR 1.55 ± 0.08; standing, 1.44 ± 0.08. Post hoc tests showed the rate of energy expenditure for use of HOVR and standing did not differ but both exceeded that of sitting ($P < 0.03$). For the time factor, the rate of energy expenditure (kcal/min) was lower during Q2 (1.44 ± 0.07) than that during Q1 (1.47 ± 0.07), Q3 (1.46 ± 0.07), and Q4 (1.45 ± 0.07) and no differences were found between Q1, Q3, and Q4.

When standardizing the metabolic response to resting metabolic rate, that is, units of MET, no interaction was found ($P = 0.135$). A main effect was observed for workstation ($P = 0.007$) and a trend was found for a main effect of time ($P = 0.056$). Data for quarter by workstation are presented in Table 1. The means for the entire observation period were 1.11 ± 0.04 for sitting, 1.25 ± 0.04 while using the HOVR, and 1.18 ± 0.04 during standing. The post-hoc test indicated a difference between use of HOVR and sitting ($P < 0.005$). The effect size for a difference between METs for the HOVR and sitting was 0.88 in Q1 and at least 0.71 in the remaining quarters. By quarter, the summary data for METs were as follows: Q1, 1.19 ± 0.04; Q2, 1.16 ± 0.03, Q3, 1.19 ± 0.03; Q4, 1.18 ± 0.04. Comparing HOVR and standing, the effect size for a difference in METs was 0.42 in Q1 and approximately 0.25 for the remaining quarters. No statistically significant relationships were detected between any index of body size and index of energy expenditure; the highest r value was less than −0.27 for BMI versus METs ($P > 0.05$).

Examining the results of the TOVA cognitive-function scores (Table 2), no effects were found for workstation or the interaction factor, but a time effect was observed. Although the increases were modest, significantly more commission errors occurred in the fourth quarter than in prior quarters and in quarter 3 versus the other

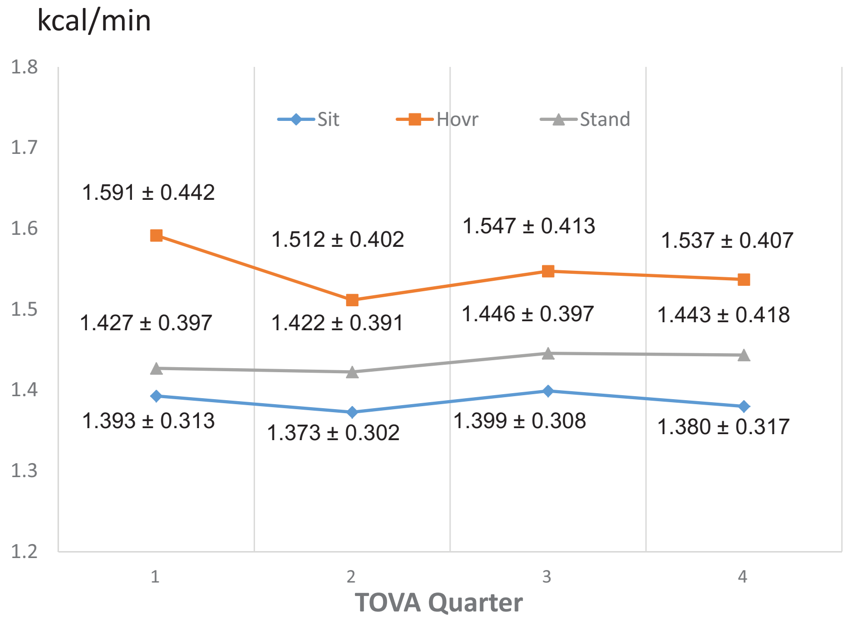

FIGURE 1. Patterns for the mean ± SD of energy expenditure rates (kcal/min) for each workstation by quarter while performing the TOVA test. $P < 0.05$ for main effect of workstation with post-hoc tests showing HOVR > sitting and standing > sitting. $P < 0.05$ for main effect of time with post-hoc tests showing Q1 > Q2, and Q3, Q4 > Q2. The interaction of workstation by time approached significance with $P = 0.057$.

quarters. Significantly more omission errors occurred in the third and fourth quarter than prior quarters. For response time (Fig. 2), no difference was seen between workstations and the workstation by time interaction, but a time effect was detected. Response time for each quarter differed from each other ($P < 0.05$) and the general pattern was one of a decrease in response time over the entirety of the test. No effects were found for response time variability.

Mean ± SD for heart rate and blood pressures for the entire observation period are provided in Table 3. Average heart rate and diastolic blood pressure were higher for the standing workstation than either seated workstation ($P < 0.05$). No other differences were found for cardiovascular responses.

DISCUSSION

Alternative desk stations are popular in occupational environments as a tactic to promote movement, increase NEAT, and help reduce risk factors for disease associated with a sedentary lifestyle. A concern about active workstations, those such as treadmill or cycle ergometers that involve higher-intensity fixed efforts, is that certain aspects of desk performance may be diminished compared with the effects of not moving (sitting or standing desks). Presently, the evidence-based opinions are mixed due to a variety of factors (acute vs chronic effects, sample size, method of assessing work productive).[19–22] There is some indication that fine-motor efforts at the desk such as typing speed, mouse use, and dictation are reduced compared with the performance at static stations.[9,13] In the present study, a workstation designed to promote spontaneous motion and elevate NEAT was found to raise calorie expenditure on average by 10% to 11% compared with the rate of energy expenditure during sitting ($P < 0.05$). When standardizing to resting metabolism (MET), the spontaneous-movement workstation produced higher values than the seated desk, and METs for the standing workstation did not differ from the seated workstation. Simultaneous with the metabolic rate assessment, subjects performed a cognitive challenge that demanded mental vigilance, and no differences in error rates nor response times were observed between the three workstations.

While fidgeting only slightly elevates metabolic rate, it may contribute to NEAT and have a cumulative effect on total daily energy expenditure. NEAT may add as many 800 kcals per day based on 24-hour measurements of subjects in room calorimeters.[7] Whether NEAT can inherently be changed is questionable. Levine et al[23] reported that variation in "posture allocation," that is, quantified fidgeting, appears to be biologically pre-determined and be influenced by production of neuropeptides and transmitters such as orexin as demonstrated in rodent models.[24] Levine et al[23] reported that lean individuals (BMI of 23 ± 2 kg/m^2) spent less time sitting and more time standing and changing body position even after overeating and gaining ~4 kg. In contrast, obese individuals (33 ± 2 kg/m^2) spent more time sitting and less time standing or ambulating even after losing 8 kg of weight. In the present study, we

TABLE 1. Means ± SD for METs for Each Workstation by Progressive Quarter (Q) of the TOVA Challenge

	Quarter[b]			
Workstation[a]	Q1	Q2	Q3	Q4
Sit	1.12 ± 0.15	1.10 ± 0.15	1.12 ± 0.14	1.11 ± 0.14
HOVR	1.27 ± 0.21	1.22 ± 0.18	1.25 ± 0.18	1.24 ± 0.18
Stand	1.18 ± 0.26	1.17 ± 0.26	1.19 ± 0.26	1.18 ± 0.28

[a] $P < 0.05$ for main effect of workstation with HOVR > Sit regardless of quarter.
[b] $P < 0.05$ for main effect of quarter with Q1 and Q3 > Q2 regardless of workstation.

TABLE 2. Mean ± SD for Errors by Progressive Quarter (Q) of the TOVA Challenge

	Q1	Q2	Q3	Q4
Commission[a]	0.389 ± 0.091	0.264 ± 0.003	2.819 ± 0.494[b]	3.819 ± 0.656[c]
Omission[a]	0.167 ± 0.063	0.139 ± 0.060	0.514 ± 0.120[b]	0.569 ± 0.151[b]
Resp Time Var	72.46 ± 3.65	73.01 ± 4.01	77.90 ± 4.03	78.14 ± 4.56

Resp Time Var, response time variability.
[a] $P < 0.05$ for ANOVA time effect.
[b] $P < 0.05$ vs Q1 and Q2.
[c] $P < 0.05$ vs Q1, Q2, and Q3.

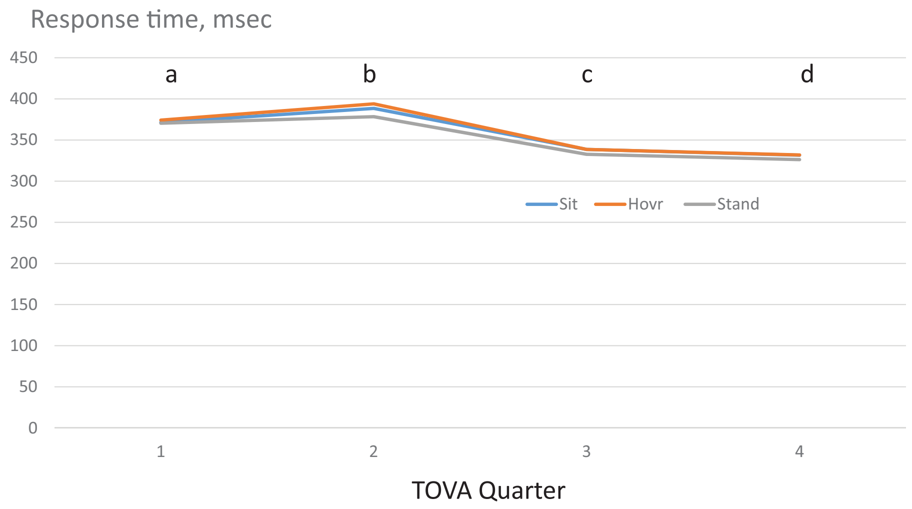

FIGURE 2. Patterns for mean ± SD of the response times (ms) per quarter while performing the TOVA test. A main effect for time existed with the means for each quarter differing from each other ($P < 0.05$).

did not see a relationship between BMI and the difference in metabolism between the seated workstation and the HOVR workstation; however, our subject sample was primarily normal-weight individuals. Restrictions in the range of BMI (only 2 of 24 subjects clearly exceeded BMI of 30), METs, and difference scores for metabolism (HOVR use minus sitting) would limit our ability to see a relationship. Whether obese individuals would have a similarly elevated NEAT despite the cognitive distraction during use of the HOVR remains to be seen. Regardless, environmental factors such as alternative workstations that promote subtle movement may be efficacious for raising NEAT and help with energy balance.

An additional objective of the present study was to determine whether spontaneous movement altered attention to desk station tasks. Workstations demanding less intense effort, that is, static workstations involving standing or a balance ball that elicits movement based on reaction, do not adversely affect cognitive performance.[9,13] Several studies even indicate improved deskwork productivity, perceived quality of work completed, cognitive function, and mood by replacing the traditional sedentary sitting position with standing or balance balls.[25–27] Employee and supervisor assessment of work performance using weekly surveys indicate work performance to not be affected during a one-year study of the benefits of treadmill workstations, and interestingly, there appeared to be adaptation toward improved performance within the year.[28]

Simultaneous with the assessment of metabolic rate at each workstation, participants in the current study were tested for cognitive function using TOVA, which to our knowledge has not previously been employed in alternative workstation research. TOVA provides a cognitive challenge that elicits a response to a visual stimulus or target. The outcome variables include correct and incorrect responses to an appropriate stimulus, the time it takes to respond, and the variability in the response times.[17] By design, the rate of promptings of the subject by TOVA is constant throughout the 22-minute test, but the ratio of targets versus nontargets changes between the first and second half of the test. Because of the mundane nature of the test, the challenge is in maintaining mental vigilance, as expectations change unknowingly to the subject. In this study, the TOVA error rates did not differ between the three workstations. As one might expect, error rate did increase over time particularly in the final two quarters presumably due to mental fatigue and loss of vigilance. The subtle increase in response time progressively across the quarters also suggests fatigue in subjects' ability to stay attentive. The test is typically used in clinical psychology to help identify disorders influencing mental attention or vigilance, but has also been shown to be sensitive in nonclinical populations to the effects of caffeine, dehydration, and exercise exhaustion.[29,30] Although reliable for detecting effects of distraction or fatigue, it remains questionable how accurately TOVA simulates all cognitive challenges faced in daily work at the desk.

TABLE 3. Means ± SD for Cardiovascular Responses During TOVA at Each Workstation

	Heart Rate	Systolic BP	Diastolic BP
Sit	75 ± 11	118 ± 14	66 ± 7
HOVR	77 ± 10	118 ± 10	67 ± 8
Stand	84 ± 11[a]	120 ± 11	72 ± 9[b]

[a] $P < 0.05$ vs Sit or HOVR.
[b] $P < 0.05$ vs Sit or HOVR.
BP, blood pressure.

A pattern of different rates of energy expenditure for each workstation was consistent through the 22-minute observation of the TOVA performance. A tendency for a statistical interaction and visual analysis suggests that when subjects used the HOVR workstation, metabolic rate started highest in the first quarter and then tended to decrease slightly to a stable rate for the remaining quarters. In contrast, energy expenditures for the static stations, seated or standing, were stable throughout. This might suggest that as the demand for concentration on TOVA increased, the mental distraction might have slightly attenuated spontaneous movement and NEAT. Through the 22-minute period, though, use of the HOVR elicited a higher metabolic rate than merely seating ($P < 0.05$) and tended to be higher than that for standing although the latter comparison was not statistically different. A slight but statistically significant difference in the rate of energy expenditure was seen for standing compared with merely sitting, an observation that is consistent with other studies.[15,31,32] The percentage difference between use of the HOVR and sitting appeared to be lower at 10% to 11% than elevations of 17% [15] and 20% [16] as previously reported, and suggests the need for further examination of the effect of the cognitive demand on NEAT and factors that influence spontaneous activity.

The elevation in metabolic rate supports that the spontaneous modest movement was sustainable while performing a mental task demanding of attention. Aside from reaching a level considered to be NEAT, the movement might be adequate to deliver other benefits such as for endothelial function for vascular benefits. In support of this, Morishima et al[8] recently reported that subtle movement as benign as a single-foot heel raise-and-lowering for 1 minute every 5th minute during a 3-hour observation period, essentially quantifiable fidgeting, maintained endothelial function based on flow-mediated vasodilation compared to blood flow in the stationary foot. Presently, it is not known whether cognitive tasks would reduce spontaneous movement that achieves desirable vascular responses.

The subject sample of 24 was drawn from a population of homogenous occupations; primarily adults that sit for reasonably long periods in a university setting as students, faculty, and staff. This is modest size sample that might explain the lack of a statistically significant difference in metabolic rate for the desk swing versus standing. Despite a more rigorous design in the present study, the absence of a difference contrasts with a difference detected in a prior report.[15] In addition, with this sample, occupations such as dispatchers, programmers, investment traders that sit for excruciatingly long hours were not represented. We also did not account for the characteristics of the subjects ranging from athleticism or attention disorders. Those having had experiences in sports or other activities that demand focus and decision making during physical effort could respond differently. The intensity of effort on the athletic field is well beyond standing or the desk swing, but there could be degree of experience that might alter the relationship between the capacity for mental focus and physical movement in such individuals. To avoid inquiring into private health information, the current subjects were also not surveyed for attention disorders such as attention deficit hyperactivity disorder (ADHD). A report from the pediatric literature indicates that movement in those with ADHD may be associated with cognitive performance. Specifically, for correct scores on a computerized Eriksen flanker test, students with ADHD exhibited leg movement of significantly higher intensity than the intensity matched to their incorrect scores.[33] Larger sample sizes of more diverse subjects or population-specific studies are required to clarify factors affecting the relationships between physical movement at a desk station and cognitive function such as mental focus.

The findings were directionally consistent with prior research[15,16] showing elevated metabolic rate, either as energy expended or MET level, for a workstation designed to promote spontaneous movement that raises NEAT. In addition, cognitive function that required progressively greater attention for response to a visual stimulus was not different from that of seated or standing workstations. This indicates that mental work may not be adversely affected by spontaneous-movement workstation. The converse might also apply that the mental challenge did not distract or diminish the ability of the subjects to sustain NEAT during the testing; however, we did not compare use of the HOVR with and without taking the TOVA challenge. Finally, it would be tempting to conclude that workstation productivity did not differ between the three versions of desks, but a lack of differences in the scores for the cognitive test (TOVA) may not adequately represent true cognitive tasks in the workplace.

REFERENCES

1. Chau JY, Grunseit AC, Chey T, et al. Daily sitting time and all-cause mortality: a meta-analysis. *PLoS One*. 2013;8:e80000.
2. van Uffelen JG, Wong J, Chau JY, et al. Occupational sitting and health risks: a systematic review. *Am J Prev Med*. 2010;39:379–388.
3. van der Ploeg HP, Chey T, Korda RJ, Banks E, Bauman A. Sitting time and all-cause mortality risk in 222 497 Australian adults. *Arch Intern Med*. 2012;172:494–500.
4. Healy GN, Dunstan DW, Salmon J, et al. Breaks in sedentary time: beneficial associations with metabolic risk. *Diabetes Care*. 2008;31:661–666.
5. Levine JA. Measurement of energy expenditure. *Public Health Nutr*. 2005; 8:1123–1132.
6. Johanssen DL, Ravussin E. Spontaneous physical activity: relationship between fidgeting and body weight control. *Curr Opin Endocrinol Diabetes Obes*. 2008;15:409–415.
7. Ravussin E, Lillioja S, Anderson TE, Christin L, Bogardus C. Determinants of 24-hour energy expenditure in man. Methods and results using a respiratory chamber. *J Clin Invest*. 1986;78:1568–1578.
8. Morishima T, Restaino RM, Walsh LK, Kanaley JA, Fadel PJ, Padilla J. Prolonged sitting-induced leg endothelial dysfunction is prevented by fidgeting. *Am J Physiol Heart Circ Physiol*. 2016;311:H177–H182.
9. Tudor-Locke C, Schuna JM, Frensham LJ, Proenca M. Changing the way we work: elevating energy expenditure with workstation alternatives. *Int J Obes (Lond)*. 2014;38:755–765.
10. Benatti FB, Larsen SA, Kofoed K, et al. Intermittent standing but not a moderate exercise bout reduces postprandial glycemia. *Med Sci Sports Exerc*. 2017;49:2305–2314.
11. Commissaris DA, Konemann R, Hiemstra-van Mastrigt S, et al. Effects of a standing and three dynamic workstations on computer task performance and cognitive function tests. *Appl Ergon*. 2014;45:1570–1578.
12. Thompson WG, Levine JA. Productivity of transcriptionists using a treadmill desk. *Work*. 2011;40:473–477.
13. Cao C, Liu Y, Zhu W, Ma J. Effect of active workstation on energy expenditure and job performance: a systematic review and meta-analysis. *J Phys Act Health*. 2016;13:562–571.
14. Straker L, Levine J, Campbell A. The effects of walking and cycling computer workstations on keyboard and mouse performance. *Hum Factors*. 2009;51:831–844.
15. Horswill CA, Scott HM, Voorhees DM. Comparison of three workstations for effect on non-exercise activity thermogenesis (N.E.A.T.). *Work*. 2017;58:447–454.
16. Koepp GA, Moore G, Levine JA. An Under-the-table leg-movement apparatus and changes in energy expenditure. *Front Physiol*. 2017;18: 318.
17. Dupuy TR, Cenedala M. *Test of Variables of Attention: User's Guide*. Los Alamitos, CA: Universal Attention Disorders; 1996, 1–77.
18. deV Weir JB. New methods for calculating metabolic rate with special reference to protein metabolism. *J Physiol*. 1949;109:1–9.
19. MacEwen BT, MacDonald DJ, Burr JF. A systematic review of standing and treadmill desks in the workplace. *Prev Med*. 2015;70:50–58.
20. Ben-Ner A, Hamann DJ, Koepp G, Manohar CU, Levine J. Treadmill workstations: the effects of walking while working on physical activity and work performance. *PLoS One*. 2014;9:e88620.
21. Torbeyns T, Bailey S, Bos I, Meeusen R. Active workstations to fight sedentary behaviour. *Sports Med*. 2014;44:1261–1273.
22. Neuhaus M, Eakin EG, Straker L, et al. Reducing occupational sedentary time: a systematic review and meta-analysis of evidence on activity-permissive workstations. *Obes Rev*. 2014;15:822–838.
23. Levine JA, Lanningham-Foster LM, McCrady SK, et al. Interindividual variation in posture allocation: possible role in human obesity. *Science*. 2005;307:584–586.
24. Kotz CM. Integration of feeding and spontaneous physical activity: role for orexin. *Physiol Behav*. 2006;88:294–301.
25. Beers EA, Roemmich JN, Epstein LH, Horvath PJ. Increasing passive energy expenditure during clerical work. *Eur J Appl Physiol*. 2008;103: 353–360.
26. Dutta N, Koepp GA, Stovitz SD, Levine JA, Pereira MA. Using sit-stand workstations to decrease sedentary time in office workers: a randomized crossover trial. *Int J Environ Res Public Health*. 2014; 11:6653–6665.
27. Mehta RK, Shortz AE, Benden ME. Standing up for learning: a pilot investigation on the neurocognitive benefits of stand-biased school desks. *Int J Environ Res Publ Health*. 2015;13:ijerph13010059.
28. Koepp GA, Manohar CU, McCrady-Spitzer SK, et al. Treadmill desks: a 1-year prospective trial. *Obesity*. 2013;21:705–711.
29. Baker LB, Conroy DE, Kenney WL. Dehydration impairs vigilance-related attention in male basketball players. *Med Sci Sports Exerc*. 2007;39: 976–983.
30. Hunt MG, Momjian AJ, Wong KK. Effects of diurnal variation and caffeine consumption on Test of Variables of Attention (TOVA) performance in healthy young adults. *Psychol Assess*. 2011;23:226–233.
31. Reiff C, Marlatt K, Dengel DR. Difference in caloric expenditure in sitting versus standing desks. *J Phys Activ Health*. 2012;9:1009–1011.
32. Thorp AA, Kingwell BA, Sethi P, Hammond L, Owen N, Dunstan DW. Alternating bouts of sitting and standing attenuate postprandial glucose responses. *Med Sci Sports Exerc*. 2014;46:2053–2061.
33. Hartanto TA, Krafft CE, Iosif AM, Schweitzer JB. A trial-by-trial analysis reveals more intense physical activity is associated with better cognitive control performance in attention-deficit/hyperactivity disorder. *Child Neuropsychol*. 2016;22:618–626.