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Metabolic Rate during a Cognitive Vigilance Challenge at Alternative Workstations

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COLLEGE OF APPLIED HEALTH SCIENCES UIC

December 3, 2017

To Whom It May Concern:

We are submitting the paper, "Metabolic Rate during a Cognitive Vigilance Challenge at Alternative Workstations," for consideration for publication in the *Journal of Occupational and Environmental Medicine.*

The paper investigates whether an alternative workstation designed to promote spontaneous low-level activity and raise metabolic rate affects attention to desk work. Our findings have implications for clinicians and worksite hygienists who seek to promote movement among desk-bound employees, and helps address whether elevated movement interferes with elements of cognitive function.

We confirm that the paper has not been previously published, nor is it in review with another journal. The work is original and each of the three authors contributed to the study design, data collection, data analysis and interpretation, and writing of the manuscript. We have stated that there are no conflicts of interest to report.

Please contact me as the corresponding author for future communications on the review process.

Kind regards,

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Title Page (include all author information)

Metabolic Rate during a Cognitive Vigilance Challenge at Alternative Workstations

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Running title: Metabolic rate, vigilance and workstation

Metabolic Rate during a Cognitive Vigilance Challenge at Alternative Workstations

Abstract

Objective: Compare energy expenditure (EE, kcal/min) at three workstations during an attention-demanding cognitive function task (Test of Variables of Attention or TOVA). Work stations included the seated desk (SIT), standing desk (STAND), and seated workstation designed to promote spontaneous movement (SWING).

Methods: Young 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 10-11% compared to sitting and could increase daily non-exercise activity thermogenesis without diminishing mental attention to desk work.

Key **words**: attention, non-exercise activity thermogenesis, NEAT, sedentary, sitting, TOVA

Introduction

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 in 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 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 was not traditional exercise, yet promoted movement and presumably increased non-exercise activity thermogenesis, or 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 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 nine 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, i.e. 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 to performance while sitting in a chair, but seated cycling had 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 to that of sitting and of standing, respectively ($p<0.05$)[15] and in another study, by 18-19% compared to 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. 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 participants 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 workstations was employed. 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, 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. 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 five minutes prior to 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 five minutes throughout the collection period.

Instrumentation and Analyses. The Test of Variables of Attention (TOVA) was used to challenge the cognitive abilities of the participants[17]. 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 quantified from the test. The test is broken into four quarters for analysis.

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:

$$\text{Energy Expenditure in kcal/min} = (3.9 \times VO_2 \text{ in L/min}) + (1.1 \times VCO_2 \text{ in L/min})$$ [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, CA).

Statistical Analysis. 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 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's 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, i.e., 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 vs. 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 4th quarter than in prior quarters and in quarter 3 vs. the other quarters. Significantly more omission errors occurred in the 3rd and 4th quarter compared to prior quarters. For response time (Figure 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 compared to 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 to the effects of not moving (sitting or standing desks). Reviews by Tudor-Locke et al.[9] and Cao et al.[13] indicate that in at least two-thirds of the studies on active workstations, desk performance such as typing speed, mouse use, and dictation was reduced compared to outcomes for the same tasks while at static stations (seated or standing). In the present study, a workstation designed to promote spontaneous motion and elevate NEAT was found to raise calorie expenditure on average by 10-11% compared to 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 or response times were observed between the three workstations.

While fidgeting only slightly elevates metabolic rate, it may contribute to NEAT has and have a cumulative effect on total daily energy expenditure. NEAT may add as many 800 kcals per day based on 24-h measurements of subjects in room calorimeters[7]. Whether NEAT can inherently be changed is questionable. Levine and colleagues[19] reported that variation in "posture allocation," i.e., 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[20]. Levine et al[19] reported that lean individuals (BMI of 23 $\pm$2kg/m^2) spent less time sitting and more time standing and changing body position even after overeating and gaining ~4kg. In contrast, obese individuals (33 $\pm$2kg/m^2) spent more time sitting and less time standing or ambulating even after losing 8 kg of weight. In the present study, we 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, i.e., 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 an alternative workstation for the traditional sedentary sitting position with standing or balance balls[21, 22, 23]. 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[24].

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 had 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 vs. non-targets 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 non-clinical populations to the effects of caffeine, dehydration, and exercise exhaustion[25, 26]. While 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.

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 to merely sitting, an observation that is consistent with other studies[15, 27, 28]. The percent difference between use of the HOVR and sitting appeared to be lower at 10-11% 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 one 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 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.

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Legend for Figure.

Figure 1. Patterns for the mean $\pm$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 $p=0.057$.

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

Figure 1

Figure 1.

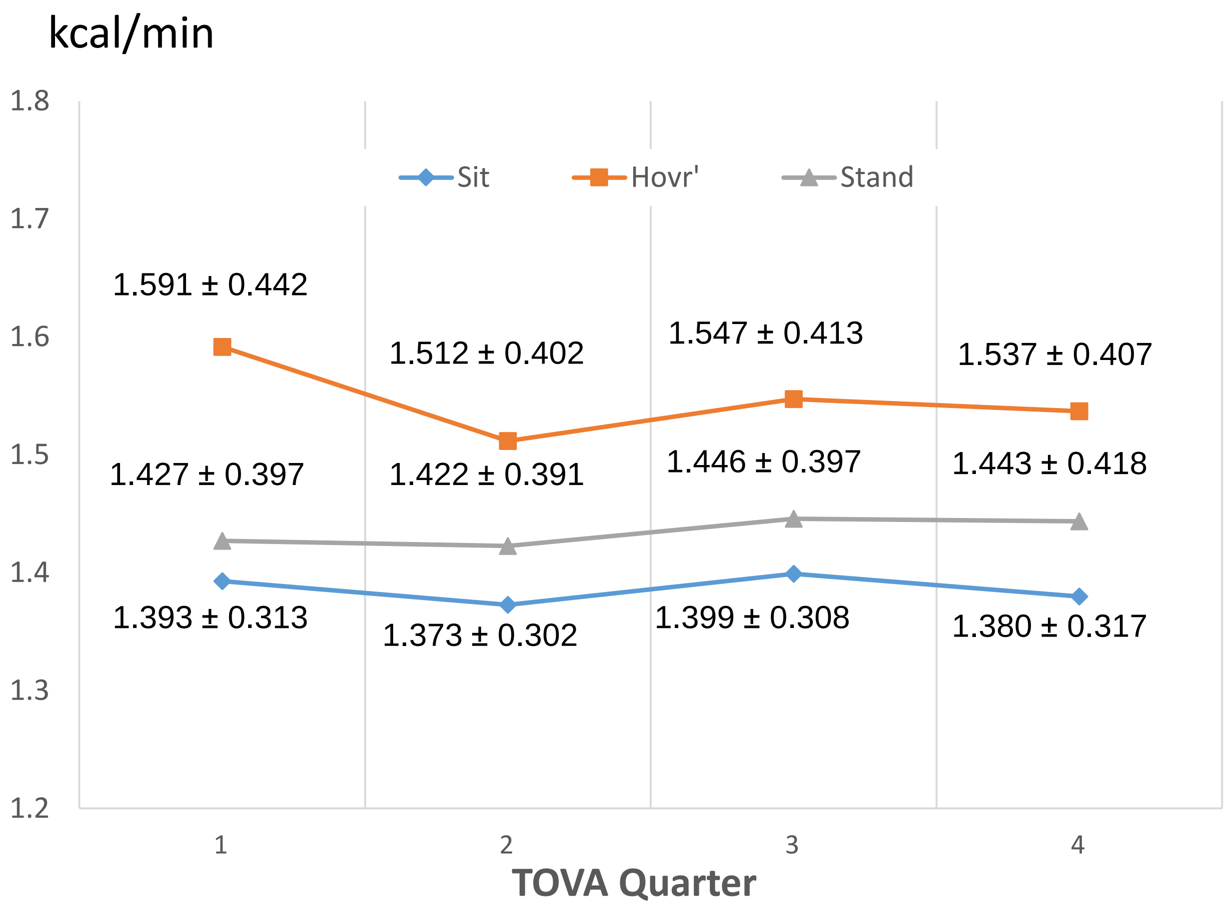

Figure 2.

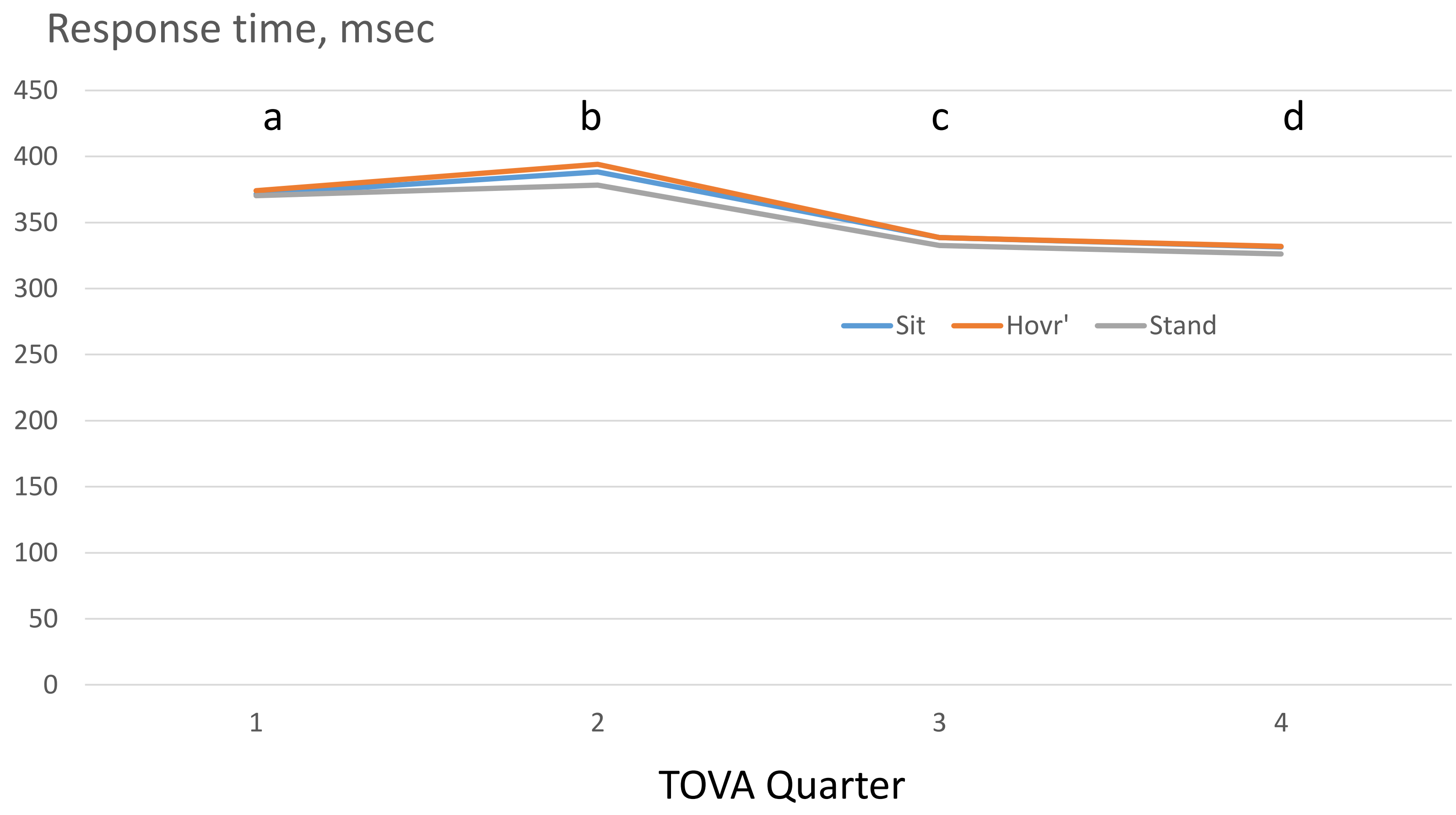
Response time, msec
450
400
350
300
250
200
150
100
50
0
a
b
c
d
Sit
Hovr'
Stand
1
2
3
4
TOVA Quarter

Table 1. Means ±SD for METs for each workstation by quarter (Q).

	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 > sitting 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 during TOVA.

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

*p<0.05 for ANOVA time effect; [a]p<0.05 vs. Q1 and Q2; [b]p<0.05 vs. Q1, Q2, and Q3.
^Resp Time Var: response time variability.

Table 3. Means ±SD for cardiovascular responses during TOVA at each workstation.

	Heart rate	Systolic BP	Diastolic BP
Sit	75 ± 11[a]	118 ± .14	66 ± 7[b]
HOVR	77 ± 10	118 ± 10	67 ± 8
Standing	84 ± 11[a]	1.20 ± 11	72 ± 9[b]

BP: blood pressure

Different superscripts indicate differences between workstations ($p<0.05$).

Clinical Significance

A workstation using an under-the-desk leg swing promoted non-exercise activity thermogenesis more so than sitting and directionally but not statistically above that of standing. The swing movement did not disrupt attention to a computer task and could help incorporate subtle movement and energy expenditure in those with sedentary desk jobs.