Metabolic Cost and Speech Quality While Using an Active Workstation

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Background: The effect of active workstation implementation on speech quality in a typical work setting remains unclear. Purpose: To assess differences between sitting, standing, and walking on energy expenditure and speech quality. Methods: Twenty-two females and 9 males read silently, read aloud, and spoke spontaneously during 3 postural conditions: sitting, standing, and walking at 1.61 km/h. Oxygen consumption (VO₂), blood pressure, and rating of perceived exertion (RPE) were obtained during each condition. Expert listeners, blinded to the purpose of the study and the protocol, assessed randomized samples of the participants’ speech during reading and spontaneous speech tasks in 3 postural conditions. Results: Standing elevated metabolic rate significantly over sitting (3.3 ± 0.7 vs. 3.6 ± 0.9 ml·kg⁻¹·min⁻¹). Walking at 1.6 km/h while performing the respective tasks resulted in VO₂ values of 7.0 to 8.1 ml·kg⁻¹·min⁻¹. There was no significant difference in the average number of syllables included in each speech sample across the conditions. The occurrence of ungrammatical pauses was minimal and did not differ across the conditions. Conclusion: The significant elevation of metabolic rate in the absence of any deterioration in speech quality or RPE support the utility of using active work stations to increase physical activity (PA) in the work environment.

Keywords: active workstation

Extreme degrees of sedentary living (physical inactivity) may contribute to disease risk in at least 2 ways. First, it contributes to the development of obesity. The health consequences associated with obesity are well documented and include diabetes, asthma, increased cardiovascular disease risk, osteoarthritis and high blood pressure. Second, an extreme degree of physical inactivity may be pathogenic in and of itself. Physical inactivity has a relationship to disease that is independent of obesity. For example, prolonged sitting has been observed to regulate key gene expressions (eg, lipoprotein lipase) that are known to regulate important molecular pathways involved in health and disease. Moreover, physical inactivity is often confounded with obesity such that the primary pathogen responsible for increased mortality and morbidity associated with obesity is blurred, and the respective roles of physical activity (PA) and obesity in pathogenesis are subject to continued debate. Consequently, increasing PA may contribute to health by decreasing the risk of obesity as well as exerting beneficial effects independent of weight loss.

Though the dose response relationship between PA and health outcomes remains an active area of inquiry several lines of research have raised the possibility that low intensity, prolonged PA may be sufficient to interdict several pathological processes such as elevated blood pressure and insulin insensitivity and thus have a positive impact on metabolic fitness and markers of disease risk. In short, PA that will not increase physical fitness or produce weight loss may still have positive health effects. An intriguing explanation for the health benefits associated with persistent low intensity activity is that at the very least, the person is not sitting for extended periods of time, a norm in many work environments. The challenge for health professionals is effecting the behavioral change to a more active lifestyle. Efforts to increase PA in human populations however, have met with limited success. Adherence to PA programs are notoriously poor and adherence rates as low as 20% after 6 months have been reported. A novel approach to addressing the high drop-out rate from PA programs is to find ways to prevent people from being inactive or mainly sedentary for most of their awake time. Creating an environment that facilitates PA that is persistent and of low intensity, may thus prove advantageous. One theoretical perspective posits that altering the work environment may be the most effective means of increasing PA and stemming population wide weight gain. Targeting the occupational environment has several advantages over the more ambitious attempts to alter entire communities. First, on average a significant part of one’s day is spent in occupational pursuits. Thus, the potential to increase PA during a large part of the day is possible. Second,
a common reason given for failing to exercise is time constraints. Efforts to modify the work environment to permit increased activity may address both of these obstacles and is a worthy goal which has generated some innovative approaches.

One of the first attempts to modify the work environment to permit increased activity was a treadmill work desk patented by Edelson in the early 1990s. Though it garnered some interest it never achieved widespread adoption. Recently, commercial versions of an adjustable height desk built over a treadmill have been developed. Levine and colleagues have provided much of the theoretical framework supporting the utility of this device. Ostensibly, these active workstations allow the user to perform their normal work activities while walking at relatively low speeds (ie, 0.5–3.2 km/h). If one were to walk 8 hours a day at 1.6 km/h the theoretical PA elicited would be between 18 to 20 MET hours per day or almost 100 MET hours per week. This workplace alteration has the potential for a profoundly positive impact on PA. However, maintaining employee productivity under these conditions will be essential in facilitating acceptance by employees and employers alike. John and colleagues recognized this concern and investigated the effect of walking 1.6 km/h on typing performance, manual dexterity, and reading comprehension. They reported small decrements in typing speed (10%), proficiency in using a computer mouse to drag and drop objects displayed on a computer monitor, and a decrement in math problem solving ability, but no effect on capabilities for maintaining attention as measured by the Stroop Color Word test. However, an important task required of many office workers includes speaking, either on the phone or in person. If speaking is significantly compromised or found to be difficult by workers who use an active workstation, then the usefulness of this intervention will be questioned. The effect of working while walking at an active work station on this important communication task remains unknown.

The purpose of this study was to assess the effects of using the active workstation on metabolic demand and voice quality. This was approached by measuring the metabolic cost of sitting, standing still, and walking while silent, while reading aloud and while speaking spontaneously. In addition, voice quality, ratings of dyspnea, and perceived exertion (RPE) were also evaluated under the 3 postural conditions to determine the feasibility and acceptability of using an active workstation in a typical office/work environment. While one of our tasks did involve reading, we did not measure reading comprehension.

Methods

Participants

Thirty-one adults (22 females and 9 males) participated in this study and averaged 37 ± 2.5 years of age (mean ± S.E.) and 74.8 ± 2.9 kg. A health history was completed before enrollment and excluded participants if they had a history of heart disease, lung disease, neurological disorder, immune system disease, voice disorder, recent illness, or smoking within the last 5 years. Almost all participants indicated that they participated in regular physical activity and none reported a smoking habit. All procedures were approved by the Miami University Human Subjects Institutional Review Board (IRB). Written informed consent was obtained from all subjects.

Apparatus

Workstation. The active workstation (Details, a Steelcase Company, Grand Rapids, MI) is a device consisting of a desk adjustable in height from 56 to 116 cm with an integrated treadmill that allows belt speeds from 0.5 to 3.2 km/h. No elevation of the treadmill is possible. The desk top was 99 cm wide and 69 cm deep. A computer monitor (Dell, Round Rock, TX) was mounted on an adjustable computer monitor arm (Details, a Steelcase Company, Grand Rapids, MI) mounted on the desktop. The computer monitor was adjusted in height to ensure a comfortable head position while reading. A wooden platform 1.24 × 1.21 m with lockable wheels was constructed and assembled at Miami University. The platform could be rolled over or away from the treadmill portion of the workstation and allowed a chair to be positioned on it for the sitting tasks. Thus the same desk and computer equipment were used for all aspects of the study.

Metabolic and Cardiovascular Instrumentation. All gas measurements were obtained using open-circuit spirometry. A face mask (Hans Rudolph, Shawnee, KS) was used to collect expired gas from the participants and the captured gas was sent to a metabolic analyzer (ParvoMedics, Sandy, UT) that provided 30 second summaries of oxygen uptake (VO2), carbon dioxide output (VCO2), pulmonary ventilation (VE), and respiratory exchange ratio. These measurements were continued for an additional minute after the speaking conditions (recovery). The energy expenditures for all postural conditions were calculated from the VO2 and were converted to kJ. Heart rate was monitored continuously during testing with a heart rate monitor (Polar Electro, Finland) and that output was linked to the metabolic analyzer. Blood pressure was measured with auscultation using an appropriate sized cuff and sphygmomanometer (Wenzhou Kangju Medical Instrument Co., China). The first Korotkoff sound was deemed systolic and disappearance of sound was used as diastolic pressure and expressed in mmHg.

Speech Instrumentation. Data for speech analysis were obtained with a headset microphone (AKG Acoustics, Austria) connected to a digital audio tape recorder (Sony Corporation of America, New York, NY). Recordings were saved on a compact disk.

Procedure

The 3 experimental postural conditions were (a) sitting, (b) standing still, and (c) walking at 1.61 km/h. The
standing and walking postural conditions, along with the order of reading and spontaneous speech, were tested in a randomized order for each participant. However, the participant always started in the sitting condition. Once a pattern of reading and spontaneous speech had been established for a particular participant, it was maintained throughout the test. For example, if a participant read aloud before spontaneous speech while sitting, he or she also read aloud before spontaneous speech while standing and walking. The completion of the reading and speaking tasks under all postural conditions lasted approximately 60 minutes (approximately 5 minutes for each of the 12 posture × reading × speaking combinations).

During each postural condition the participants completed a sequence of tasks which included (a) a quiet baseline, (b) silently reading 3 standard passages used in speech assessment, (c) reading 3 matched passages aloud, and (d) speaking spontaneously in response to questions or inquiries designed to elicit more than 1-word answers.

Before the initiation of each of the postural conditions, a signal was established between the participant and investigator, which allowed the participant to inform the investigator that he/she wanted to stop the test immediately. During the first 2 segments of the task sequence (quiet baseline and silent reading), the participant wore the face mask and baseline measurements of heart rate, VO₂, and blood pressure were established while the participant remained quiet and breathed normally for 5 minutes. After the 5-minute quiet baseline condition, participants were asked to silently read 3 passages displayed on the computer monitor mounted on the active workstation. The computer monitor was adjusted by the investigator to ensure a comfortable head position for the participant while reading. Metabolic and heart rate responses continued to be monitored. Blood pressure was measured during the fifth minute of the quiet baseline period for each postural condition. At the end of silent reading, participants were then asked to rate perceived effort on a 10 point Borg Scale, and perceived dyspnea (RPD) on a 10 point scale. The participants were asked to read 3 passages aloud and the order was counterbalanced. During the reading, the participants were prompted to take a 15-second break between each passage. Following this task, the RPE and RPD were assessed.

After the quiet baseline and silent reading were completed for each postural condition, the face mask was removed and the participant wore the headset microphone connected to the digital audio tape recorder for voice data analysis. The participant completed the next 2 segments (reading 3 passages aloud and answering questions aloud to elicit spontaneous speech) wearing just the microphone. These 2 segments were completed a second time with the face mask in place while wearing the microphone. This resulted in approximately a 5-minute bout for each of the speech components.

For the spontaneous speech condition, the investigators asked open-ended questions to prompt spontaneous speech from the participants for the same amount of time that it took the participants to read the 3 passages aloud. An example of an open-ended question is “what did you do this weekend?” and “please describe the storyline of the last book you read.” The questions were randomly arranged for each participant. Investigators asked the participants to give as much detail as possible, and to think aloud when answering the questions. As the participant began to answer the first question, the investigators recorded the duration of the participant’s spontaneous speech sample with a stop watch. Following the spontaneous speech task, measures of RPE and RPD were again obtained from the participant.

Speech Data Measurement
To analyze the speech samples, the samples were digitized using Adobe Audition 1.0 software (Adobe Systems Inc., San Jose, CA) saved on a desktop computer (Dell Inc., Round Rock, TX). The second reading of the 3 standardized reading passages was always used for the analysis of the reading aloud samples. The number of syllables per phrase and the number of inappropriate pauses during the passage were assessed by 2 investigators listening to the samples and indicating the presence of an audible pause. The investigators listened to the passage and independently marked all pauses heard throughout the passage on a hard copy of the passage. They compared results and listened to the passages together when any variance in results occurred. Inappropriate pauses (those that occurred at nongrammatical markers) were identified and the number of syllables per phrase were calculated.

Statistical Analyses
Multiple repeated measures analyses of variance (ANOVAs) were used to assess differences between the postural conditions (sit, stand, walk) in heart rate, VO₂, energy expenditure, RPE, dyspnea, phrase location, and syllables per phrase. Post hoc pairwise comparisons were used and Bonferroni correction procedures were applied to evaluate significant differences identified. A significance level of $P < .05$ was used for all analyses (two-tailed).

Results
Metabolic Response
The mean ± S.E. elevation in VO₂, across the sitting, standing and walking conditions are shown in Figure 1 for all experimental treatments. VO₂ is presented relative to body weight and increased significantly from 3.2 ± 0.13 at sitting to 4.0 ± 0.18 standing and to 7.4 ± 0.33 ml·kg⁻¹·min⁻¹ walking. The oxygen cost of sitting, standing and walking were significantly different from each other under all experimental conditions. The walking conditions elicited an energy expenditure that ranged from 314 to 419 KJ over the sitting position.
Cardiovascular Response

The mean ± S.E. heart rate responses for the 3 postural conditions are shown in Figure 2. A statistically significant elevation of heart rate was observed during the standing and walking conditions compared with sitting. The largest difference was between the sitting and walking conditions. However, the increase in heart rate during the walking condition only ranged between 14 to 16 bpm higher than the sitting condition across all 3 experimental tasks. The heart rate increase was small, but oxygen pulse (VO₂/HR), an index of stroke volume, doubled from 3.0 ml of O₂/heart beat during the sitting condition to 6.0 ml of O₂/heart beat during the walking condition.

Walking elevated systolic blood pressure to 129 ± 3 mmHg compared with 123 ± 3 mmHg during sitting and 124 ± 3 mmHg during standing (Figure 3). In contrast, diastolic blood pressure during sitting (76 ± 3 mmHg) was significantly different than both standing (82 ± 3 mmHg) and walking (80 ± 3 mmHg) but standing and walking were not significantly different from each other (Figure 3).

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**Figure 1** — The oxygen consumption in ml·kg⁻¹·min⁻¹ for the 3 postural conditions of sitting (filled bars), standing (open bars), and walking (gray bars) for each experimental task are shown. * = significant difference (P < .05) from the corresponding sitting condition; # = significant difference (P < .05) from both corresponding sitting and standing conditions.

**Figure 2** — The heart rate (bpm) for the 3 postural conditions of sitting (filled bars), standing (open bars), and walking (gray bars) for each experimental task are shown. * = significant difference (P < .05) from the corresponding sitting condition; # = significant difference (P < .05) from both corresponding sitting and standing conditions.
Rating Perceived Effort (RPE)

The RPE responses are shown in Figure 4. Overall, individual perceptions of the effort required to walk (1.3 ± 0.2) were significantly different than sitting (0.5 ± 0.2) and standing (0.7 ± 0.2). There was no significant difference between sitting and standing within the tasks. However, there was a significant difference between the sitting quietly and silent reading while sitting conditions, and the speaking aloud (1.4 ± 0.2) and spontaneous speaking (1.2 ± 0.2) conditions. However, all ratings were below “two” indicating very low perceived effort during the tasks.

Dyspnea

The perception of breathing effort (breathlessness) using the Borg Scale (10 point) during the warm-up, silent reading and the speech conditions of reading aloud and spontaneous speech are shown in Figure 5. All ratings were lower than “two” (very slight). Walking consistently elicited a higher rating than sitting or standing (P < .05) and, in addition the speech conditions of reading aloud and spontaneous speech were significantly higher than the silent conditions.

Speech Assessment

The average number of syllables per phrase (Figure 6) was 23.3 ± 1.1, and there was no significant difference in the average number of syllables included in each breath sample across the conditions. The number of ungrammatical pauses (Figure 7) that occurred when the participants were reading aloud was minimal (0–1 ungrammatical pause(s) per reading) and the occurrence of these ungrammatical pauses did not differ across the conditions.

Discussion

The primary finding of this experiment was that the performance of several speaking and reading tasks while walking at a speed of 1.61 km/h elicited a metabolic demand of approximately 2.5 METs without compromising the quality of speech. This extends the work of John et al. to another potential occupational demand and lends further support to the utility of using active workstations as a means of increasing PA in the work environment.

The metabolic measurements are in basic agreement with the Compendium of Physical Activity for tasks involving sitting, standing and walking at 1.61 km/h. These observations are also consistent with the metabolic measurements reported by Levine and Miller for individuals using an earlier prototype desk and the same postural conditions. Assuming individuals walked between 25 to 50% of a work day, the hours per day walking would be between 2 to 4 hours or 5 to 10 MET hours per day which is 25 to 50 MET hours per week. This is a significant increase in PA and is above the criteria used to distinguish sedentary from active individuals in several epidemiological studies. For example, the Nurse’s Health Study found that compared with those women who were completely sedentary (<2 MET hours per week in 1986 to 1988), women who were consistently active (>10.4 MET hours per week in 1986 to 1988) had the lowest risk of diabetes. Women who increased their physical activity level from 2.1 MET hours in 1986 to 4.0 MET hours per week in 1988 had a lower risk of diabetes compared with those women who were completely sedentary. In terms...
**Figure 4** — The rating of perceived effort (Borg 10 pt scale) is shown. * = Walking was significantly higher than sitting and standing ($P < .05$). There was no significant difference between sitting and standing within the tasks. The difference between sitting quietly and sitting while silently reading, were not significantly different from each other. Speaking aloud and spontaneous speaking conditions (^) were significantly higher than the corresponding silent conditions ($P < .05$).

**Dyspnea**

**Figure 5** — The responses on the Borg 10 pt scale for perceived breathlessness (dyspnea) are shown for all conditions. * = Walking was significantly higher than sitting and standing under all conditions ($P < .05$). Speaking aloud both spontaneously, and while reading, were significantly higher than the corresponding silent conditions (^).

**Figure 6** — The average syllables per phrase are shown. No significant differences between conditions were observed.
of additional energy expenditure using the workstation 2 to 4 hours per day represents approximately a 419 to 838 kJ per day increase in energy expenditure over a seated condition and a 2095 to 4190 kJ per week increase over rest. In a year’s time this could yield a potential weight loss of 6.4 to 13.1 kg if other influences on energy balance are stable. However, we agree with Donnelly et al.,\textsuperscript{29} that estimates of weight loss derived from potential energy expenditures are fraught with error and can be misleading in terms of the potential value of modifying the workplace with active workstations. Nevertheless, the volume of activity possible in the occupational setting is impressive and may help close the “energy gap” responsible for the seemingly inexorable gains in bodyweight shown by American adults.\textsuperscript{30} Further support for the feasibility of active workstations is reflected in the speech analysis. The tendency to take breaths at grammatical locations is very strong.\textsuperscript{31} However, oxygen demand can alter that tendency.\textsuperscript{32} During progressive exercise, the likelihood of breaths at nongrammatical locations increases and possibly reflects a hierarchy of needs such that metabolic demand supersedes an imperative for speech quality. However, no evidence of inappropriate pauses or changes in syllables per phrase was observed during these experiments. In short, the activity elicited by active workstation use at 1.6 km/h and speaking did not provoke inappropriate speech patterns. This suggests that competition between the ventilatory demand for metabolism and speech requirements was minimal and participants were not under much duress. However, the slightly higher metabolic cost in the recovery period after speech suggests some compensation in ventilation though not enough to compromise speech.

The RPE and RPD results are also consistent with this assessment. Though significant differences were observed between sitting and walking, a 1-unit difference speaks more to the validity of the RPE and RPD scales to distinguish differences in activity state than it does as an indicator of serious exertion.

**Strengths and Limitations**

To our knowledge this is the first attempt to assess voice quality in a simulated working environment while using an active workstation at 1.6 km/h. Speaking and reading are routine tasks encountered in the workplace and in some occupations are major components of the job requirement. Thus, the practicality of the findings is of immediate use. All tasks were completed on the same desk and computer and this minimized any influences wrought by variability between sitting, standing and walking conditions. A relatively large sample size was studied, but a possible limitation is the duration of the specific tasks. Longer periods of continuous reading or speaking might alter the findings.

**Conclusions**

The active workstation has the potential to significantly increase PA and energy expenditure. This study found that the active workstation significantly increased metabolic activity without compromising an important task in a typical work setting, specifically speaking. Future research is required to establish the effectiveness of active workstations to contribute to increases in metabolic fitness and help individuals maintain a healthy bodyweight. If positive changes in disease risk are found, employers might see the cost-benefit ratio as favorable enough to warrant the implementation of this novel worksite intervention.

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