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The Effects of Walking Workstations on Biomechanical Performance

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Abstract

Prolonged sitting has been associated with negative health effects. Walking workstations have become increasingly popular in the workplace. There is a lack of research on the biomechanical effect of walking workstations. This study analyzed whether walking while working alters normal gait patterns. Nine participants completed four walking trials at 2.4 km·h⁻¹ and 4.0 km·h⁻¹: baseline walking condition, walking while performing a math task, a reading task, and a typing task. Biomechanical data were collected using standard motion capture procedures. The first maximum vertical ground reaction force, stride width, stride length, minimum toe clearance, peak swing hip abduction and flexion angles, peak swing and stance ankle dorsiflexion and knee flexion angles were analyzed. Differences between conditions were evaluated using analysis of variance tests with Bonferroni correction ($p < 0.05$). Stride width decreased during the reading task at both speeds. Although other parameters exhibited significant differences when multitasking, these changes were within the normal range of gait variability. It appears that for short periods, walking workstations do not negatively impact gait in healthy young adults.

Keywords

Biomechanics; Exercise; Gait Analysis; Motor Control; Motion Analysis

Introduction

In this computer-centered generation, individuals are spending more time in environments that not only limit physical activity but also require prolonged sitting¹. In 2010, a national survey found that 86 percent of adults who work full time are required to sit all day². Several studies have shown that prolonged sitting is associated with negative health effects, including increased musculoskeletal pain and increased risk of developing chronic health conditions such as cardiovascular disease, diabetes, and cancer later in life³.

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Biswas et al. found that these health hazards are the greatest for people who sit 8 or 9 hours a day and are especially pronounced in people who do not exercise regularly⁴. Because of the negative impact of sedentary behavior on physical health, there is increasing interest in reducing the amount of time per day individuals spend seated in the workplace^{5,6}.

Walking workstations and standing workstations have become increasingly popular in the workplace over the past several years, and their implementation has led to reduced pain and improved mood of many workers⁶. Several studies have performed qualitative analyses, showing that walking while working results in higher work satisfaction, less boredom, and less stress compared to sitting while working^{7,8}, however studies examining cognitive efficiency have had mixed results^{9–11}.

While it is important to understand how users work while they walk, it is also important to consider how users walk while they work. There is currently a lack of research on the gait biomechanics of walking workstation users. Working while walking may alter movement patterns, as previous studies have demonstrated that the performance of a secondary task during walking alters gait^{12–14} especially in older populations¹⁵.

Common metrics used to quantify normal gait mechanics are vertical ground reaction force, stride length and width, minimum toe clearance, as well as ankle, knee, and hip angles and moments. Understanding whether walking while working impacts these metrics will provide more information on the potential long-term biomechanical effects of walking workstations and help determine whether these machines can be safely implemented into a workplace.

The purpose of this study was to analyze the biomechanics of walking workstation users while performing cognitive tasks. We hypothesized that gait mechanics of walking workstation users would significantly change between baseline walking and walking while performing cognitive tasks in a similar manner for both slow and fast walking. Specifically, we predicted that the mean of peak vertical ground reaction forces would be lower while performing tasks because the subject may distribute load to the workstation if he or she leans on the desk while writing or using the computer. We also expected that the participants would exhibit greater swing hip abduction, stride width, stride length, minimum toe clearance and swing and stance ankle, hip, and knee flexion as a means to stabilize the center of mass, prevent trips, and remain near the workstation while performing the tasks. The biomechanical effect of walking workstations on users has not been shown and may provide insight on gait adaptations associated with multitasking.

Methods

Nine healthy participants were recruited from the local community (5F/4M, 21.8 ± 0.4 y, BMI 23.0 ± 2.0) to be included in this study. Exclusion criteria included current lower extremity injuries, prior serious hip, knee, or ankle injuries, or any neurological injury that may have altered gait biomechanics. All participants provided written informed consent to participate in this study, which was approved by the Institutional Review Board.

Following enrollment in this study, participants completed one testing session in which they performed walking trials for eight different testing conditions. The treadmill wide desk was

adjusted to each user's elbow height (i.e. standard for standing desks¹⁶). Centered on the desk was a computer monitor, a keyboard directly in front of the computer, and a mouse to the right of the keyboard. Participants walked with and without cognitive tasks at two speeds: 2.4 km·h⁻¹ and 4.0 km·h⁻¹. Previous studies have identified the effects of walking workstations on cognitive ability at walking speeds between 2.4 km·h⁻¹ and 3.2 km·h⁻¹ 6,17. This study examined faster walking since walking workstation users may choose faster speeds to exercise.

The cognitive tasks evaluated mathematical reasoning, reading comprehension, and typing speed. Accuracy outcomes were recorded for each task. The math task was completed by typing answers into a word document, although scratch paper and a pencil were provided. For the reading task, participants were given a short passage then completed multiple choice questions using a mouse. The typing task was completed by duplicating text shown on the monitor. These cognitive measures are directly translatable to workplace activities.

Depending on the time to complete each cognitive task, trial duration ranged from 30 seconds to 3 minutes in length. The order of the eight walking trials was randomized for each subject.

Kinematic and kinetic data for each walking trial was collected via an 8-camera motion analysis system at 60 Hz, (Motion Analysis Corp., Santa Rosa, CA, USA) as participants walked at 2.4 km·h⁻¹ and 4.0 km·h⁻¹ on a split-belt treadmill (Bertec Corp., Columbus, OH, USA) with two embedded force plates capturing at 1080 Hz. Markers were placed on anatomical landmarks on the pelvis, thigh, knee, shank, ankle, and foot. This marker set can be seen in Figure 1. This figure shows markers along the entire body but only lower body markers were used in this study, meaning the shoulder, chest, neck, and arm markers in Figure 1 were not used. Data processing was completed using Cortex and Visual 3D (C-Motion Inc., Bethesda, MD, USA), and kinematic data were filtered using a Butterworth low-pass filter at 6 Hz¹⁸.

The biomechanical variables of interest were peak vertical ground reaction force (vGRF, expressed as percent body weight), stride width, stride length, swing phase hip abduction angle, swing phase hip flexion angle, stance and swing phase knee flexion and ankle dorsiflexion angles, and minimum toe clearance. These variables were chosen because they are common metrics used to quantify normal gait mechanics. All parameters were measured over the entirety of the testing period and the average of the peak values from each gait cycle were examined. Joint angles and spatio-temporal parameters were calculated using Visual 3D.

A separate, two-way repeated measures ANOVA was conducted for each response using nine participants and within factors of task (math, no task, reading, typing) and speed (2.4 km·h⁻¹, 4.0 km·h⁻¹). The structure of this analysis assumed normality, lack of outliers, and presence of residuals. Mauchly Sphericity was tested and if significant Greenhouse Geisser values were examined for the Omnibus test. If there were no interactions between independent variables Bonferroni corrections were completed for levels of significance

within factors. If significance was found within factors then pairwise comparisons were examined and reported.

Results

Nine subjects (5F/4M, 21.8 ± 0.4 years, BMI 23.0 ± 2.0) completed a full testing session. Changes were noted within the task variables when speed wasn't taken into consideration. Stride width decreased from the baseline trial to the reading trial (0.18 m vs 0.17 m, $p = .037$) and increased between the reading trial and typing trial (0.17 m vs 0.19 m, $p = .033$).

Simple pairwise comparisons between conditions at $2.4 \text{ km}\cdot\text{h}^{-1}$ revealed significant differences (Table 1). Stride width decreased from the baseline trial to the reading trial (0.18 m vs 0.17 m, $p = .012$), decreased from the math trial to the reading trial (0.18 vs. 0.17 m, $p = .048$), and decreased from the typing trial to the reading trial (0.19 m vs. 0.17 m, $p = .020$). Minimum toe clearance decreased from the baseline trial to the math trial (0.066 m vs 0.065 m, $p = 0.008$) and from the math trial to the reading trial (0.064 m vs 0.063 m, $p = .025$). Stance phase knee flexion decreased from the baseline trial to the math trial (62.1° vs 61.1° , $p = .035$), and increased from the baseline trial to the typing trial (42.5° vs 42.9° , $p = .008$) and increased from the math trial to the reading trial (41.6° vs 42.9° , $p = .008$). Swing phase hip flexion decreased between the reading trial and the typing trial (27.9° vs 26.4° , $p = .017$). vGRF decreased from the baseline trial to the math trial (107.1 vs. 104.9 %BW, $p = .024$) and increased between the math trial and the reading trial (104.9 vs. 107.4 %BW, $p = .008$).

Simple pairwise comparisons between conditions at $4.0 \text{ km}\cdot\text{h}^{-1}$ also revealed significant differences (Table 2). Stride width decreased from the baseline trial to the reading trial (0.174 m vs 0.166 m, $p = .016$), decreased from the math trial to the reading trial (0.18 m vs. 0.17 m, $p = .035$), and from the typing trial to the reading trial (0.18 m vs 0.17 m, $p = .009$). Stride length increased from the typing trial to the reading trial (1.21 m vs. 1.25 m, $p = .005$). Minimum toe clearance decreased from the baseline trial to the reading trial (0.066 m vs 0.063 m, $p = .011$) and decreased from the math trial to the reading trial (0.064 m vs 0.063 m, $p = .010$). Stance phase ankle dorsiflexion increased from the math trial to the reading trial (11.6° vs 12.4° , $p = .017$) and decreased from the reading trial to the typing trial (12.4° vs 11.1° , $p = .014$). Stance phase knee flexion increased from the baseline trial to the typing trial (42.6° vs 44.5° , $p = .016$) and increased from the reading trial to the typing trial (41.2° vs 44.5° , $p = .048$). Swing phase hip flexion increased from the baseline trial to the math trial (29.1° vs 31.4° , $p = .006$), decreased their swing phase dorsiflexion from the reading trial to the math trial (12.8° vs. 12.1° , $p = .028$), and decreased from the reading trial to the typing trial (12.8° vs. 11.8° , $p = .031$). Participants also increased vGRF from the math trial to the reading trial (111.8 vs. 116.0 %BW, $p = .003$).

Discussion

The purpose of this study was to analyze the biomechanics of walking workstation users while they performed cognitive tasks. We hypothesized that all of the gait mechanics of walking workstation users would significantly increase relative to the baseline at both

speeds. Using pairwise comparisons, we found that numerous gait variables were affected by the implementation of cognitive tasks at each speed. Relative to baseline at 2.4 km·h⁻¹, vertical ground reaction forces decreased 2.2 % during the math task, minimum toe clearance decreased 0.001 mm during the math task, and stance phase knee flexion increased 0.4 ° during the typing task. Relative to baseline at 4.0 km·h⁻¹, we observed increased minimum toe clearance 0.003 mm during the math task, increased stance phase knee flexion 1.9 ° during typing, and decreased swing knee flexion 1.0 ° and increased swing phase hip flexion 2.3 ° during the math task. Even though there were statistically significant changes in numerous gait variables, all were within the range of normal gait variability^{19–27}. Furthermore, most of the gait variables of interest didn't exhibit any statistically significant changes from the baseline. These findings were inconsistent with our hypothesis that all of the gait variables of interest would increase and in the same manner at both walking speeds.

The only gait variable to change that was outside the normal range of gait variability was stride width which decreased between the baseline and the reading task by 0.01 m. Previous studies have found that subjects increase their stride width when they feel unstable²⁸, which suggests that our subjects did not feel unstable during the reading task. Paradoxically, this shortening of stride width actually leads to an increased chance of falling²⁹.

Having the desk to lean on while reading may have given subjects an additional feeling of stability but unfortunately, no upper body motion data was collected in our study so neither upper extremity loads nor trunk lean can be investigated. No concurrent change in peak vertical ground reaction force was recorded which suggests that only small amounts of weight could have been shifted onto the desk. However, previous studies have shown that even the lightest touch (<0.98 N) is sufficient to reduce sway of the center of mass and promote stability³⁰. Small decreases in stride width are probably not a safety concern in healthy young adults³¹, especially since walking workstation users may use the desk for support if needed.

The gait variables that did exhibit statistically significant change between the baseline and the tasked trials only revealed differences across one type of task. Relative to baseline stride width decreased during the reading task, minimum toe clearance decreased during the math task, and standing knee flexion changed during the typing task. Furthermore, many of the gait variables exhibited statistically significant differences between the math, reading, and typing tasks independent of the baseline. These differences across the individual tasks suggest that performing cognitive tasks while walking not only slightly alters biomechanics in healthy young adults, but the type of cognitive task performed also has an impact on the way that the biomechanics are altered.

The changes in gait mechanics found in this study are consistent with earlier studies regarding only small changes in young healthy adults' walking gait mechanics while performing cognitive tasks^{12–14}. Previous studies have also observed differences in biomechanical adaptations across different types of cognitive tasks¹². The major difference between this study and previous studies is that some of the other researchers used self-paced walking and over ground walking labs to determine the effect that multitasking had on gait mechanics^{12–15}. This study used fixed walking speeds and faster walking speeds on a split

belt treadmill which could explain why the results of this study differ slightly from previous work that observed slightly different changes in subjects' biomechanics.

There were some limitations to our study. Firstly, we investigated a small sample of healthy young subjects from a relatively uniform demographic that did not vary in age, activity level, or BMI that was not representative of the typical workforce of men or women of all ages and abilities. The younger subject pool may have also been more accustomed to performing cognitive tasks while walking, such as working on a cell phone, than an older population who may perform more poorly due to lack of experience. For example, the dual task of memorizing word lists while walking becomes more difficult with age¹¹, suggesting older subjects may respond differently to a walking workstation. Furthermore, the cognitive and physical tests may not have been strenuous enough to simulate actual work-related tasks or an entire work day. Studies on standing workstations have suggested that progressive fatigue can lower worker performance throughout the day, and the additional strain from prolonged standing may cause negative effects on the circulatory system and the legs and feet³².

From this study we find that, for short periods, walking workstations do not adversely impact walking kinematics and kinetics in healthy young adults. Future research needs to be conducted before walking workstations can be determined a safe office tool. Workplace ergonomics experts should wait to recommend walking workstations to general employees until further research is completed.

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Figure 1:
Marker set used in this study, excluding arm, shoulder, chest, and neck markers.

Table 1:Mean outcome parameters for each cognitive task at 2.4 km·h⁻¹ at the walking workstation

Tasks	2.4 km·h ⁻¹			
	No Task	Math	Reading	Typing
Stride Length (m)	0.87 ± 0.19	0.89 ± 0.13	0.91 ± 0.09	0.88 ± 0.08
Stride Width (m)	0.18 ± 0.03	0.18 ± 0.02	0.17 ± 0.02 [^a]	0.19 ± 0.03 [^b]
Swing Hip Flexion (°)	26.9 ± 5.3	27.3 ± 6.2	27.9 ± 5.5	26.4 ± 5.4 [^b]
Swing Hip Abduction (°)	5.0 ± 2.9	5.6 ± 3.3	6.2 ± 4.0	5.1 ± 3.2
Swing Knee Flexion (°)	56.6 ± 5.8	57.0 ± 4.2	56.0 ± 5.5	57.9 ± 4.7
Swing Dorsiflexion (°)	13.8 ± 2.7	13.6 ± 3.1	14.7 ± 3.4	11.9 ± 4.0
vGRF (%Body Weight)	107.1 ± 12.0	104.9 ± 10.7 [^a]	107.4 ± 9.7 [^a]	105.6 ± 12.5
Minimum Toe Clearance(m)	0.066 ± 0.005	0.065 ± 0.005 [^a]	0.065 ± 0.005	0.064 ± 0.004 [^a]
Standing Ankle Flexion (°)	13.2 ± 2.7	12.9 ± 3.1	13.8 ± 3.5	12.1 ± 4.1
Standing Knee Flexion (°)	42.5 ± 4.5	41.6 ± 7.7	41.8 ± 5.0	42.9 ± 5.3 [^a]

[^a] Note. Difference from No Task[^a] Math, Reading[^b] ($p < .05$)]

Table 2:Mean outcome parameters for each cognitive task at 4.0 km·h⁻¹ at the walking workstation

Tasks	4.0 km·h ⁻¹			
	No Task	Math	Reading	Typing
Stride Length (m)	1.23 ± 0.06	1.23 ± 0.07	1.25 ± 0.07	1.21 ± 0.08 [<i>b</i>]
Stride Width (m)	0.174 ± 0.02	0.18 ± 0.02	0.166 ± 0.02 [<i>*, a</i>]	0.18 ± 0.02 [<i>b</i>]
Swing Hip Flexion (°)	29.1 ± 6.9	31.4 ± 5.4 [<i>*,</i>]	30.4 ± 7.1	29.5 ± 7.6
Swing Hip Abduction (°)	5.5 ± 3.1	5.8 ± 3.0	6.2 ± 4.4	6.5 ± 4.5
Swing Knee Flexion (°)	62.1 ± 5.3	61.1 ± 5.6 [<i>*,</i>]	61.8 ± 4.8	61.8 ± 5.0
Swing Dorsiflexion (°)	10.1 ± 6.9	12.1 ± 3.8	12.8 ± 3.5 [<i>a</i>]	11.8 ± 3.8 [<i>b</i>]
vGRF (%Body Weight)	112.9 ± 16.0	111.8 ± 12.8	116.0 ± 12.3 [<i>a</i>]	112.6 ± 14.5
Minimum Toe Clearance (m)	0.066 ± 0.005	0.064 ± 0.004	0.063 ± 0.004 [<i>*, a</i>]	0.064 ± 0.005
Standing Ankle Flexion (°)	10.2 ± 6.9	11.6 ± 3.8	12.4 ± 3.6 [<i>a</i>]	11.1 ± 3.7 [<i>b</i>]
Standing Knee Flexion (°)	42.6 ± 5.3	42.8 ± 5.2	41.2 ± 7.7	44.5 ± 5.1 [<i>*, b</i>]

[**,*] Note. Difference from No Task[*a*] Math[*b*] Reading (*p* < .05)