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Research Article

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Effects of Active Workstation Use on Walking Mechanics and Work Efficiency

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Abstract

Recently, the amount of time dedicated to sedentary work-related tasks has increased. Further, this trend toward decreased physical activity in the workplace is expected to increase. Active workstations such as treadmill desks provide health benefits; however, concerns for the ability to walk safely and work efficiency remain unclear. The purposes of this investigation were to: 1) compare kinematics of treadmill walking (TW) with kinematics of walking while performing computer mousing tasks (WC) using a treadmill desk, and 2) examine work efficiency in terms of the time to complete computer mousing tasks during WC compared to standing (SC). Trunk and lower-extremity kinematic data were obtained from 9 males (23.4 ± 4.2 yrs; 81.7 ± 16.4 kg; 176.3 ± 5.5 cm) and 7 females (23.0 ± 3.3 yrs; 58.4 ± 6.5 kg; 171.7 ± 9.0 cm) using a 10-camera motion capture system. Kinematic data were normalized to the gait cycle and were divided into sub-phases for analysis. Kinematic data of the first and last 10 WC strides were compared to identify short-term kinematic adaptations ($\alpha=0.05$). Neither computer task performance ($p=0.071$) nor walking velocity ($p=0.089$) was sacrificed during WC compared to SC and TW, respectively. Significant kinematic changes occurred in response to WC ($p<0.05$). Significant differences were identified between the first and last 10 WC strides ($p<0.05$), which revealed that some participants trended toward a return to normal gait as exposure to WC increased. Results suggest that active workstations do not diminish computing performance, and that walking safety is not sacrificed after initial exposure. We suggest gradual introduction to an active workstation, particularly if the computer task is challenging.

Keywords: Cognition; Dual-task; Kinematics; Locomotor safety

Abbreviations: TW: Treadmill Walking; WC: Walking and Computing; SC: Standing and Computing

Introduction

Over the past several decades, the energy expenditure requirement of many occupations has diminished, and therefore, professions have become increasingly more sedentary [1] and as a result the amount of time dedicated to sedentary work-related tasks has drastically increased [2]. Unfortunately this trend toward decreased physical activity is expected to continue [3]. Workplace physical inactivity presents a number of health consequences [2] including an earlier onset of chronic disease, resulting in higher health care costs [4]. For example, men who reported more than 23 hours of sedentary activity per week were found to be at a 64% greater risk of mortality than those who reported less than 11 hours per week [5]. Further, higher levels of sedentary behaviors are associated with a 112% increased risk for diabetes, 147% increased risk for cardiovascular disease, 90% increased risk for cardiovascular mortality, and a 49% increase in the risk of all-cause mortality [6].

As the general public has developed a greater understanding of the association between sedentary behavior and health compromises [5,7,8], researchers have begun to investigate ways to reduce sedentary workplace time using multicomponent workplace interventions [9]. These interventions include sit-stand workstations [10] as well as active workstations consisting of height adjustable desks with an integrated treadmill [11-14] or cycle ergometer [15]. Individuals at risk of certain health challenges are expected to experience additional health benefits after implementing frequent breaks in sedentary time rather than reducing total sedentary time [7]. Such benefits are the result of repeated variations in postural control that positively affect energy homeostasis. Consequently, active workstations have the potential to create a healthier workforce by increasing daily energy expenditure. However, there is currently no evidence relative to the ability to walk safely (avoiding slips or trips) when using an active workstation, and current evidence relative to the effects of an active workstation on work efficiency is inconclusive [16-18].

Locomotor safety and work efficiency can be accurately assessed using a dual-task paradigm [19], also known as concurrent performance. Dual-task interventions are effective measures of the attention demands of a task because an individual is required to execute a primary task and a secondary task simultaneously. If considerable attention is required to perform one or both tasks, the performance of either task can suffer [20]. Likewise, utilizing an active workstation presents potential threats to safe locomotion and work efficiency because the cognitive demand of the work-related tasks may interfere with segmental control required during walking. Impeding segmental control can increase the likelihood of experiencing a trip or fall. Some individuals adapt their movements in order to prevent a trip or fall by increasing foot-ground clearance, which is accomplished by producing greater knee flexion and ankle dorsiflexion [21]. Conversely, if an individual places a majority of his or her cognitive efforts on safely walking, the efficiency of the work-related task might decrease. As such, the purpose of this study was to examine the feasibility of an active workstation on aspects of locomotor safety and work efficiency. Specifically, we sought to compare the kinematics of treadmill walking with the kinematics of walking while performing computer mousing tasks. We examined work efficiency in terms of the time to complete computer mousing tasks while walking compared to

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standing. In this investigation, we focused our assessment on the acute effects of the experimental conditions.

Materials and Methods

A sample of convenience consisting of nine males (23.4 ± 4.2 yrs; 81.7 ± 16.4 kg; 176.3 ± 5.5 cm) and seven females (23.0 ± 3.3 yrs; 58.4 ± 6.5 kg; 171.7 ± 9.0 cm) participated in this investigation. This sample size exceeded the 13 participant recommendation of an a priori power analysis (G*Power, version 3) according to the typing performance data of Funk et al. [22], with a proposed effect size of 1.1, alpha of 0.05, power (1-β) of 0.95, and a correlation between measures of 0.5. All participants were free of injury for at least six months prior to testing and had no limitations that would have affected their ability to walk unassisted for 15 minutes, in 5-minute blocks. Prior to completing the experimental tasks, all testing procedures were explained to each participant and written informed consent was provided in accordance with the local Institutional Review Board (Protocol #1403-4759).

We examined walking mechanics while the participants performed the treadmill walking (TW) and walking and computing (WC) conditions. Additionally, we examined computer task times during the WC and standing and computing (SC) conditions. TW data were collected first for all participants. To control for sequencing effects, we used a counterbalanced design when delivering the WC and SC conditions such that every odd numbered participant completed the WC condition before the SC condition, and every even numbered participant completed the SC condition before the WC condition.

A commercially available walking workstation (DZ9500, Signature Treadmill Desks, Fort Wayne, IN) was used in this study. The workstation consisted of a treadmill desk equipped with velocity and motorized desk height controls. All computer-interactions were performed using an Apple MacBook Pro laptop computer (Apple, Inc., Cupertino, CA) with an attached USB mouse. The computer was connected to a wireless Internet network. A 10-camera motion capture system (Vicon Motion Systems, Ltd., Oxford, UK; 200 Hz) was used to obtain three-dimensional kinematic data bilaterally.

Following written consent and explanations of the testing protocol, demographic and anthropometric characteristics were measured/recorded (age, height, mass, gender) and proper use of the testing apparatus was demonstrated. Thirty-five reflective markers were adhered to the participants according to the Vicon Full-body Plugin Gait model. Then, static and dynamic calibrations were performed with the participant first standing motionless (static) and then walking on the treadmill at a comfortable speed (dynamic). Participants then completed a five-minute warm-up that consisted of walking on the treadmill at a self-selected pace (blinded) while completing a number of computer mousing tasks such as sending and receiving email, and browsing the Internet. During the warm-up, the participants adjusted the height of the desk as well as the positioning of the computer display to their preferred positions. Following the warm-up, participants completed computer mousing tasks during two of the three experimental conditions. All walking speeds for the TW and WC conditions were self-selected by the participants, and the participants were blinded to the speeds they selected.

During the TW condition, participants were asked to walk for a total of five minutes. The first four minutes of walking were used to establish a consistent gait pattern at their self-selected walking speed. Kinematic data were collected during the final minute of the five-minute trial. The WC condition was performed identically to the TW condition, but with the addition of the computer mousing tasks. The WC and SC tasks included four questions and required web browsing to locate the answers. Specifically, participants were asked to access a regional news website by typing the complete URL (www.reviewjournal.com) and locate the answer for each question asked. For each question, participants were asked to navigate the website using the computer mouse while attempting to identify and verbally provide the correct answer for the question. Each question required the participants to find the current headline for one of the following topics: local news, university sports, business conventions, or local weather for the following day. These questions were selected because the answers could not be located in the same manner and required question-specific searching throughout the web page. During the WC and SC experimental conditions, the orders of the web interaction questions were counterbalanced across participants. This counterbalancing required every even numbered participant to answer questions 1 and 2 during the WC condition and questions 3 and 4 during the SC condition in that order. Every even numbered participant answered questions 4 and 3 during the SC condition and questions 2 and 1 in the WC condition in that order. Kinematic and work efficiency data were collected immediately after the first question of each block was asked and continued until the participant verbally provided the correct answer to the second of two questions. The procedure was repeated for the second block of questions. If an incorrect response was provided for any question, the participants were instructed to continue searching for the correct response. If a participant was unable to locate and provide the correct answer for any question or trial block (set of two questions) within two minutes, the trial was terminated and the kinematic data during the two-minute collection were used for analysis and the participant was assigned a task to completion of time of two-minutes.

The SC condition was performed in the same manner as the WC condition relative to the web browsing and computer mousing tasks. However, in this condition, the participants stood on the treadmill while the belt was motionless. Participants were asked to stand using a comfortable two-footed stance while attempting to locate and provide the answers for the two blocks of web interaction questions, which were delivered in the same manner as the WC condition. The time required for the participants to verbally provide the correct answer for each question was recorded. Similar to the WC condition, if a participant was unable to locate and provide the correct answer within two minutes for any question or trial block, the trial was terminated and the kinematic data during the two-minute collection were used for analysis and the participant was assigned a task to completion time of two-minutes.

Kinematic data were processed in Vicon Nexus (version 1.8.5) to apply the Full Body Plugin Gait Model, smooth data, and compute trunk angles, and hip, knee, and ankle angles and bilaterally. A Woltring gap fill procedure was applied with a maximum gap of 60 frames. Then, marker trajectories were smoothed using a fourth-order low pass Butterworth digital filter with a cutoff frequency of 6 Hz. Sagittal plane lower-extremity joint angles were calculated representing the relative rotations at the hip, knee, and ankle joints during each walking stride. Forward trunk lean was computed as the absolute angle of the thorax segment relative to the vertical. The static calibration trial was used to represent zero degrees for each kinematic parameter. Once processed, data were exported to MATLAB (R2014a; The Mathworks, Inc., Natick, MA) to extract the variables of interest. The TW and WC conditions were separated into individual strides identified as the time between consecutive heel strikes of the same foot. Each stride was identified from the respective condition trials using a velocity based treadmill algorithm [23]. Each stride was then normalized to 100% of the gait cycle (101 data points). The number of trials per participant ranged from 15-119 with the average number of trials across participants and conditions being 45.6 ± 18.5, bilaterally. The gait cycle was then divided into the following sub-phases defined as a percent range of the total gait cycle [24]: loading response (0-10%), mid-stance (11-30%), terminal stance (31-50%), pre-swing (51-60%), initial swing (61-73%), mid-swing (74-87%), and terminal swing (88-100%).

To examine task-specific differences in walking velocity and work efficiency, velocity was compared between the TW and WC conditions while the time to complete the computer mousing tasks was compared between the WC and SC conditions using paired-samples t-tests. Statistical significance for all analyses was set a priori at α=0.05. To examine the acute effects of the experimental conditions on locomotor safety, a point-to-point analysis was performed. First, ensemble mean time-histories were computed bilaterally across strides, per participant, per condition, for each kinematic parameter. Model Statistic single-subject analyses [25] were conducted between the TW and WC conditions for each participant at each of the 101 data points. This procedure was performed to determine whether distinct movement coordination differences could be identified throughout the gait cycle from the kinematic data. Statistical significance for the Model Statistic tests was established a priori at α=0.05.

The WC condition was further examined to determine whether participant-specific kinematic adaptations occurred while completing the WC task. For this procedure, ensemble mean time-histories were computed bilaterally for each participant across the first 10 and last 10 strides, respectively. One participant completed the tasks in fewer than 20 strides. Therefore, that participant was excluded from this analysis to avoid overlap between the first and last blocks of strides. The average ± one standard deviation for the number of strides completed by the left and right limbs during the WC condition was 43.7 ± 18.6 and 44.9 ± 18.7, respectively. Model Statistic analyses (α=0.05) were conducted between the first and last blocks at each of the 101 data points to determine whether learning or task-specific familiarization occurred. Each block of strides was divided into the sub-phases described previously.

Results

Data are presented as mean ± one standard deviation. No significant difference was found between the TW and WC conditions for treadmill velocity (1.17 m/s ± 0.20 m/s, TW; 1.21 m/s ± 0.23 m/s, WC; p=0.089). Furthermore, no significant difference was found for time to complete the mousing tasks between the WC and SC conditions (42.1 sec ± 22.5 sec, WC; 29.1 sec ± 10.6 sec, SC; p=0.071).

For each participant, the percentages of significant hip position differences for TW and WC during the left and right strides at each sub-phase are documented in Table 1. Collapsed across participants, 46 ± 44% and 38 ± 47% of the loading response phase was found to be significantly different between conditions during left and right strides, respectively (p<0.05). During mid-stance and terminal stance, 54 ± 43% and 57 ± 42% (mid-stance) and 59 ± 42% and 57 ± 42% (terminal stance) of the phases were significantly different between conditions during the left and right strides, respectively. During pre-swing, 65 ± 45% (left) and 54 ± 45% (right) of the phase was significantly different between conditions (p<0.05). During initial swing, 58 ± 41% and 56 ± 39% of the phase was significantly different for the left and right strides, while 72 ± 40% and 65 ± 44% of the mid-swing phase was significantly different for the left and right strides, respectively. Lastly, 57 ± 42% and 64 ± 40% of the terminal swing phase was different between conditions for the left and right limbs (p<0.05) (Table 1).

At the knee, 59 ± 44% and 61 ± 40% of the loading response phase was significantly different between TW and WC conditions for the left and right strides, respectively (p<0.05). During mid-stance, 52 ± 40% (left strides) and 48 ± 40% (right strides) of the phase was significantly different between conditions, while 54 ± 41% and 23 ± 32% of the terminal stance phase was significantly different between conditions for the left and right strides. During pre-swing, 60 ± 42% and 56 ± 43% of the phase was significantly different for the left and right strides, respectively (p<0.05). Throughout initial swing, 56 ± 43% and 58 ± 33% of the phase was significantly different between conditions for the left and right strides. During mid-swing, 57 ± 46% (left) and 58 ± 42% (right) of the phase was significantly different between conditions, while

Subject	Loading Response		Mid Stance		Terminal Stance		Pre Swing		Initial Swing		Mid Swing		Terminal Swing		Complete Stride	
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Mean	SD
1	100%	0%	95%	90%	75%	55%	50%	10%	54%	54%	100%	100%	100%	100%	74%	13%
2	80%	0%	100%	15%	80%	100%	100%	60%	92%	0%	29%	0%	0%	50%	52%	24%
3	0%	0%	0%	0%	0%	0%	20%	0%	31%	0%	0%	57%	0%	43%	10%	6%
4	0%	100%	30%	80%	85%	100%	0%	80%	0%	92%	86%	100%	79%	100%	69%	34%
5	80%	0%	45%	0%	100%	30%	100%	70%	100%	100%	100%	100%	64%	71%	66%	23%
6	100%	100%	100%	65%	35%	5%	100%	100%	85%	69%	93%	93%	100%	100%	77%	11%
7	0%	100%	90%	100%	100%	95%	100%	0%	100%	31%	64%	100%	50%	100%	78%	3%
8	40%	0%	0%	5%	25%	60%	100%	100%	100%	62%	100%	0%	100%	0%	45%	20%
9	80%	0%	85%	80%	90%	30%	100%	50%	100%	100%	100%	100%	21%	21%	69%	18%
10	0%	0%	0%	0%	0%	0%	0%	0%	46%	0%	100%	0%	100%	57%	21%	18%
11	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	0%
12	0%	80%	0%	90%	0%	60%	0%	100%	0%	100%	0%	29%	0%	0%	32%	46%
13	100%	100%	65%	100%	100%	25%	100%	100%	31%	77%	100%	64%	100%	100%	81%	5%
14	10%	10%	100%	95%	100%	100%	100%	100%	77%	54%	86%	100%	57%	100%	82%	3%
15	0%	0%	0%	20%	50%	85%	90%	0%	0%	0%	0%	0%	0%	0%	20%	1%
16	50%	20%	50%	70%	0%	60%	0%	0%	8%	62%	100%	100%	36%	86%	48%	19%

Note: Percent values represent the percentage of significant hip position differences (p<0.05) between the Treadmill Walking (TW) and Walking and Computing (WC) conditions for the left and limbs for each participant throughout each sub-phase of the gait cycle; Complete stride = Percentage of significant differences between TW and WC throughout the gait cycle collapsed by limb; SD = One standard deviation.

Table 1: Percentage of significant hip position differences during each sub phase of the gait cycle between the TW and WC conditions.

69 ± 29% (left) and 62 ± 38% (right) of the terminal swing phase was significantly different between conditions (p<0.05). The percentages of significant knee position differences during the left and right strides at each sub-phase of the gait cycle are presented in Table 2.

At the ankle, when collapsed across participants, 64 ± 44% and 75 ± 40% of the loading response phase was significantly different between conditions for the left and right strides (p<0.05). During mid-stance, 62 ± 34% and 69 ± 33% of the phase was significantly different between conditions for the left and right strides, while 69 ± 37% and 49 ± 33% of terminal stance was significantly different between conditions for the left and right strides, respectively. Throughout the pre-swing phase, 63 ± 37% and 71 ± 35% of the phase was significantly different between conditions for the left and right strides, while 50 ± 41% (left strides) and 74 ± 35% (right strides) of the initial swing phase was significantly different between conditions (p<0.05). During mid-swing, 77 ± 35% and 69 ± 40% of the phase was significant different between conditions for the left and right strides, while 66 ± 35% and 70 ± 31% of terminal swing was significantly different between conditions during the left and right strides, respectively (p<0.05). The percentages of significant ankle position differences during the left and right strides at each sub-phase of the gait cycle are presented in Table 3.

At the trunk, 83 ± 37% and 81 ± 36% of the loading response phase was found to be significantly different between conditions when collapsed across participants during left and right strides, respectively

Subject	Loading Response		Mid Stance		Terminal Stance		Pre Swing		Initial Swing		Mid Swing		Terminal Swing		Complete Stride	
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Mean	SD
1	0%	90%	20%	10%	60%	0%	20%	10%	85%	69%	7%	14%	7%	100%	34%	4%
2	100%	40%	100%	20%	50%	0%	100%	0%	85%	0%	100%	64%	100%	93%	59%	41%
3	20%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	1%
4	100%	100%	20%	75%	0%	50%	50%	100%	46%	100%	100%	93%	100%	93%	68%	22%
5	100%	70%	100%	100%	100%	5%	100%	0%	15%	46%	100%	0%	100%	0%	61%	39%
6	50%	40%	55%	5%	100%	100%	100%	100%	92%	77%	100%	100%	100%	100%	79%	9%
7	100%	40%	100%	95%	100%	5%	80%	0%	77%	0%	100%	0%	100%	71%	64%	43%
8	10%	0%	60%	0%	75%	55%	100%	100%	46%	77%	29%	100%	29%	14%	49%	4%
9	100%	100%	90%	60%	90%	0%	100%	100%	100%	100%	100%	86%	100%	86%	82%	20%
10	0%	0%	0%	0%	0%	0%	50%	40%	100%	54%	7%	0%	7%	0%	15%	6%
11	50%	100%	30%	65%	65%	50%	100%	100%	85%	85%	64%	64%	64%	86%	68%	8%
12	20%	20%	0%	40%	0%	10%	0%	70%	0%	54%	0%	100%	0%	57%	25%	32%
13	100%	100%	80%	100%	85%	75%	30%	40%	92%	77%	100%	57%	100%	71%	81%	6%
14	100%	100%	100%	100%	55%	25%	100%	60%	77%	77%	93%	100%	93%	79%	81%	8%
15	0%	70%	10%	30%	85%	0%	30%	80%	0%	69%	7%	43%	7%	43%	33%	13%
16	100%	100%	70%	75%	0%	0%	0%	100%	0%	38%	0%	100%	0%	93%	45%	30%

Note: Percent values represent the percentage of significant knee position differences (p<0.05) between the Treadmill Walking (TW) and Walking and Computing (WC) conditions for the left and limbs for each participant throughout each sub-phase of the gait cycle; Complete stride = Percentage of significant differences between TW and WC throughout the gait cycle collapsed by limb; SD = One standard deviation.

Table 2: Percentage of significant knee position differences during each sub phase of the gait cycle between the TW and WC conditions.

Subject	Loading Response		Mid Stance		Terminal Stance		Pre Swing		Initial Swing		Mid Swing		Terminal Swing		Complete Stride	
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Mean	SD
1	100%	90%	100%	100%	65%	100%	90%	90%	0%	0%	43%	14%	86%	79%	70%	1%
2	100%	100%	70%	45%	85%	25%	70%	100%	92%	62%	86%	100%	79%	86%	75%	11%
3	0%	100%	100%	65%	100%	0%	40%	90%	38%	46%	0%	0%	7%	64%	48%	2%
4	10%	80%	30%	100%	25%	100%	70%	90%	0%	85%	93%	57%	100%	29%	62%	24%
5	100%	10%	100%	35%	100%	15%	20%	80%	15%	92%	100%	100%	100%	50%	66%	21%
6	100%	100%	100%	100%	100%	100%	100%	100%	77%	85%	86%	79%	100%	93%	95%	1%
7	0%	100%	65%	95%	95%	40%	80%	30%	8%	100%	100%	100%	57%	64%	69%	9%
8	100%	100%	30%	55%	50%	65%	100%	90%	92%	77%	100%	36%	100%	100%	73%	3%
9	100%	100%	100%	100%	100%	35%	100%	100%	100%	100%	100%	100%	71%	79%	90%	8%
10	0%	0%	0%	0%	15%	30%	0%	0%	0%	0%	0%	0%	0%	0%	4%	2%
11	70%	100%	60%	70%	100%	65%	100%	80%	100%	100%	100%	100%	79%	100%	86%	1%
12	80%	X	30%	X	0%	X	0%	X	15%	X	100%	X	100%	X	44%	X
13	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
14	20%	100%	60%	100%	100%	20%	50%	60%	100%	100%	100%	100%	29%	100%	75%	8%
15	80%	0%	20%	25%	75%	60%	30%	0%	69%	92%	79%	86%	36%	43%	50%	6%
16	100%	70%	70%	75%	20%	35%	100%	80%	46%	100%	64%	100%	43%	100%	68%	13%

Note: Percent values represent the percentage of significant ankle position differences (p<0.05) between the Treadmill Walking (TW) and Walking and Computing (WC) conditions for the left and limbs for each participant throughout each sub-phase of the gait cycle; 'X' Represents missing data for corresponding participants; Complete stride = Percentage of significant differences between TW and WC throughout the gait cycle collapsed by limb; SD = One standard deviation.

Table 3: Percentage of significant ankle position differences during each sub phase of the gait cycle between the TW and WC conditions.

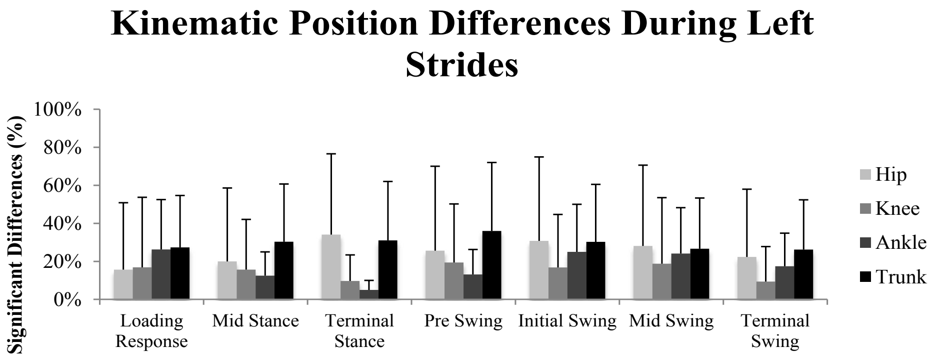
(p<0.05). During mid-stance and terminal stance, 88 ± 34% and 77 ± 37% (mid-stance) and 81 ± 35% and 77 ± 38% (terminal stance) of the phases were significantly different between conditions during the left and right strides, respectively. During pre-swing, 79 ± 36% (left) and 90 ± 28% (right) of the phase was significantly different between conditions (p<0.05). During initial swing, 88 ± 34% and 88 ± 28% of the phase was significantly different for the left and right strides, while 88 ± 34% (left) and 80 ± 37% (right) of the mid-swing phase was significantly different. Finally, 79 ± 39% and 78 ± 40% of the terminal swing phase was different between conditions for the left and right limbs, respectively (p<0.05). The percentages of significant trunk position differences during the left and right strides at each sub-phase of the gait cycle are presented in Table 4.

Some participants did not display significant hip position differences between the first 10 and last 10 left and right strides (p>0.05). However, the percentages of significant differences that were observed in most participants during each sub-phase were no less than 10% and were as high as 100%. Moreover, the participants who displayed differences during left strides typically displayed a similar number of significant differences during right strides at each joint and segment. Collapsed across sub-phases and limbs, the average number of participants who exhibited significant differences between the first and last blocks of strides was 5.4 ± 1.6 participants. At the knee, the percentage of significant differences ranged between 5% and 100% for the participants who displayed kinematic adaptations. Collapsed across sub-phases and limbs, the average number of participants who exhibited significant knee position differences was 5.3 ± 1.5 participants. Similar to the knee, the percentage of significant ankle joint position differences collapsed across sub-phases ranged between 5% and 100%. The average number of participants who exhibited significant knee position differences when collapsed across sub-phases and limbs were 5.6 ± 2.2 participants. At the trunk, the range of significant trunk position differences ranged between 10% and 100%. Collapsed across sub-phases, the average number of participants to exhibit significant trunk position differences was 5.9 ± 0.8 participants. The average number of significant differences between the first 10 and last 10 strides when collapsed across participants for the hip, knee, ankle, and trunk positions during each sub-phase are illustrated in Figures 1 and 2, respectively. An exemplar representation of the significant differences in joint and trunk position between the first and last blocks of strides is presented in Figure 3.

Subject	Loading Response		Mid Stance		Terminal Stance		Pre Swing		Initial Swing		Mid Swing		Terminal Swing		Complete Stride	
	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Mean	SD
1	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	0%
2	100%	100%	100%	90%	50%	0%	0%	0%	0%	0%	0%	0%	29%	93%	42%	2%
3	0%	0%	0%	0%	0%	25%	0%	100%	0%	54%	0%	0%	0%	0%	11%	15%
4	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	0%
5	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	0%
6	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	0%
7	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	0%
8	30%	0%	100%	70%	100%	100%	100%	100%	100%	100%	100%	64%	29%	0%	74%	13%
9	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	0%
10	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	0%
11	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	0%
12	100%	60%	100%	10%	80%	100%	40%	100%	100%	62%	100%	29%	100%	57%	74%	23%
13	100%	100%	100%	35%	100%	60%	100%	100%	100%	100%	100%	100%	100%	100%	90%	15%
14	0%	40%	0%	20%	0%	0%	60%	40%	100%	100%	100%	86%	0%	0%	35%	3%
15	100%	100%	100%	100%	60%	40%	70%	100%	100%	100%	100%	100%	100%	100%	89%	1%
16	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	0%

Note: Percent values represent the percentage of significant trunk position differences (p<0.05) between the Treadmill Walking (TW) and Walking and Computing (WC) conditions for left and limbs for each participant throughout each sub-phase of the gait cycle; Complete stride = Percentage of significant differences between TW and WC throughout the gait cycle collapsed by limb; SD = One standard deviation.

Table 4: Percentage of significant trunk position differences during each sub phase of the gait cycle between the TW and WC conditions.



Note: Percentages are collapsed across participants during each sub-phase of the gait cycle; error bars represent one standard deviation.

Figure 1: Percentage of significant hip, knee, ankle, and trunk position differences between the first and last 10 walking strides for the left leg.

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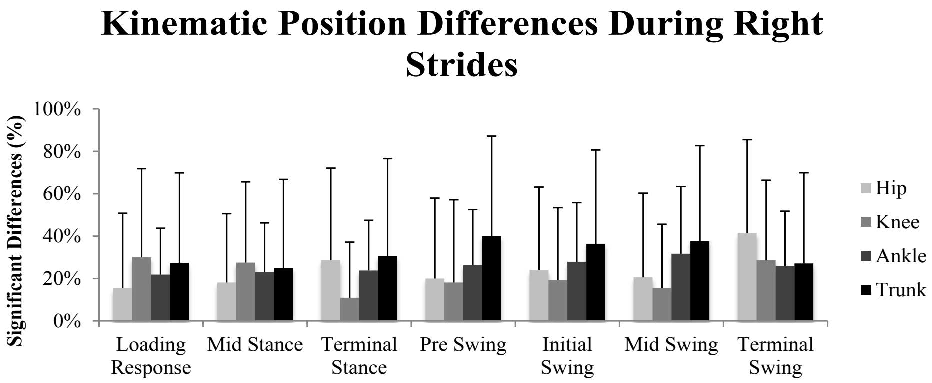
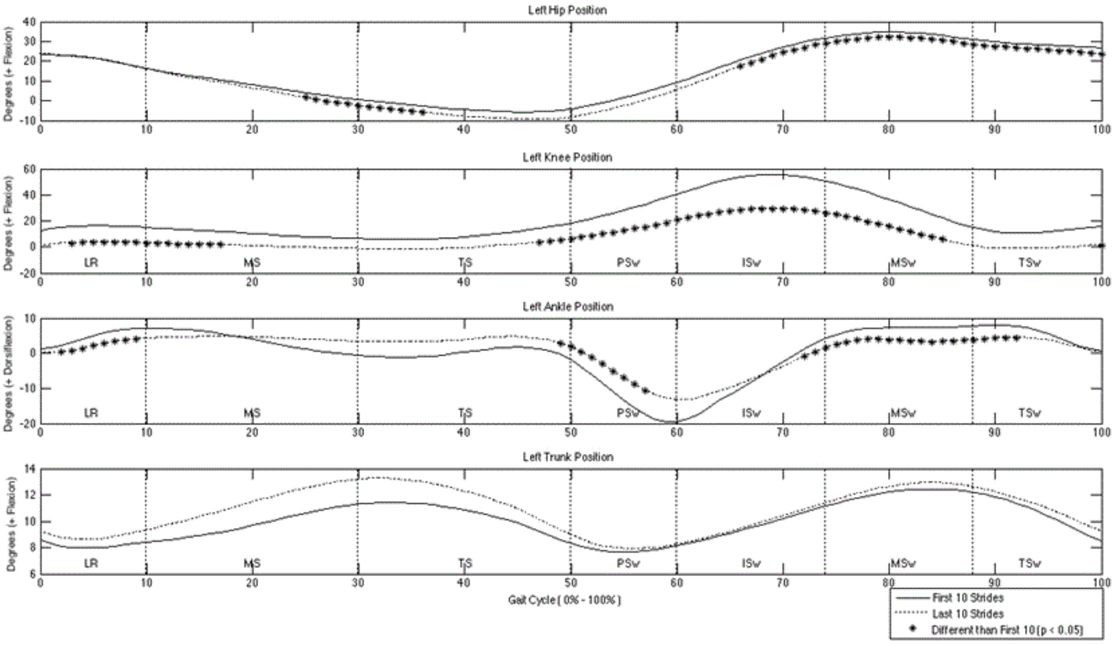


Note: Percentages are collapsed across participants during each sub-phase of the gait cycle; error bars represent one standard deviation.

Figure 2: Percentage of significant hip, knee, ankle, and trunk position differences between the first and last 10 walking strides for the right leg.



Note: LR = Loading response; MS = Mid stance; TS = Terminal stance; PSw = Pre-swing; ISw = Initial swing; MSw = Mid-swing; TSw = Terminal swing; Significant differences (p<0.05) between the first 10 and last 10 strides are denoted with an asterisk.

Figure 3: Exemplar representation of the number of significant joint and segment position differences between the first 10 and last 10 WC strides.

Discussion

The purpose of this study was to examine the feasibility of an active workstation on aspects of locomotor safety and work efficiency. Work efficiency was quantified as the time taken to perform computer mousing tasks, which required simultaneous cognitive input as well as physical movement control. Safety of locomotion was examined via changes in lower extremity joint and trunk movement patterns, quantified by the number of significant differences detected throughout the gait cycle.

The results of this analysis suggest computer mousing time was not affected by walking (WC) when compared to standing (SC), which is in agreement with recent findings [18]. Conversely, this finding is inconsistent with another similar investigation that found walking workstations diminished short-term working performance [16]. Differences relative to the difficulty of the computer mousing tasks may partially explain the inconsistency between these data and previously reported findings. Typing pre-determined words and dragging them into different columns [16] might be more attention-demanding than transcribing tapes [18] or navigating a web page to find certain news headlines as in the current study. As such, the difficulty of the psychomotor tasks should be taken into consideration when using an active workstation. Likewise, since there was an accommodation (discussed later) with experience demonstrated in this study, it may be prudent for active workstation users to initially incorporate simple tasks while progressing to more challenging computer mousing tasks. Because the difficulty among common computer tasks varies, a controlled progression during early implementation might diminish any potential reductions in task performance.

It is possible that walking speed partially influences mousing task performance. Walking at self-selected speeds (approximately 1.21 m/s) during WC tasks appears more beneficial that walking at slower (approximately 0.88 m/s) pre-determined speeds [16], as significant reductions in performance were observed at slower walking speeds compared to standing [16]. Conversely, in the current data, greater magnitudes of variability (greater standard deviation values) in computer mousing time were observed during WC as compared to SC. In combination, it appears as if walking too slowly bears negative consequences relative to working performance using a walking workstation, while a more rapid walking speed may not reduce performance but might limit the repeatability of the mousing task. Limited repeatability that was observed during WC may be related to the constraint of arm movements that assist with balance throughout the gait cycle [26] in addition to the greater cognitive demand to concurrently maintain balance and perform computer mousing tasks. Above-normal cognitive demands produce interference to the necessary attentiveness that is specific to each task [20]. Therefore, the required constraint of such arm movements during the WC task (to allow for mousing and typing) could explain the diminished mousing task repeatability that was observed since our participants were adapting to an unfamiliar walking task. Nevertheless, regular use of an active workstation might mitigate any issues specific to mousing task, while concurrently producing improvements in work performance [14].

Generally, trunk and lower-extremity kinematics were much different between the TW and WC tasks across sub-phases. This suggests that the participants changed their posture and walking mechanics as an acute response to the additional cognitive requirement of the mousing task even though the kinematic changes did not affect mousing time. The most consistent change was observed in trunk position. A majority of participants (9 of 16) exhibited significant trunk differences across 100% of the gait phases with an additional three participants exhibiting trunk position difference across 75% of the walking stride. Kinematic differences at the lower extremity joints were more variable. Some study participants (9,11,13,14) demonstrated a greater number of kinematic differences between TW and WC. Others (3,10,12) exhibited very similar lower extremity kinematics between walking conditions. Because some participants exhibited zero differences at certain sub-phases while other participants exhibited up to 100% differences, the magnitudes of variability for each kinematic parameter were quite large when collapsed across participants. Hausdorff et al. [27] previously reported that walking while successfully performing a secondary cognitive task was dependent on a maintaining consistent gait pattern so that executive function specific to the secondary task can be emphasized. It may be that kinematic alterations that occur during initial use of an active workstation are dependent on the visual attention required for the secondary (computer mousing) task [28]. This may pose a potential threat to maintaining stability during walking, which could explain the kinematic differences we observed between TW and WC. Reductions in horizontal swing velocity may have also influenced the kinematic alterations observed during WC [29]. Because the nature and/or difficulty of the secondary task appears to determine requisite changes in gait mechanics, the degree to which cognitive function is challenged is an important consideration during acute exposures to a WC task.

The noted kinematic differences between TW and WC appear influenced by the novelty of the WC task. When dividing the WC task into blocks of first 10 and last 10 strides, we observed a trend toward short-term accommodation for our sample of participants. Although some participants exhibited zero significant kinematic differences between the first and last ten strides of WC data (i.e., no adaptation), a number of participants exhibited significant differences at each sub-phase during the secondary WC adaptation comparison. These differences in joint motion, while statistically significant, may not be impactful relative to an increased risk of experiencing a trip or fall. This is supported by the fact that no participant in this sample experienced a slip, trip or fall during the WC task, nor did their gait mechanics appear affected such that their walking mechanics became unsafe. This speaks to the repeatability of gait [30] and the rapid ability to mechanically adjust so that a return to normal kinematics can occur when learning to perform a novel task [31]. It may be that the necessary mechanical adaptations to perform computer mousing tasks and maintain walking abilities are subconsciously performed during walking. The short-term kinematic adaptations during the WC tasks could have been influenced by the removal of voluntary control over the gait pattern [32] following an adjustment to emphasize the dual-task demands.

A possible limitation of this study was the participant sample examined. Our participants were healthy young adults, and therefore, these results may be limited to similar populations. Additionally, the computer mousing tasks examined were intended to be similar in terms the difficulty to locate the answers. It may be that greater cognitive demands of more challenging mousing tasks present considerably greater threats to movement safety compared to the questions examined herein, which warrants specific investigation. Finally, the use of a laptop computer may have hindered the applicability of our results. Laptop computers have limited adjustability relative to screen and keyboard position compared to desktop computer configurations. However, many workplace environments have laptop workstations for mobility purposes, which support the use of a laptop computer in this examination. Nevertheless, inclusion of a desktop workstation may be a consideration during subsequent examinations.

The current findings suggest that acute exposure to a walking workstation does not diminish the time required to complete a secondary computer mousing task, though the repeatability of the secondary task might be sacrificed while adjusting to the dual-task demands. Statistically significant alterations in trunk and lower-extremity kinematics occur as an acute response to the walking workstation, but walking kinematics trended toward a return to normal following approximately thirty seconds of exposure. Individuals interested in the use of active workstations may benefit from a gradual introduction to the dual-task challenges, particularly if the secondary mousing task is more challenging.

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