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Gait Symmetry Is Unaffected When Completing a Motor Dexterity Task While Using a Walking Workstation in Healthy, Young Adults

Heather R. Vanderhoof [1], Emily A. Chavez [1] and Jeffrey D. Eggleston [1,2,*]

[1] Interdisciplinary Health Sciences Doctoral Program, College of Health Sciences, The University of Texas at El Paso, El Paso, TX 79968, USA
[2] Department of Kinesiology, The University of Texas at El Paso, El Paso, TX 79968, USA
* Correspondence: jdeggleston@utep.edu

Abstract: Walking workstations may counteract sedentarism in working adults; however, performing dual-task walking may affect gait or work performance. The purpose of this study was to examine gait symmetry parameters and work performance while completing a fine motor dexterity task during walking workstation use. Gait function, quantified as gait symmetry, was used to identify attentional resource allocation of the co-occurring tasks during the dual-task conditions. Eighteen college-aged students performed the Purdue Pegboard Test (PPT) with left and right hands separately while using a walking workstation at a self-selected speed. Gait symmetry indices were computed on stride length and lower extremity angular joint positions and were analyzed for a comparison of the baseline and PPT dual-task conditions. No asymmetries were found in stride length or lower extremity angular joint positions at any sub-phase of gait during walking workstation use. PPT scores decreased significantly in the walking condition compared to the seated and standing conditions. Overall, gait symmetry did not change at any lower extremity angular joint position at any sub-phase; however, there was a decrease in PPT performance, which may relate to decreased work performance. However, increased exposure to the PPT task while using a walking workstation may improve work performance over time.

Keywords: dual-task; fine dexterity task; gait function; Purdue Pegboard Test

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1. Introduction

Walking workstations have been a focus in contemporary human subjects' research due to the increased risk of sedentary-related health issues associated with prolonged sitting [1] and have been implemented in working environments to increase the activity levels of sedentary office workers [2] to create a healthier lifestyle by allowing users to walk while performing work-related tasks [3]. When using a walking workstation, users attempt to maintain upright locomotion while performing a co-occurring task that can be a motor task, such as typing or clicking a computer mouse, or a cognitive task, such as recalling and vocalizing a five-digit number [4] or spelling backwards [5]. However, due to the dual-task nature of using a walking workstation, attentional resources are split, creating a competition between work performance and gait function. There are several theoretical constructs that have examined attentional resources during dual-task walking such as the bottleneck model [5], the sharing model [6], and the posture-first strategy [7]. The foundational argument of each construct is that there is a limited amount of attentional resources that can be allotted for both tasks, and that one task, either walking or the co-occurring task, may exhibit a decrease in performance.

Previous research has reported that individuals may prioritize performance on a cognitive task if the cost of the movement is lower than that of the cognitive task [8]. For instance, walking workstation users presented with a visuomotor task walked at a decreased velocity that allowed for quicker information processing speed and increased overall gait function [8]. However, kinematic accommodations did not occur while using a walking workstation when completing simple cognitive tasks but did occur with more complex cognitive tasks [9], suggesting an inverse relationship exists between movement cost and cognitive performance. Notably, in dual-task walking scenarios with healthy adults, individuals do not consciously adapt their gait mechanics while completing a co-occurring task [6]; rather, gait mechanics are considered rhythmic and non-attention demanding [10]. Recently it has been suggested that using a computer mouse while on a walking workstation could lead to a greater risk of an adverse gait-related event (trip, slip, or fall) due to the division of attention associated with the task [11,12]. Straker and colleagues [13] revealed that when users walked at a predetermined and constant speed, work performance decreased in mouse-clicking accuracy, though the effects on gait mechanics were not measured. A comparable study that observed mouse-clicking tasks on gait mechanics found that gait mechanics were altered initially, but normal gait returned with increased exposure time to the walking workstation [14]. Additional research revealed that users exhibit differences in stride width during walking workstation use and mouse-clicking, but gait remained relatively unaltered [15]. Although the effects of walking workstations on gait mechanics have been studied, the potential effects of gait symmetry, and thus gait function, remain less prevalent.

Gait symmetry has been used as an indicator of gait function in pathological and healthy populations [16]. Typically, gait symmetry has been used to categorize pathological gait characteristics, wherein symmetry analyses conducted on populations with neurological impairments have provided highly valuable information relative to limb function [17] and limb function responses to various system perturbations [18]. Gait asymmetry has also been used to characterize gait mechanics in additional clinical populations with pathological gait, such as individuals who are post stroke [19], individuals with hip osteoarthritis and/or total hip replacements [20], and elderly populations both with and without Parkinson's disease [21]. Additionally, due to the cyclical nature of gait, gait symmetry is helpful in interpreting gait data [22] and can provide insight into how the limbs function when compared to each other. For example, high inter-limb asymmetry may reflect motor control impairment in foot placement [23], thus increasing the risk of falls. While gait asymmetry has been found to correlate with fall incidences in healthy populations [24], thus, relative gait symmetry implies adequate gait function, it is worth mentioning that gait asymmetry can still be observed in healthy populations without falls [22]. Gait symmetry analysis is of interest during dual-task conditions that have a higher demand on attentional resources as individuals may place more attention on the task than on walking efficiency. Grindle and colleagues [25] measured the effects of a walking workstation on gait symmetry in healthy adults and found only small changes to symmetry while completing a cognitive task; however, gait speeds were predetermined and controlled. Considering the combination of attentional demands and adaptations to a new dual-task condition, it is important to consider gait symmetry as a metric for gait function during walking workstation use as well as the type of concurrent task used. Fine dexterity motor tasks have yet to be measured concurrently with gait symmetry; thus, it is worth examining their effect on gait symmetry to provide valuable information on gait function in response to an attention-demanding task [22]. Considering the combination of attentional demands and adaptations to a new dual-task condition, it is important to consider gait symmetry as a metric for gait function during walking workstation use.

Considering the paucity of literature examining the dual-task conditions of work performance tasks on gait function during walking workstation use, the purpose of the current study was two-fold: (1) to examine lower extremity gait symmetry while completing a fine motor dexterity task; and (2) to quantify and compare fine motor hand dexterity task performance while using a walking workstation compared to a baseline. In consideration of the sharing model, which states that there is a limit on the performance of one of the two tasks being performed, yet both tasks share the ability to be performed [6], and previous gait-related outcomes on walking workstations, it is hypothesized that either gait function or task performance will be impaired due to shared attentional resources and the assumption that both tasks will co-occur successfully.

2. Materials and Methods

2.1. Participants

Eighteen college-aged students (nine males and nine females; 25.35 ± 3.76 years; 1.71 ± 0.09 m; 75.46 ± 15.69 kg) participated in this study. All but one participant was right-handed. To be included in the study, participants needed to be between the ages of 18 and 34 years and able to walk unassisted on a treadmill. Prospective participants were excluded if they had an injury within the previous six months that altered their ambulatory function. Prior to completing any laboratory activities, all participants signed an institutionally approved informed consent document in accordance with the 1964 Declaration of Helsinki.

2.2. Procedures

After obtaining consent, initial baseline performance of the Purdue Pegboard Test (PPT) was established. The PPT is a fine and gross motor dexterity and coordination test of hands, fingers, and arms that is valid and standardized [26], making it suitable for examining the effects of a co-occurring fine motor dexterity task on gait function when using a walking workstation. The PPT board consists of two parallel lines of 25 holes where participants must place as many pins in the holes as quickly as they can within 30 s, with the right and left hand separately (see Figure 1). Participants received the standardized PPT instructions (excluding instruction for both hands) by completing the right hand first, followed by the left hand, both in seated positions; then participants completed the PPT task in an upright standing position for comparison. Once baseline PPT was obtained, participant age, height, and mass were measured and recorded, and then participants walked on a TracMaster TMX425 treadmill (TracMaster, Newton, KS, USA) for five minutes to warm up. During this time, participants were also instructed to identify a comfortable treadmill walking speed they could maintain for 15 min without stopping; this speed was then used in subsequent walking workstation conditions.

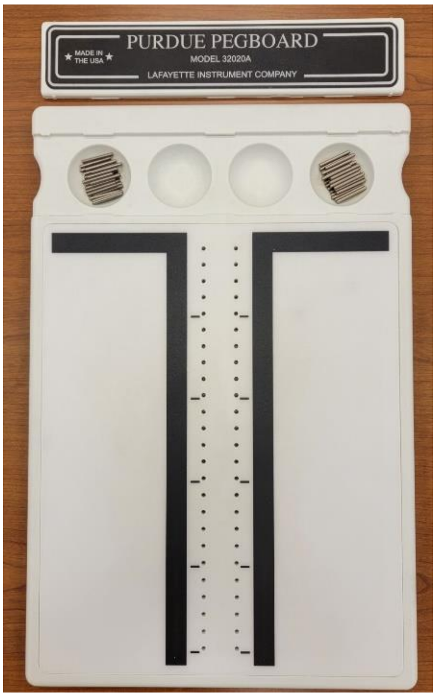

Figure 1. Purdue Pegboard setup and pins.

Once treadmill speed was identified, participants had retroreflective markers adhered to the following bilateral anatomical locations: anterior superior iliac spine, posterior superior iliac spine, medial and lateral knee joint center, medial and lateral ankle joint center, and base of the second toe. Three-marker clusters were also placed on the right and left heels. Four four-marker clusters were placed bilaterally on the lateral aspect, mid-segment, of the thighs and legs. An additional single marker was placed on the sacrum to aid in tracking pelvis motion. Participants were then given instructions on how to safely step onto the walking workstation and adjust the desk height to ensure their forearms could rest comfortably on the desk, without excessive trunk motion while walking. An ActiveStep treadmill (Simbex, Lebanon, NH, USA) was used with a Steelcase FitWork Workstation desk (Steelcase Inc., Grand Rapids, MI, USA) workstation desk equipped with motorized desk height control, which allowed users to choose the most comfortable height (see Figure 2). Then, participants were informed when the treadmill would start, allowing them to gradually increase in speed until they reached their previously selected preferred speed. Treadmill velocity was controlled by an external computer run by a member of the research team; however, the predetermined velocity was used for the remainder of the session. Participants walked for ninety seconds, with their hands off the desk, to acclimate to the treadmill speed and to obtain baseline gait data. After baseline data were collected, participants continued walking at the same speed and were given instructions for performing the PPT as they walked. Both right and left hand PPT scores were collected separately during walking conditions. Data were collected for 30 s at each condition for baseline and PPT conditions. During baseline and experimental conditions, three-dimensional kinematic data were obtained by a 10-camera motion capture system (200 Hz, Vicon Motion Systems, Ltd., Oxford, UK).

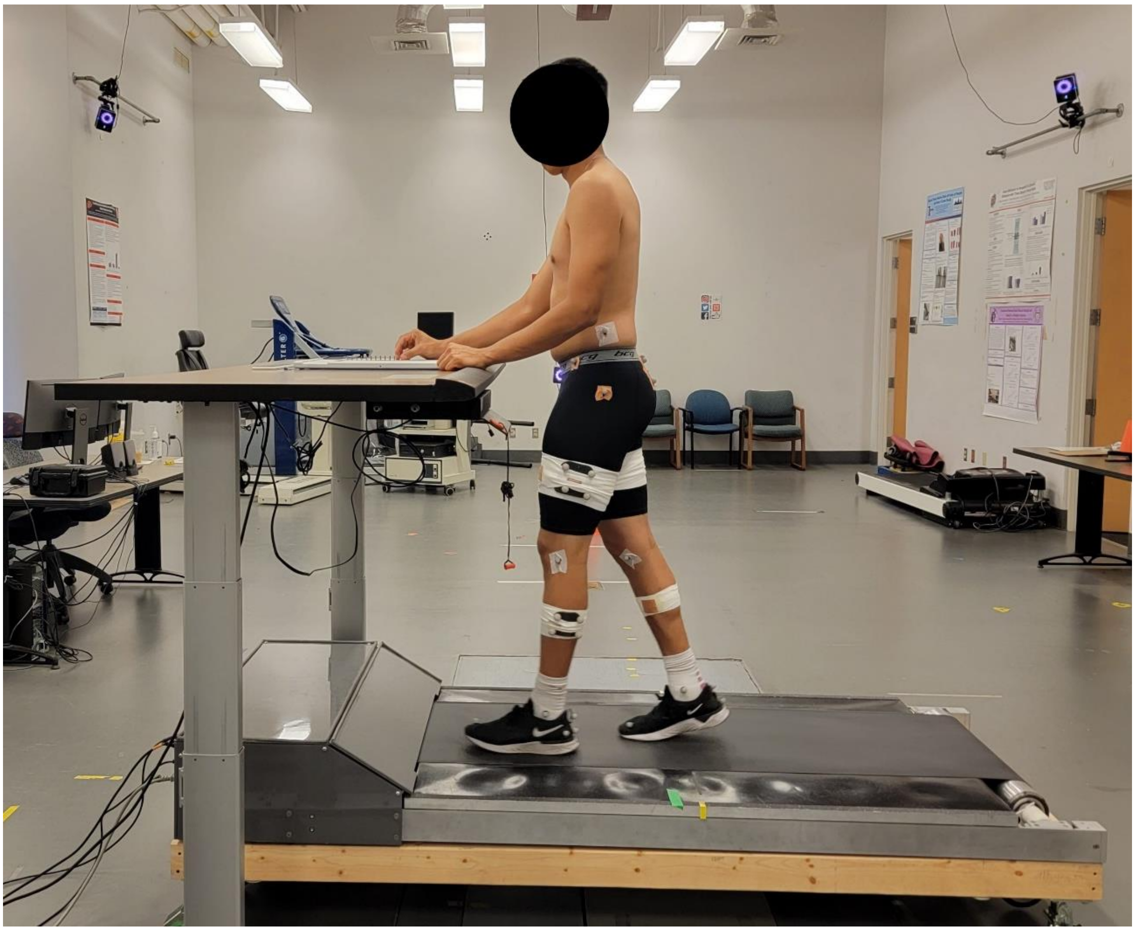

Figure 2. Participant on the walking workstation with lower extremity markers completing the PPT.

2.3. Data Reduction

Kinematic data were exported from Vicon Nexus v2.9.1 to Visual 3D biomechanical software suite (C-Motion, Inc., Germantown, MD, USA) for further analysis and variable calculations. A seven-segment model was constructed from the marker trajectories, which included the pelvis, left and right thigh, leg, and foot segments. Heel strikes were identified using the velocity-based algorithm presented by Zeni and colleagues [27], and then data were normalized to 100% of the gait cycle (101 data points). Marker trajectories were filtered with a fourth-order low-pass Butterworth digital filter (6 Hz). The smoothed marker trajectories were used to compute sagittal plane hip, knee, and ankle angular joint positions using a Cardan (*x*-*y*-*z*) rotation sequence as well as stride length. Symmetry of bilateral lower extremity angular joint positions (sagittal plane hip, knee, and ankle), and stride length were used for analysis where symmetry was computed using the symmetry index ratio (*SI*) proposed by Robinson and colleagues [28]: $SI = \frac{X_R - X_L}{\frac{1}{2}(X_R + X_L)} * 100$, where X_R is a gait-related variable from the right limb and X_L is a gait variable from the left limb [29]. In this mathematical formula, perfect symmetry results in an $SI = 0$ [22,29]. To remove any confusion for negative *SI* outcomes, absolute values of each *SI* outcome are reported below. For angular joint positions, symmetry magnitudes were averaged at each gait sub-phase represented by the loading response (0–10%), mid-stance (11–30%), terminal stance (31–50%), pre-swing (51–60%), initial swing (61–63%), mid-swing (74–87%), and terminal swing (88–100%) [30], for each joint and used for comparison.

2.4. Statistical Analysis

Statistical analyses were performed in SPSS Software (v24; IBM Corp ©, Armonk, NY, USA). A two (hand: right/left) by three (condition: seated/standing/walking) factorial repeated measures ANOVA ($\alpha = 0.05$) was used to determine if PPT scores were statistically different between the standardized sitting condition and the standing and walking conditions. If an interaction was detected, one-way repeated measures ANOVAs with Sidak adjustments were used on both unilateral comparisons among conditions, while dependent t-tests were used for between-hand comparisons. Data normality was assessed using the Shapiro–Wilk test. For symmetry magnitude measurements, left- and right-hand conditions were collapsed into a single dual-task walking condition. While left- and right-hand fine motor dexterity tasks were collected separately, the main aim of the study was to examine the possible effect of dual-task on gait function, not whether hand dominance influenced gait symmetry. Dependent *t*-tests ($\alpha = 0.05$) were used to test for statistically significant differences in angular joint position symmetry magnitudes at each gait sub-phase, and stride length symmetry magnitudes between the baseline and dual-task condition.

3. Results

Shapiro–Wilk test results revealed a normal distribution for stride length between both limbs and conditions, $p > 0.05$ in all comparisons. Additionally, the assumption of sphericity was not violated ($p > 0.05$). There was not a significant difference in stride length symmetry between the baseline ($M = -0.01$, $SD = 0.08$) and dual-task condition ($M = -0.005$, $SD = 0.09$), $t(17) = -0.217$, $p = 0.831$. Stride length means and standard deviations comparing baseline walking to the collapsed dual-task walking condition for the left and right limbs are displayed in Figure 3.

Mean and standard deviation symmetry magnitudes for baseline and DT conditions, *t*-scores, and *p*-values are displayed in Table 1 for the hip, knee, and ankle lower extremity joints in all sub-phases of gait comparing the baseline symmetry measures to the dual-task walking condition measures.

PPT Scores

Mean and standard deviation values for all PPT scores are displayed in Figure 4. Shapiro–Wilk test results revealed a normal distribution for PPT scores in each condition: $p > 0.05$ in all conditions. Results from the factorial repeated measures ANOVA revealed the assumption of sphericity was not violated ($p > 0.05$). There was no significant condition by hand interaction, $F(2,68) = 1.85$, $p = 0.170$. However, there was a condition main effect $F(2,68) = 17.54$, $p < 0.001$, with pairwise comparisons revealing that PPT scores while walking were significantly lower compared to seated ($p < 0.003$) and standing ($p < 0.001$) scores, but there was no significant difference between seated and standing scores ($p = 0.065$). Additionally, right hand PPT scores were significantly greater than left hand scores ($p = 0.011$).

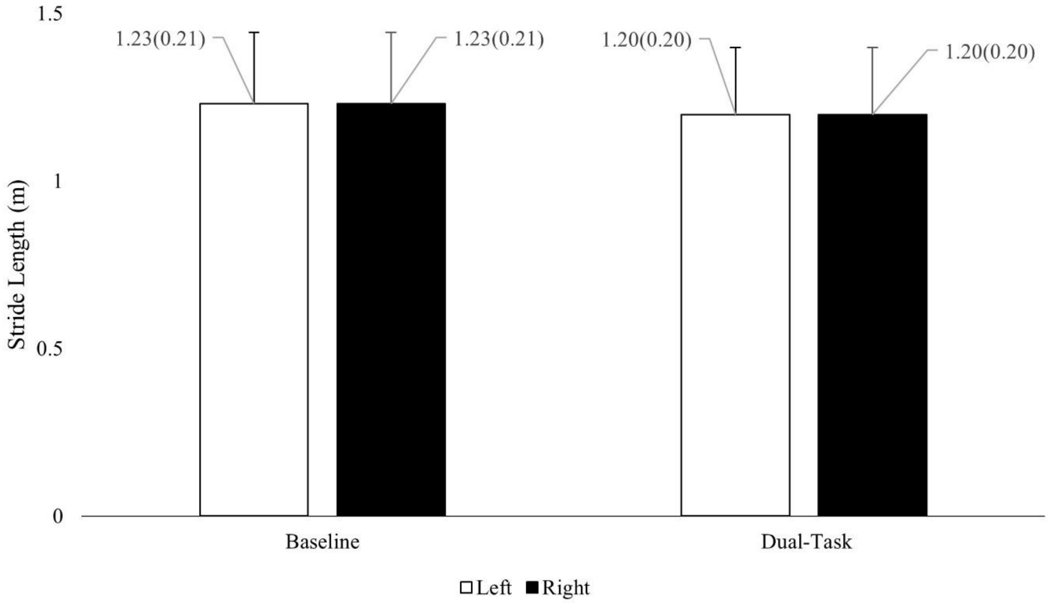

Figure 3. Stride length means and standard deviations between left and right limbs for baseline and dual-task conditions.

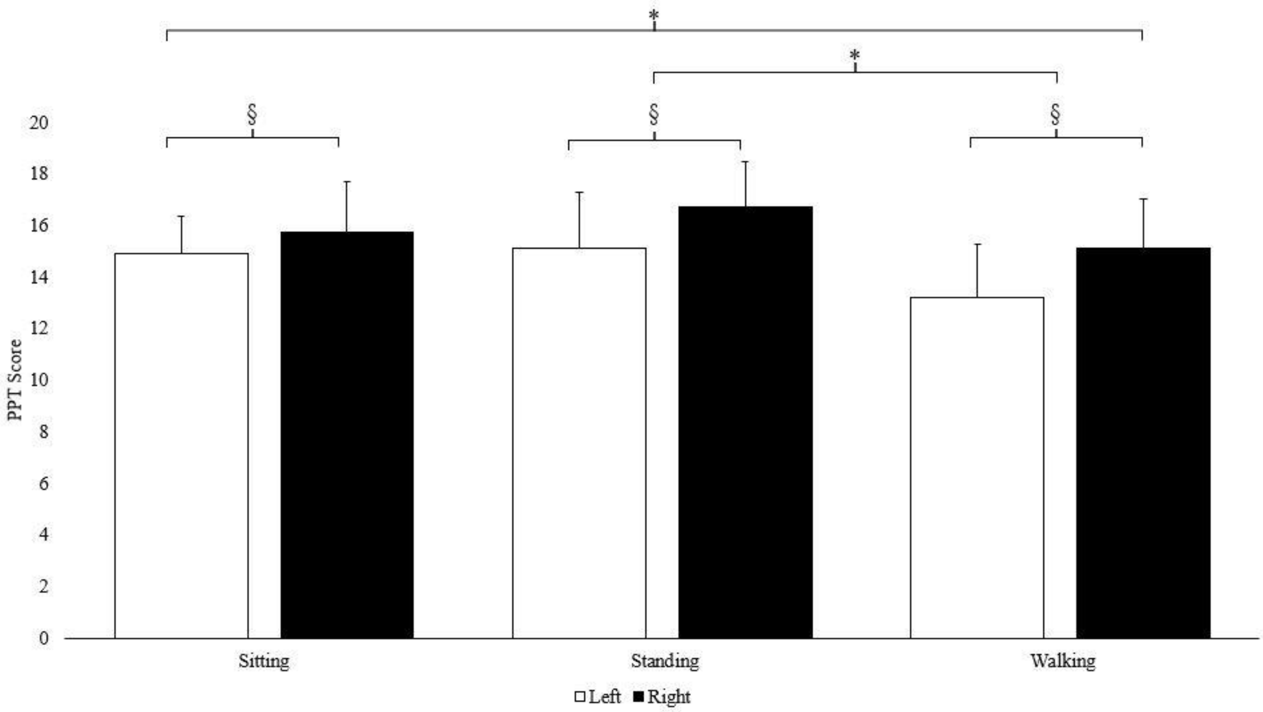

Figure 4. PPT score means and standard deviations. Symbol '*' indicates a condition main effect ($p < 0.05$). Symbol '§' indicates a hand main effect ($p < 0.05$).

Table 1. Symmetry magnitude mean and standard deviation values for baseline and DT conditions for lower extremity angular joint positions at each gait sub-phase.

	Baseline: Mean (SD)	DT: Mean (SD)	*t*	*p*
Loading Response				
Hip	5.83 (6.30)	6.81 (8.33)	−1.396	0.181
Knee	17.19 (18.72)	20.31 (19.87)	−1.162	0.261
Ankle	279.08 (757.16)	100.99 (80.93)	0.997	0.333
Mid-stance				
Hip	9.59 (10.72)	8.86 (12.01)	0.511	0.616
Knee	15.23 (20.69)	14.38 (16.24)	0.349	0.731
Ankle	115.46 (151.39)	190.46 (367.85)	−0.866	0.399
Terminal Stance				
Hip	83.72 (142.64)	97.50 (102.71)	0.464	0.648
Knee	25.41 (23.27)	21.21 (27.18)	1.418	0.174
Ankle	22.39 (17.12)	24.68 (18.88)	−0.773	0.450
Pre-swing				
Hip	56.86 (88.90)	68.80 (121.36)	−0.357	0.725
Knee	18.50 (19.41)	16.93 (17.81)	0.560	0.58
Ankle	21.97 (14.86)	25.00 (20.48)	−1.305	0.209
Initial Swing				
Hip	56.16 (74.30)	67.96 (192.02)	−0.284	0.780
Knee	7.24 (5.53)	7.81 (5.90)	−0.743	0.468
Ankle	183.50 (431.66)	852.28 (3043.52)	−0.943	0.359
Mid-swing				
Hip	7.33 (7.76)	7.73 (9.41)	−0.535	0.600
Knee	4.50 (4.80)	4.86 (4.92)	−0.689	0.500
Ankle	990.82 (3724.77)	298.69 (433.80)	0.795	0.438
Terminal Swing				
Hip	4.75 (6.82)	5.72 (7.62)	−1.316	0.206
Knee	10.65 (10.71)	10.23 (10.78)	0.324	0.750
Ankle	228.54 (663.02)	61.36 (75.57)	1.170	0.258

4. Discussion

The main purpose of this study was to examine gait symmetry parameters while completing a fine motor dexterity task during walking workstation use. The secondary purpose was to quantify the performance of a fine motor dexterity task when completed on a walking workstation. It was hypothesized that based on the sharing model [6], either gait symmetry or work performance outcomes would decrease while using the walking workstation due to the attentional resources being shared while completing a dual-task condition. The outcomes from this study supported the hypothesis, wherein the walking task took precedence, and the fine motor dexterity task displayed a hindered performance. Neither stride length symmetry nor lower extremity joint symmetry magnitudes displayed significant differences across gait sub-phases when comparing baseline treadmill walking to dual-task walking. However, the fine motor dexterity task performance was compromised while using the walking workstation, based on the significantly lower PPT score outcomes during walking compared to baseline measurements.

Stride length symmetry did not differ between limbs nor condition in the current study, suggesting there were no changes in gait function. Potentially, participants utilized a posture-first strategy by prioritizing attentional resources for gait function, resulting in a decrease in performance on the fine motor dexterity task [7]. Eggleston and colleagues [15], and Grindle and colleagues [25] both displayed similar findings of unaltered stride length magnitudes during dual tasks, but both also revealed an altered stride width. Lower extremity angular joint position symmetry magnitudes were not statistically different between conditions, nor at any gait sub-phase; results that do not align with the findings from Arauz et al., [31] where sagittal plane angular knee joint motion was asymmetrical while walking on a workstation and completing a typing task. Similarly, the current study did not reveal differences at the sub-phases at gait, although Dufek and colleagues [14] revealed short-term gait accommodations, wherein gait mechanics altered at first during walking workstation use before returning to normal. However, the current findings indicate that walking workstations do not affect gait function while completing a fine motor dexterity task simultaneously, suggesting that walking workstations may be viable options to decrease sedentary workstyles for young, healthy adults during dual-task conditions.

The results of the PPT score outcomes agreed with previous findings that task performance decreased significantly while using a walking workstation [13], even when users were allowed to determine their own walking speed. Additionally, scores were significantly higher when performed by the right hand versus the left hand, which could be due to all but one of the participants being right-hand dominant. Furthermore, the left-hand dominant participant did not display increased left-handed scores: PPT score outcomes by condition were seated 16/18 (L/R); standing 17/17 (L/R); and walking 17/17(L/R). Nevertheless, PPT scores were significantly lower overall while walking compared to the baseline and to standing, suggesting that the dual-task scenario does affect motor dexterity task performance, likely due to adopting a posture-first strategy, which prioritized gait function rather than work performance [7]. These findings suggest that work performance may decrease in a work environment during walking workstation use. However, users can maintain upright locomotion while using the walking workstation, and it may be possible to increase work performance over time with more exposure, as these results only reflect acute work performance.

A primary limitation of the current study was not recording the chosen desk height by each participant. It is possible that this may have influenced gait symmetry and PPT outcomes; however, this is not likely since each participant was instructed to choose the height they were most comfortable with. In doing so, the current study replicated realistic walking workstation use in the workplace where ergonomic standards may not be readily available or known to individuals. Additionally, the current study did not account for any added function that the desk may have provided if participants leaned on it during the dual-task condition, as all participants naturally decided to perform the PPT tasks with the non-working hand resting on the desk. Regardless, participants completed the task the way they would in a workplace setting, and again, this can be considered more realistic. As such, the outcomes are likely not confounded by strict instructions on how to stand and complete the task. Notably, the standard deviations of the lower extremity angular joint position symmetry index were high; however, this could likely be due to the high variability of walking strategies used among the participants. Additionally, when comparing PPT scores, the current statistical model did not control for hand dominance, as only one participant out of the eighteen was left-handed. Nevertheless, the findings from the current study provide both task performance outcomes and gait function measurements that have not been previously observed in combination. While the current study observed healthy, young adults, future research should examine gait function in middle-aged adults while using a walking workstation, as that population may be more inclined to be in sedentary work environments than young adults [32].

5. Conclusions

The current study quantified gait symmetry parameters and fine motor dexterity task performance while using a walking workstation. It was hypothesized that the attentional resources required to complete both tasks simultaneously would diminish either gait function or work performance. While lower extremity angular joint position symmetry index magnitudes were not significantly different between conditions, task performance was hindered while using the walking workstation. According to the current outcomes, walking workstations did not alter gait function but did decrease work performance in healthy, young adults. However, it is possible that long-term exposure to the PPT task while using a walking workstation could improve fine motor hand dexterity, thus improving work performance over time.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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Conflicts of Interest: The authors declare no conflict of interest.

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