



Differences in Temporal Gait Parameters When Walking on Even Surface Walkway, Treadmill, and Pushing a Constant Resistant Sled

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Abstract: Motorized treadmills and weighted sleds are employed in clinical settings to improve lower extremity strength, power, and endurance. However, little is known about how the spatio-temporal parameters compare when walking on an even surface walkway, walking on a treadmill, or pushing a sled. This study aimed to examine the variations in spatial and temporal gait parameters when walking on an even surface walkway (EW), on a treadmill (TW), and while pushing a sled (SP). Forty healthy subjects participated in this pilot study. The mean age and BMI of all participants were 24.39 (\pm 2.86) years and 68.26 (\pm 13.92) kg/m², respectively. Spatio-temporal parameters were gathered using the Mobility Lab ADPM software and six sensors containing accelerometers and gyroscopes. Participants were directed to walk at a normal and comfortable speed for 7 m on an even surface walkway for two trials. Next, the subjects walked on the treadmill for two trials at a speed based on age. For males aged <30 and females 20-40 years of age, the speed was 1.3 m/s. While for males aged 30 or older, the speed was set to 1.4 m/s. Finally, participants were instructed to walk at their normal pace while pushing a 60 lb sled for 9.1 meters (m). Treadmill walking provoked a significant increase in temporal variables, whereas pushing a sled significantly reduced the temporal variables. Treadmill walking resulted in a decrease in double limb support time and an increase in single-limb support time compared with even surface walking. Although cadence was greater when walking on a treadmill versus an even surface walkway, the difference may be attributed to a fixed speed on the treadmill, which was determined by age. Treadmill gait training is recommended for subjects that could benefit from an increase single limb support time to improve dynamic balance such as Parkinson patients. On the other hand, for those participants that dynamic activities are challenging, such as concussion and vestibular patients, pushing the sled will slow down gait parameters allowing gait training with an added resistance benefit. Finally, it has been proposed that further investigation should focus on the differences in lower extremity muscle activation and recruitment patterns under various walking conditions.

Keywords: Gait parameters, Walking, Treadmill

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1. Introduction

Gait training is a commonly used intervention in physical therapy to address deficits in gait mechanics and improve safety and independence with ambulation in one's environment. Gait training is often warranted after surgery, injury, or a decline in functional mobility secondary to complicating medical conditions [1, 2]. Gait training can be performed on even surfaces with or without the use of assistive devices. However, recently equipment like treadmills, suspension machines, and sleds have been used during gait training to provide additional assistance or further challenge patients in the rehabilitation setting [3-5].

Treadmill training is commonly used in individuals with various gait and balance deficits. For instance, treadmill training has been used in post-stroke patients with Parkinson's disease to improve gait speed and single-limb support time [6,7]. Similar findings have been found in children with cerebral palsy, where treadmill training has increased endurance, gait speed, and single-limb stance time [8]. While treadmill training has been used to improve gait mechanics, it has also been shown to improve balance in older adults [9,10]. In a randomized control trial by Pirouzi *et al.*, (2014), forward walking on a treadmill improved Berg balance score, reduced postural sway, and improved gait speed in the elderly population [9]. In addition, speed-dependent training on a treadmill has been shown to improve scores on the dynamic gait index and Berg balance scale in people living with Parkinson's disease [11]. Therefore, as mentioned above, treadmill training has been shown to be an effective intervention for improving both gait and balance parameters in a variety of populations.

Another upcoming intervention used for gait training is the use of resisted sled training. Sled training has been used to improve sprinting speed and lower extremity strength in athletes. However, resisted sled training can also be used to improve lower extremity power, functional strength, and endurance in the general population [5]. Previous studies by Rosario MG. (2020) examined the influence of the XPO-sled trainer on lower limb musculature [12]. This study showed that faster neuromuscular recruitment occurs in the leg muscles as the speed increases. Pushing the resistance sled during slow and fast speeds causes a reduction in the muscle activation period as a response to faster neuromuscular recruitment. The leg musculature is isolated using the sled as a form of training to improve motor control and motor coordination [12]. On the other hand, during walking

activities, muscle activation occurs later or is delayed in walk-push compared to walking tasks, making the constant resistance of the sled a useful feature to prevent muscle fatigue. Pushing against a constant resistance during different velocities can provoke distinct patterns of neuromuscular recruitment speed and peak muscle activation, which makes it a promising tool for gait training [12,13].

While there is a large amount of research that compares overground walking to treadmill walking, little is known about how these two methods of gait training compare to pushing a sled. In addition, the spatio-temporal parameters associated with pushing a sled compared to walking overground or on a treadmill at a fixed speed have yet to be explored. Therefore, the research question of this current work is: What are the differences in spatial and temporal gait parameters when walking on an even surface walkway (EW), a treadmill (TW), and while pushing a weighted sled (SP)? Knowing the specific surface-related gait adaptations will aid on tailored interventions for a diverse population.

2. Methods

Participants were recruited via word of mouth at Texas Woman's University (TWU) Dallas Campus Dallas TX, USA and neighboring areas. The current investigation and procedures were approved by the Institutional Review Board of the Texas Woman's University Dallas Campus (Protocol A20091). Prior to starting the study protocol, participants were informed about what the study entailed, and signed consent was obtained.

Research Preparation: Participants from both genders, ages of 21-45 years old were invited to participate. The time commitment for each participant was one session lasting approximately 30 minutes. First, the participants' demographic and anthropometric information (age, weight, and height) was documented. Participants were asked basic health questions to ensure that the participant did not have the following conditions: low back or leg injury in the last 6 months, medications that could potentially cause drowsiness, severe balance problems, and the possibility of pregnancy. Similar to Rosario and Mathis (2020), this study also required subjects to walk without assistive equipment, endure standing for at least 30 minutes, and have the ability to push a 60 lb sled [14]. Prior to testing, a research assistant took the

following vitals at rest to ensure cardiovascular stability: blood pressure, heart rate, and blood oxygen levels.

Instrumentation: Each participant was equipped with kinematic sensors, gyroscopes, and accelerometers that captured spatial-temporal gait parameters (Mobility-Lab system Arlington County, Virginia). Sensors were placed on the participants in the following areas: right and left wrists, right and left ankles, chest, and lower back. After the sensors were positioned, the participant began the three walking protocols (gait, treadmill, and sled) with two trials per protocol.

Even surface gait protocol: A walkway was set up using two cones that were placed 20 feet apart from one another. Participants were instructed to start walking from one cone to the other at a self-selected pace for a total of 7 m when they heard the first tone from the Mobility Lab software. The trial was concluded at the sound of the second tone, which marked the completion of the 7-meter distance. A rest break was given to the participants if requested prior to the start of the second trial.

Treadmill Protocol: The treadmill speed was determined for each participant based on findings from a meta-analysis of 41 articles that provided the average walking speed by age and gender [15]. For males under 30 years old and females between 20-40 years of age, the speed was set to 1.3 m/s. Further, for males aged 30 or older, the speed was set to 1.4 m/s [15]. At the sound of the tone, participants were instructed to press the start button on the treadmill at the preselected speed and to push the stop button at the sound of the second tone. Each trial (2 total) consisted of a 7-meter distance determined by the tones mentioned above. A rest break was given to the participants if needed prior to the start of the second trial.

Sled Protocol: For the sled protocol, a 30-foot walkway was set up using two cones. Participants were instructed to walk at their normal speed while pushing a 60 lb sled from one cone to another. Once the participants reached the 9.1 m mark, they were instructed to release the sled and continue walking until a total of 7 m was achieved, however the data points were collected only at the beginning of the test. Similar to the previous two protocols, the trial started and ended with a tone cueing the participant to initiate and terminate walking. This protocol was designed to gather the anticipatory postural adjustments at the

beginning of the trial only; hence, the reason participants pushed the sled only during that particular portion of the test. A rest break was provided between the trials upon request.

2.1. Data Analysis

This study collected kinematic data, such as cadence (steps/minute), gait speed (m/s), step duration (s), double limb support time (% of ground contact time), single limb support time (% of ground contact time), stride length (meters), and postural sway (m^2/s^4). The kinematic data were placed into the SPSS Data Analysis 25 system screened for normality prior utilizing a repeated analysis of variance. All variables were compared by the different walking conditions: walking on even surface walkway (EW), walking on a treadmill (TW), and pushing a sled (SP). Descriptive statistics and pairwise comparisons were conducted for the variables of interest. In this study, the P-value was set as equal to or less than 0.01 for statistical significance.

3. Results

Table 1 shows the demographic characteristics of the participants. This study included 40 participants, 35 women and 5 men. The mean age of the participants was 24.38 ± 2.86 . Participants had an average height of 1.64 ± 0.09 (m), weight of 68.26 ± 13.92 (kg), and body mass index of 25.30 ± 4.61 (kg/m^2). Of the 40 participants, 23 were right-leg dominant and 17 were left-leg dominant. Leg dominance was identified using Bowman and Rosario's (2021) protocol [16].

Table 2 presents the temporal variables analyzed in this study. There was a significant difference in cadence when comparing EW (111.06 ± 8.40) to TW (115.63 ± 6.06), $p < .001$, and TW to pushing a sled (108.43 ± 7.94), $p < .001$. There was a significant increase in gait speed when comparing EW (1.12 ± 0.13) to TW (1.21 ± 0.03), $p < .001$, and TW to pushing a sled (1.11 ± 0.12), $p < .001$. Step duration was significantly longer when walking on EW (0.54 ± 0.04) compared to TW (0.52 ± 0.03), $p < .001$, and longer when pushing a sled (0.56 ± 0.04) compared to walking on the TW ($p < .001$).

Table 3 displays a comparison of the spatial parameters under the three walking conditions. Double limb support time was significantly greater when walking on EW (19.33 ± 2.30) compared to TW (18.27

± 2.02), $p < .008$ and when pushing a sled (19.51 ± 2.32) compared to TW ($p = .002$). Single leg support time was significantly shorter during EW (40.35 ± 1.15) than TW (40.92 ± 1.03), $p = .004$, and when pushing a sled (40.23 ± 1.17) compared to TW ($p = .001$). Stride length was significantly longer when TW (1.26 ± 0.07)

compared to EW (1.21 ± 0.09), $p = .002$. Lastly, postural sway was significantly greater when pushing a sled (27.72 ± 7.26) compared to EW (16.68 ± 5.01), $p < .001$, and with pushing a sled and TW (15.75 ± 4.50), $p < .001$.

Table 1. Demographic data of all participants

Age (years)	M= 24.38 ± 2.86
Gender	Male= 5 Female = 35
Weight (kg)	68.26 ± 13.92
Height (m)	1.64 ± 0.09
BMI (kg/m ²)	25.30 ± 4.61
Dominant Leg	23 right leg 17 left leg

Table 2. Comparison of temporal variables (cadence, gait speed, and step duration) between three walking conditions. Results of a MANOVA performed comparing tasks. Significance level set at $p \leq 0.01$

Cadence (steps/minutes)	Means and SD	Means and SD	P-Value
	EW: 111.06 ± 8.40	TW: 115.63 ± 6.06 SP: 108.43 ± 7.94	$p < .001^*$ $p = .098$
	TW: 115.63 ± 6.06	SP: 108.43 ± 7.94	$p < .001^*$
Gait Speed (m/s)	Mean and SD	Mean and SD	P value
	EW: 1.12 ± 0.13	TW: 1.21 ± 0.03 SP: 1.11 ± 0.12	$p < .001^*$ $p = .850$
	TW: 1.21 ± 0.03	SP: 1.11 ± 0.12	$p < .001^*$
Step duration (s)	Mean and SD	Mean and SD	P value
	EW: 0.54 ± 0.04	TW: 0.52 ± 0.03 SP: 0.56 ± 0.04	$p < .001^*$ $p = .032$
	TW: 0.52 ± 0.03	SP: 0.56 ± 0.04	$p < .001^*$
^P=P-Value ^S.D.=Standard Deviation ^P-Value>.01 is not significant *P-Value≤.01 is significant SD=Standard Deviation			

Table 3. Comparison of spatial parameters (double limb support time, single limb support, and step length) between three walking conditions. Results of a MANOVA performed comparing tasks. Significance level set at $p \leq 0.01$

Double limb support time (%GCT)	Means and SD	Means and SD	P-value
	EW: 19.33 ± 2.30	TW: 18.27 ± 2.02 SP: 19.51 ± 2.32	$p = .008^*$ $p = 1.00$
	TW: 18.27 ± 2.02	SP: 19.51 ± 2.32	$p = .002^*$
Single Limb Support time (%GCT)	Mean and SD	Mean and SD	P-value
	EW: 40.35 ± 1.15	TW: 40.92 ± 1.03 SP: 40.23 ± 1.17	$p = .004^*$ $p = 1.00$
	TW: 40.92 ± 1.03	SP: 40.23 ± 1.17	$p = .001^*$
Stride length (m)	Mean and SD	Mean and SD	P-value
	EW: 1.21 ± 0.09	TW: 1.26 ± 0.07 SP: 1.22 ± 0.10	$p = .002^*$ $p = 1.00$
	TW: 1.26 ± 0.07	SP: 1.22 ± 0.10	$p = .011$
Postural Sway (m^2/s^4)	Means and SD	Means and SD	P-Value
	EW: 16.68 ± 5.01	TW: 15.75 ± 4.50 SP: 27.72 ± 7.26	$p = .909$ $p < .001^*$
	TW: 15.75 ± 4.50	SP: 27.72 ± 7.26	$p < .001^*$
$\wedge P = P\text{-Value}$ $\wedge S.D. = \text{Standard Deviation}$ $\wedge P\text{-Value} > .01$ is not significant $*P\text{-Value} \leq .01$ is significant SD = Standard Deviation			

4. Discussion

This study examined the differences in spatial and temporal gait parameters when walking on an even surface (EW), treadmill walking (TW), and pushing a weighted sled (SP). The current inquiry postulated the following research question: What are the differences in spatial and temporal gait parameters when EW, TW, and SP? Various adaptations in the temporal and spatial gait variables were identified among the surfaces.

The first outcome that was discovered in this study was the increase in temporal gait parameters when walking on a treadmill (TW) compared to an even surface (EW) and a decrease in temporal variables when pushing a sled (SP) compared to TW. Similar to other studies, the current study found few distinctions when comparing EW to TW and SP [14,17,18]. These differences are mostly related to joint angles and lower limb neuromuscular activation for TW; however, for SP gait, temporospatial and

neuromuscular variables endure more changes according to the literature [12, 14, 18, 19]. Similar to Murray MP *et al.*, (1985), the current research found adaptations such as faster cadence [18]. Additionally, when TW and SP were compared, gait adaptation such as reduced cadence also emerged. Rosario and Mathis (2020) compared EW with SP with the same speed-dependent constant resistant sled [14]. The authors found that similar temporospatial gait adaptations were associated with speed, such as a decrease in cadence with SP compared to EW [14].

In this study, gait speed for TW was adapted by the participant's age, contrary to SP and EW, which was a self-selected speed. This previous report suggests that speed is an important gait component that regulates and explains our findings related to temporal variables. Based on these findings, we suggest modifying the speed to clients' needs. For instance, a participant that requires gait training and postural control such as people with Parkinson disease,

we recommend SP and EW, which will provoke more steps per minute and step durations requiring more muscle recruitment. Nevertheless, based on the previous scenario, reducing the speed on the treadmill should facilitate the same advantages. Future studies should investigate muscle activation during the tasks and speeds presented in this research. Further, prospective endeavors could examine the impact of different speeds and inclinations among the three tasks (EW, TW, and SP).

The second finding of our study was that TW provoked a reduction in double limb support time and increased single-limb support time. These findings suggest that participants required more stability during EW, thus compensating by increasing the DLS and decreasing SLS. Contrary to previous research that supports an increase in double limb support time found in TW our study demonstrates the opposite [18, 20]. We speculate that the characteristics exhibited by DLS and SLS are related to the treadmill gait speed. The faster the treadmill speed, the faster the gait speed, and therefore, a shorter double and greater single-limb support. Single-and double-limb supports are variables related to dynamic balance [21]. A shorter DLS with a greater SLS represents adequate dynamic balance when evaluating gait on an even surface [21]. The opposite direction of these variables is indicative of dynamic balance issues. Rosario *et al.*, (2022) identified few gait variables affected in individuals with controlled diabetes compared with age-and weight-matched non-diabetics [22]. One of these variables was a reduction in SLS time, which the authors pointed out to be of clinical importance as a predictor tool. Therefore, we recommend TW for those subjects with dynamic balance issues such as diabetics and people living with HIV. As previously mentioned, the current study adjusted the treadmill speed to the subjects' ages. The fact that participants adjusted to TW and EW in an inverted trend also suggests that the participants in this study commonly walk at a slower pace, which is unsettling. Usually, as we age, gait speed is a variable that reduces as a compensation mechanism [23]. The knowledge that the participants in this study walked slower in their twenties was alarming. We suggest early identification and measurements of gait in people of all ages, or at least starting in their mid-twenties, including those in their youth that are mostly inactive while in school, like the subjects in this study. Future research should adjust treadmill speed to a self-selected pace similar to EW to better understand the changes in these variables. As a final note, similar to Rosario *et al.*, (2021) study,

prospective inquiries could assess muscle fatigue measured by lactate levels on the aforementioned surfaces [24]. Also, based on Rosario *et al.*, (2022a) and Rosario *et al.*, (2022b) studies, future investigations could add muscle activation components and controlled cadence respectively, to the current gait protocol [25, 26].

5. Conclusion

The objective of this study was to compare and understand the gait implications of diverse walking tasks in young, healthy adults. Temporal and spatial modifications were found when comparing SP and TW to EW. Outcomes suggest that gait speed, regardless of the activity, is an important factor to regulate during gait training activities. This study compared EW with TW, a device that adds a facilitating component to gait with the moving belt in contrast to the SP, which added resistance to gait. Future studies should focus on a methodology similar to that presented in this report; however, regulating by speed and inclination, two factors that modify gait variables distinctively. We recommend utilizing SP when more ground contact is recommended, such as those experiencing balance problems. We also recommend employing TW when the client's clinical scenario requires gait training, while regulating speed, since it is an important factor affecting other gait variables according to the outcomes of this report. Future research should also delve into muscle activation during TW and the impact of inclination on gait variables at diverse speeds.

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Ethics Approval

IRB approval by Texas Woman's University, protocol # A20091.

Consent to participate

All participants gave signed consent for this study.

Authors' contributions

Both authors contributed equally to the study conception and design.

Conflict of interest

The Authors have no conflicts of interest to declare that they are relevant to the content of this article.

Does this article screened for similarity?

Yes

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