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A comparison of variability in spatiotemporal gait parameters between treadmill and overground walking conditions

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ABSTRACT

Motorized treadmills are commonly used in biomechanical and clinical studies of human walking. Whether treadmill walking induces identical motor responses to overground walking, however, is equivocal. The purpose of this study was to examine differences in the spatiotemporal gait parameters of the lower extremities and trunk during treadmill and overground walking using comparison of mean and variability values. Twenty healthy participants (age 23.8 ± 1.2 years) walked for 6 min on a treadmill and overground while wearing APDM 6 Opal inertial monitors. Stride length, stride time, stride velocity, cadence, stance phase percentage, and peak sagittal and frontal plane trunk velocities were measured. Mean values were calculated for each parameter as well as estimates of short- (*SD*1) and long-term variability (*SD*2) using Poincaré analyses. The mean, *SD*1, and *SD*2 values were compared between overground and treadmill walking conditions with paired *t*-tests ($\alpha = 0.05$) and with effect size estimates using Cohen's *d* statistic. Mean values for each of the gait parameters were statistically equivalent between treadmill and overground walking ($p > 0.05$). The *SD*1 and *SD*2 values representing short- and long-term variability were considerably reduced ($p < 0.05$) on the treadmill as compared to overground walking. This demonstrates the importance of consideration of gait variability when using treadmills for research or clinical purposes. Treadmill training may induce invariant gait patterns, posing difficulty in translating locomotor skills gained on a treadmill to overground walking conditions.

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1. Introduction

The use of motorized treadmills is common in both research and clinical settings. Compared with overground walking, the compact nature of a treadmill has advantages of decreased space requirements, ease of observing repeated strides and controllability of walking speed. However, if motor responses differ between treadmill and overground walking, the transferability of training from treadmill to overground walking may be impacted. Several studies comparing gait parameters between treadmill and overground walking have reported equivocal findings [1–6]. Riley et al. [5], for example, reported that spatiotemporal gait parameters such as cadence, stride length, stride time and single and double support time were very similar in treadmill and overground walking and concluded that walking on a treadmill produced no discernable difference in the timing of gait cycle events. In contrast, others have reported that individuals walk with shorter strides and increased cadences on a treadmill [1,4]. While the research regarding spatiotemporal gait parameters is quite extensive—though conflicting—research regarding differences in the variability of these gait parameters during treadmill and overground walking is less readily available. Assessing stride-to-stride variability in spatiotemporal gait parameters, such as in step width, stride time, and swing time, has been shown to potentially be more sensitive to change than measures of gait based on average stride patterns [7].

In the limited studies comparing the variability of spatiotemporal gait parameters in healthy participants for treadmill and overground walking, treadmill walking may be associated with reduced variability in stride time and trunk accelerations [8,9]. However, additional spatiotemporal gait parameters are in need of investigation. In studies examining gait variability,

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classical linear measures of variability (e.g. comparing standard deviations (SDs) and coefficients of variation) are often used [10]. Nonlinear Poincaré analyses may offer a more descriptive method for assessing variability; Poincaré analyses produce plots of consecutive data points that can be used to quantify measures of short- and long-term variability. Poincaré analyses have been used in cardiovascular research to quantify heart rate variability [11] and their application as a measure of gait variability is emerging [12]. No study, to our knowledge, has compared gait variability in overground and treadmill walking via Poincaré analyses.

Several studies comparing rehabilitation outcomes for patients undergoing treadmill training versus overground training have reported differences between the two training modalities [13–16]. For example, Combs-Miller et al. [14] reported that when participants with chronic stroke were matched for task and dose of walking interventions, an overground walking training group demonstrated significantly greater improvements in walking speed, gait symmetry and activity than a treadmill training group. Discrepancies in rehabilitation outcomes occurring with treadmill versus overground training emphasize potential differences in the two walking modalities. Since those discrepancies are present, understanding how treadmill ambulation differs from overground ambulation is important. The purpose of this study was to examine multiple spatiotemporal gait parameters during treadmill and overground walking by comparing traditional mean values of the measurements as well as variability of those same measurements via nonlinear Poincaré analyses. We hypothesized that when individuals ambulate on a treadmill, they would demonstrate comparable mean values but reduced variability when compared with overground walking.

2. Methods

2.1. Participants

Twenty healthy volunteers (9 males, 11 females) participated in this study. A convenience sampling method was used. Participant characteristics are shown in Table 1. For inclusion, participants were required to have previous experience with treadmill walking and be able to complete two consecutive 6 min walks. Individuals reporting any abnormalities (e.g. due to orthopedic injury, lower limb pain, or neurological injury) that may impact gait or balance were excluded from participation. All participants gave written informed consent prior to beginning the trials. The experimental protocol was approved by the local Institutional Review Board.

2.2. Instrumentation

Gait parameters during treadmill and overground walking were measured using the APDM Movement Monitoring inertial sensor system (APDM Inc., Portland, OR). The 22 g sensors include triaxial accelerometers, gyroscopes, and magnetometers. A six sensor configuration was used, consisting of two ankle, two wrist, one sternal, and one waist sensor. Signals were sampled at 1280 Hz with 14 bit resolution, and the data streamed wirelessly to a computer. Data were automatically analyzed with the corresponding Mobility Lab™ software package. The IWalk plugin for Mobility Lab™ was chosen due to its ability to measure gait parameters during the full 6 min of testing.

Table 1
Participant descriptive characteristics.

	Mean	SD	Minimum	Maximum
Age (years)	23.8	1.2	22	27
Body mass (kg)	72.2	15.0	49.9	96.6
Body height (m)	1.74	0.10	1.54	1.90
Overground velocity (m/s)	1.57	0.15	1.24	1.80

SD: standard deviation. Overground velocity was determined by mean of three repetitions of the 10 m walk test.

2.3. Procedure

Subjects were asked to wear comfortable walking shoes and clothes suitable for completing light exercise. Upon arrival, each participant signed an informed consent form. Each participant then self-reported age and height; body weight was measured via a Healthometer scale. The order of the walking trials (i.e. treadmill first or overground first) was randomized. Self-selected walking speed was calculated for each participant using a 10 m walk test (10MWT). For the 10MWT, each participant was instructed to walk at his/her normal, comfortable walking speed across a 14 m walkway. Time taken to complete the middle 10 m of the walkway was recorded via stopwatch. Three trials were completed and times averaged across the trials to calculate self-selected walking speed. During the treadmill trial, the treadmill speed was set at each participant's self-selected walking speed. The treadmill used in this study was a standard motorized treadmill (Quinton Medtrak Cr60).

After determining self-selected walking speed, each participant was fitted with the six inertial sensors. The inertial sensors were reconfigured prior to application for each participant. The sensors were placed thusly: bilateral ankles (lateral to the tendon of the tibialis anterior); low back (L4–L5 region); sternum; bilateral wrists (dorsal surface). The sensors were secured snugly via elastic straps. For both the treadmill and overground trials, participants were given the instructions: "Do not start moving until I say go; once you start, continue walking until I say stop." No encouragement or additional verbal instructions were given during trials. The participant was notified at the halfway point and when 1 min remained during each trial. A 3 min seated rest break was permitted between trials.

For the overground trial, each participant walked along a 42 m path within a hallway in a hospital rehabilitation unit. This path length was determined to be the longest range the inertial sensors could record without substantial lag time. Each participant walked back and forth at a comfortable pace for 6 min.

For the treadmill trial, participants walked on a treadmill set at each subject's preferred walking speed, as determined by the 10MWT. Once the treadmill reached the preferred walking speed, data collection began. At the completion of 6 min, data collection was halted and the researcher stopped the treadmill.

2.4. Data processing

Signal processing and calculation of gait parameters were performed via the automatic analysis algorithms of the Mobility Lab™ system's IWalk plugin. Turns during the overground walking condition were detected with gyroscopes in the trunk and lumbar sensors with a mathematical model described by Salarian et al. [17] and data from gait cycles during turns were filtered out of the analysis. Additionally, since we desired to analyze steady-state ambulation during both overground and treadmill walking conditions, data from gait cycles in which participants decelerated into turning cycles or accelerated from turning cycles were also filtered out of the analysis by identifying measures that departed by three or more standard deviations from mean values during steady state ambulation.

Of the many parameters analyzed in the IWalk plugin, we opted to include seven specific gait parameters for further analysis: stride time and cadence measures were used as markers of temporal

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