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Treadmill walking is not equivalent to overground walking for the study of walking smoothness and rhythmicity in older adults

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ABSTRACT

Treadmills are appealing for gait studies, but some gait mechanics are disrupted during treadmill walking. The purpose of this study was to examine the effects of speed and treadmill walking on walking smoothness and rhythmicity of 40 men and women between the ages of 70-96 years. Gait smoothness was examined during overground (OG) and treadmill (TM) walking by calculating the harmonic ratio from linear accelerations measured at the level of the lumbar spine. Rhythmicity was quantified as the stride time standard deviation. TM walking was performed at two speeds: a speed matching the natural OG walk speed (TM-OG), and a preferred TM speed (PTM). A dual-task OG condition (OG-DT) was evaluated to determine if TM walking posed a similar cognitive challenge. Statistical analysis included a one-way Analysis of Variance with Bonferroni corrected post hoc comparisons and the Wilcoxon signed rank test for non-normally distributed variables. Average PTM speed was slower than OG. Compared to OG, those who could reach the TM-OG speed (74.3% of sample) exhibited improved ML smoothness and rhythmicity, and the slower PTM caused worsened vertical and AP smoothness, but did not affect rhythmicity. PTM disrupted smoothness and rhythmicity differently than the OG-DT condition, likely due to reduced speed. The use of treadmills for gait smoothness and rhythmicity studies in older adults is problematic; some participants will not achieve OG speed during TM walking, walking at the TM-OG speed artificially improves rhythmicity and ML smoothness, and walking at the slower PTM speed worsens vertical and AP gait smoothness.

1. Introduction

Reduced walking smoothness and rhythmicity indicate an increased fall risk among older adults [1–3], making these variables important for quantifying function. The use of treadmills for such studies is appealing, since turning corners while walking disrupts gait smoothness [4] and long, straight walking trials improve the precision of acceleration variables [4,5]. The use of treadmills to study gait function may be appropriate for some variables, since they are equivalent between overground and treadmill walking, including kinematic variability [6] and long term stride interval dynamics [7]. However, walking on a treadmill causes an increased step width [8–10], and energy expenditure [9–13] while disrupting walking coordination [14], kinematics [15–19], and kinetics [13], making these aspects of gait function appear to be *worse* than actual function during overground walking. Additionally, treadmill walking increases cadence [14], stability [6,20] and rhythmicity [20] while reducing variability [6,8,20], which would cause these aspects of gait function to appear to be better on a treadmill than actual function during overground walking [20]. It is unknown how treadmill walking affects gait smoothness and rhythmicity of older adults; it is possible that these variables could be over- or under-estimated on the treadmill for older adults, causing inaccurate functional assessments.

Treadmill-induced changes in walking function may be due to altered optic flow [21], perceived instability [8], a constrained walking speed [6], and intra- and inter-stride variations in the treadmill belt speed [22], which may increase the cognitive load of treadmill walking. A secondary task paradigm is used to study the cognitive challenge of walking, as it appears to disrupt the automaticity of gait [1]. A dual task condition can reveal early mobility difficulties of healthy older adults, such as worse smoothness as indicated by a reduced harmonic ratio [4], but walking speeds slower than the preferred walking speed also reduce the harmonic ratio [23], and slower speeds of walking are common with both treadmill walking [11] and dual-task conditions [4,24]. It is unclear whether treadmill

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walking imposes a cognitive challenge in the same way as dual-tasking.

Though gait smoothness has been evaluated using treadmill walking [25,26], its equivalency with overground walking is unknown. Many seniors cannot match their overground walking speed on a treadmill without using the handrails [19], making a slower preferred treadmill walking speed necessary [11], though slower walking worsens gait smoothness and rhythmicity [23]. To our knowledge, it is unknown if rhythmicity, represented by stride or step time variability [27], is altered for older adults on the treadmill, as it is for young adults [20], and it is unknown whether treadmill walking for older adults adds a cognitive load that disrupts these variables similarly to a divided attention task. Therefore, the purpose of this study was to determine if treadmills can be used to reflect natural overground walking for the study of gait smoothness and rhythmicity in older adults, and if it is disrupted, whether it is similar to the disruption posed by a dual-task condition. We hypothesized that (1) gait smoothness and rhythmicity would be equal during treadmill and overground walking at the same speed, but (2) worsened (lower harmonic ratio, higher stride time variability) when walking at a slower preferred treadmill speed, and (3) the slower preferred treadmill speed would cause equal smoothness and rhythmicity to a condition involving a divided attention task during overground walking.

2. Methods

2.1. Participants

The study was approved by our Institutional Review Board and participants provided written informed consent. Forty men and women (age range: 70–96 years, Table 1) were recruited using the local newspaper and retirement facilities, and were community-dwelling or lived in condominiums or apartments in the retirement communities. One participant was excluded as a high functioning outlier based on scores being more than 2.5 standard deviations (SD) from the group mean. The inclusion criteria were age of at least 70 yrs, ability to walk overground and on a treadmill without an assistive device and while not holding onto the treadmill handrails, repeatedly sit and stand from a chair, and use stairs while free of muscle, bone or joint pain due to medical conditions or medications, able to travel to one of our testing sites, and intact cognitive function (Mini-Mental State Examination score > 23). Participants self-rated their health as good (23.1%), very good (51.3%), or excellent (25.6%), reported taking an average of 2.3 (standard deviation: 2.1) medications for chronic conditions (range: 0–7 medications, median: 2.0 medications), and 12 (30.7%) reported having experienced a fall within the past 12 months.

Table 1
Participant Characteristics (mean (SD) where applicable).

	Full sample ($n = 39$)	Participants who completed TM-OG condition ($n = 29$)	Participants who did not complete TM-OG condition ($n = 10$)
Age	80.6 (6.5)	79.10 (5.89)	84.00 (7.00)*
Sex (% Fem.)	59%	55.2%	70%
Height (m)	1.68 (0.10)	1.69 (0.09)	1.62 (0.21)
Body mass (kg)	72.3 (16.7)	73.32 (16.94)	69.46 (16.73)
BMI (kg/m^2)	25.6 (3.9)	25.67 (4.23)	25.73 (4.10)
Grip Strength (kg)[a]	61.0 (40.73)	69.0 (39.0)	50.5 (19.0)*
TUG (s)[a]	8.72 (2.13)	8.25 (1.83)	10.51 (2.59)*
SPPB (points)[a]	1.04 (0.08)	11.0 (2.0)	9.50 (1.00)*
ABC (%)[a]	96.56 (5.60)	96.88 (2.75)	88.91 (13.75)*
Number of people who fell in the past year	12 (30.8%)	8 (27.6%)	4 (40.0%)
Current regular or occasional TM user	46.2%	48.3%	40%
Regular or occasional TM use in the past	25.6%	27.6%	20%
Little or no prior TM experience	25.6%	24.1%	40%

Different between sub-groups: * $p < 0.05$

[a] median and interquartile range presented for non-normally distributed variables.

2.2. Procedures

Testing was conducted at three locations, a fitness center and two local retirement facilities. Participants completed an interview regarding their fall history within the past year, health history, and activities-specific balance confidence (ABC), followed by a hand grip strength test, the 8-ft Timed Up and Go (TUG) and Short Physical Performance Battery (SPPB) to characterize their physical function. Participants walked overground and on a treadmill during a single testing session. Given that the testing was conducted at different sites, different treadmills were used; each had handrails, were set to 0% incline, and did not include a safety harness, but included safety stop tethers that were attached to the participants while not interfering with natural movement.

Four indoor walking conditions were conducted; two were overground and two were on a treadmill. The overground trials were completed over a distance of 22.9–25.7 m and a walkway width varying from approximately 2 m to the width of a gym, depending on facility constraints. The first overground condition was at a self-selected natural walking speed (OG), and the second involved a dual-task (OG-DT) of counting in reverse by five from a randomly selected integer greater than 100 and divisible by five. Walking speed was calculated by dividing the distance walked by the time it took to cross the distance. In order to be at their comfortable walking speed within the testing distance, participants began walking approximately two meters prior to the start line and kept walking two meters beyond the finish line.

Following the two OG conditions, two one-minute treadmill (TM) walking conditions were conducted following a familiarization period, which involved determining the preferred treadmill speed over about 5 min. Part of the familiarization procedure was to become accustomed to walking without the handrail, given the effect it has on stride interval dynamics [7]. Two speeds were conducted on the treadmill: the average overground speed (TM-OG) and a preferred treadmill walking speed (TM-PWS). In order to experience the OG speed on the treadmill, it was necessary to always conduct overground prior to treadmill conditions. TM-PWS was conducted because self-selected walking speed on the treadmill is slower than OG walking [11], and many older adults are unable or unwilling to complete the TM-OG condition, due to it feeling too fast [19]. Indeed, only 29 of the 39 participants were willing to have the treadmill speed increased to their OG walking speed. TM-PWS was identified by averaging the upper and lower bounds of comfortable walking speed [28] by gradually increasing and decreasing the speed until the upper and lower boundary speeds for comfortable walking on the treadmill were consistently identified as being 'uncomfortably fast' or 'uncomfortably slow,' and there was not a difference of more than 0.2 mph (0.32 km/h) between the repeated trials of the upper or lower boundaries [28]. Participants were blinded to the treadmill speed. TM-PWS was calculated as the average of the mean upper and lower speeds of the comfortable range.

2.3. Instrumentation

Participants were instrumented with a triaxial accelerometer (G-Link® -LXRS® Wireless Accelerometer Node, LORD MicroStrain