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Section I – Kinesiology

Spatiotemporal Parameters are not Substantially Influenced by Load Carriage or Inclination During Treadmill and Overground Walking

by
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Influences of load carriage and inclination on spatiotemporal parameters were examined during treadmill and overground walking. Ten soldiers walked on a treadmill and overground with three load conditions (00 kg, 20 kg, 40 kg) during level, uphill (6% grade) and downhill (-6% grade) inclinations at self-selected speed, which was constant across conditions. Mean values and standard deviations for double support percentage, stride length and a step rate were compared across conditions. Double support percentage increased with load and inclination change from uphill to level walking, with a 0.4% stance greater increase at the 20 kg condition compared to 00 kg. As inclination changed from uphill to downhill, the step rate increased more overground (4.3 ± 3.5 steps/min) than during treadmill walking (1.7 ± 2.3 steps/min). For the 40 kg condition, the standard deviations were larger than the 00 kg condition for both the step rate and double support percentage. There was no change between modes for step rate standard deviation. For overground compared to treadmill walking, standard deviation for stride length and double support percentage increased and decreased, respectively. Changes in the load of up to 40 kg, inclination of 6% grade away from the level (i.e., uphill or downhill) and mode (treadmill and overground) produced small, yet statistically significant changes in spatiotemporal parameters. Variability, as assessed by standard deviation, was not systematically lower during treadmill walking compared to overground walking. Due to the small magnitude of changes, treadmill walking appears to replicate the spatiotemporal parameters of overground walking.

Key words: *gait, uphill, downhill, external load.*

Introduction

Treadmill walking gait analyses are frequently conducted due to their ease of collecting multiple strides of data, minimal space required and ability to finely control speed. The question of whether a treadmill (TM) walking gait replicates an overground (OG) walking gait on a level surface has been extensively studied (Alton et al., 1998; Dingwell et al., 2001; Lee and Hidler, 2008; Riley et al., 2007). From a spatiotemporal perspective, TM walking on a level surface generally simulates OG walking (Lee and Hidler, 2008; Riley et al., 2007). However, variability of spatiotemporal parameters has not been assessed in level walking. Treadmills are advantageous to simulate common outdoor terrain changes in laboratory setting, such as uphill and downhill locomotion; however, these conditions have not been compared between treadmill and overground walking.

Previous research into how spatiotemporal parameters change during uphill and downhill walking compared to level walking was inconclusive. Several overground studies had participants choose a self-selected speed for each

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inclination. Half of these overground studies of inclination reported increased (McIntosh et al., 2006) or decreased (Kawamura et al., 1991) speed with uphill and downhill walking compared to level. Regardless of speed changes, participant cadence increased during downhill walking in both studies. These varied speeds make it difficult to attribute changes found due to inclination instead of the effect of speed. In contrast, other researchers found no change in speed with inclination concurrent with decreased step length in downhill walking (McVay and Redfern, 1994; Redfern and DiPasquale, 1997). With speed held constant across multiple inclinations, one study found no changes in stride length (Lay et al., 2006). In contrast, a treadmill study with speed held constant found increases in step time as inclination increased from level to uphill (Tulchin et al., 2010). Studies examining the influence of inclination have exclusively examined treadmill or overground walking with no comparison across modes at different levels of inclination.

In the workplace it is common for military personnel and first responders to carry loads on both flat and inclined terrain. During level walking, studies indicated that double support increased as load carried increased (Ghori and Luckwill, 1985; Harman et al., 2000; Kinoshita, 1985; Martin and Nelson, 1986). However, these increases were modest, less than 5% of the gait cycle. Additionally, studies have reported mixed results for changes in stride length and cycle time during load carriage (Harman et al., 2000; Kinoshita, 1985; Martin and Nelson, 1986). These studies were conducted on level terrain, and as downhill walking resulted in shorter step lengths, it is possible that double support will increase more during declined walking when subjects carry loads compared to without any load.

No study to date has comprehensively assessed spatiotemporal variables during TM and OG walking at multiple inclinations and large, workplace relevant loads. Therefore, the purpose of this study was to compare spatiotemporal variables for the uphill, level and downhill walking gait between treadmill and overground modes at a constant speed. We hypothesized that there would be no difference in spatiotemporal mean values and a decrease in spatiotemporal variability, as measured by standard deviation, between treadmill and overground modes at any of the inclinations or load conditions. We further hypothesized that there would be differences in spatiotemporal parameters among three levels of inclination with subjects increasing stride length and percentage of double support while decreasing the step rate with uphill walking compared to level and downhill walking. Finally, we hypothesized that as load increased, these changes due to inclination would increase in magnitude.

Material and Methods

Participants

Ten subjects aged 20.6 ± 2.8 years, body height 1.70 ± 0.05 m and mass 72.3 ± 5.9 kg volunteered to participate in this study. Subjects were male soldiers who had completed their initial Army training. Ethical approval was granted by the Institutional Review Board at the United States Army Research Institute of Environmental Medicine. Written informed consent was obtained from all subjects prior to participation. An *a priori* power analysis revealed that for a large effect size of 1.0, using α=0.05 and β=0.80, 10 subjects were necessary to adequately power the study.

Measures

Subject instrumentation included several retro-reflective markers placed on the heel, toe, sternum and bilateral acromia. For the lowest load (00 kg) condition, subjects wore standard military issue physical training uniforms (t-shirt and shorts), combat boots, plus a helmet and carried a simulated M16A1 rifle in both hands. In the 20 kg load, subjects wore clothing and equipment from the 00 kg load condition plus a standard military issue ballistic protective vest and the load carrying vest of a standard military issue backpack. The vests were loaded with soldier equipment (i.e., simulated ammunition, simulated fragmentation grenades, canteen, etc.) to achieve the 20 kg load. For the 40 kg load, subjects wore the 20 kg configuration plus a standard military issue backpack weighted with soldier equipment to reach the total load. For the data collection sessions, OG data were collected on a 12 m grade-adjustable walkway. The TM walking trials were conducted on a split-belt treadmill (AMTI, Watertown, MA, USA) with two belts (107 x 56 cm) in a fore/aft configuration.

Procedures

Subjects completed four separate sessions: one orientation session and then three sessions of OG and TM walking with one inclination (downhill, -6% grade; level, 0% grade or uphill, +6% grade) and three load conditions (00 kg, 20 kg and 40 kg) per session. The grades were chosen to ensure energy expenditure changes were significantly different from level walking while keeping heart rate under 80% of the maximum heart rate (Duggan and Haisman, 1992; Wanta et al., 1993). The loads were chosen to fall within the guidelines defined in Field Manual 21-18 for a fighting load (< 23 kg) and heavier loads carried, such as a sustainment load (Army, 1990). At the orientation session, subject self-selected speed was determined from an average of 10 strides at the 2 min mark during a 3 min bout of OG walking on a level surface. That speed was then utilized in the orientation session for treadmill acclimatisation as well as during the data collections. The testing session order and OG and TM order within a session were counterbalanced across subjects. The order of load conditions was randomized for each session. Each subject completed OG and TM conditions for a given load condition then had 15 min of rest prior to testing the subsequent load condition.

Following subject instrumentation at the testing session, subjects walked for 3 min on the treadmill at the set pace and grade and then 3 min overground walking back and forth on the ramp at the same inclination used in testing. The OG range of speeds was self-selected speed ± 5%, which was monitored by timing gates (IRE and IRD-75, Brower Timing Systems, Salt Lake City, UT, USA). Three trials comprising several strides of marker data were collected at 120 Hz (QTM, Qualisys Medical AB, Gothenburg, Sweden). A successful trial was defined as subjects walking within their self-selected speed range. A minimum of 5 strides total were used for the OG data analysis. The treadmill kinematic data were collected after a 5 min warm-up within the same capture volume as the OG data. Six consecutive strides of TM data from both lower extremities were selected for analysis.

Statistical Analysis

Kinematic data were filtered at 6 Hz in Visual3D (C-motion, Germantown, MD, USA). Heel strike and toe-off were determined as the maximum anterior heel position and the maximum posterior toe position relative to a torso marker, respectively (Zeni et al., 2008). This method was used for consistency between OG and TM trials. Stride length, the step rate, double support time and speed were calculated in Visual3D, with stride length and the step rate averaged across limbs. Double support time was then divided by the stance time and multiplied by 100 to calculate double support percentage. Additionally, the standard deviation (SD) across the trials was calculated for each condition.

Data were tested for normality and sphericity. If data violated sphericity, then a Greenhouse-Geisser correction factor was applied in the analyses. Repeated measures ANOVAs (2x3x3) were used to evaluate differences in the mode (TM, OG) and inclination (uphill, level or downhill) and a load condition (00 kg, 20 kg, 40 kg) for the mean data (SPSS version 21, IBM, Armonk, NY, USA). Additionally, to confirm speed was constant across sessions, another repeated measures ANOVA (2x3x3) was conducted with the same dependent variables for the mode, inclination and the load condition. For the SD analysis, the data were collapsed across inclination to elucidate the influence of the mode and load on the variability of these measures. Repeated measures ANOVAs (2x3) were used to evaluate differences in mode and load condition for the SD data. For statistically significant ANOVA results ($p \le 0.05$), post-hoc t-tests were performed using a Bonferroni correction.

Results

For the step rate, there was an interaction between inclination and the mode (p=.009, Figure 1). As inclination increased from level to uphill, the step rate decreased more during OG walking compared to TM walking (2.7 vs. 0.9 steps/min). Additionally, the step rate increased in the 20 kg load condition compared to the 00 kg (p=.021) and 40 kg (p=.049) load conditions with no difference between 00 kg and 40 kg. The step rate SD increased by 0.4 steps/min in the 40 kg condition compared to the 00 kg condition (p=.041).

For stride length there were significant differences due to the load condition as well as inclination (Figure 2a). As inclination increased from level to uphill, stride length increased by 0.017m (p=.034). Stride length decreased by

0.017m as the load increased from 00kg to 20kg (p=.046). There was a 0.028 m increase in stride length for OG walking compared to TM walking (p=.024). For the SD analysis, stride length SD was 0.01 m higher during OG walking than treadmill walking (Figure 2b, p<.001).

For double support percentage, there was an interaction between inclination and the load (p=.003, Figure 3a). As inclination increased from level to uphill, percentage of time in double support increased more in the 20kg condition compared to the 00 kg condition (1.7% vs 1.3% stance). Overall, as inclination and the load both increased, double support percentage increased. Double support percentage was greater by 0.6% stance during OG walking compared to TM walking (p=.030). Double support percentage SD increased by 1.5% stance during TM walking compared to OG walking (Figure 3b, p<.001) and increased by 0.3% stance from the 20kg to 40kg conditions (p=.017). Speed was within ±2.5% for each comparison and it was not different across modes (p=0.724), loads (p=0.321) or inclination (p=0.691).

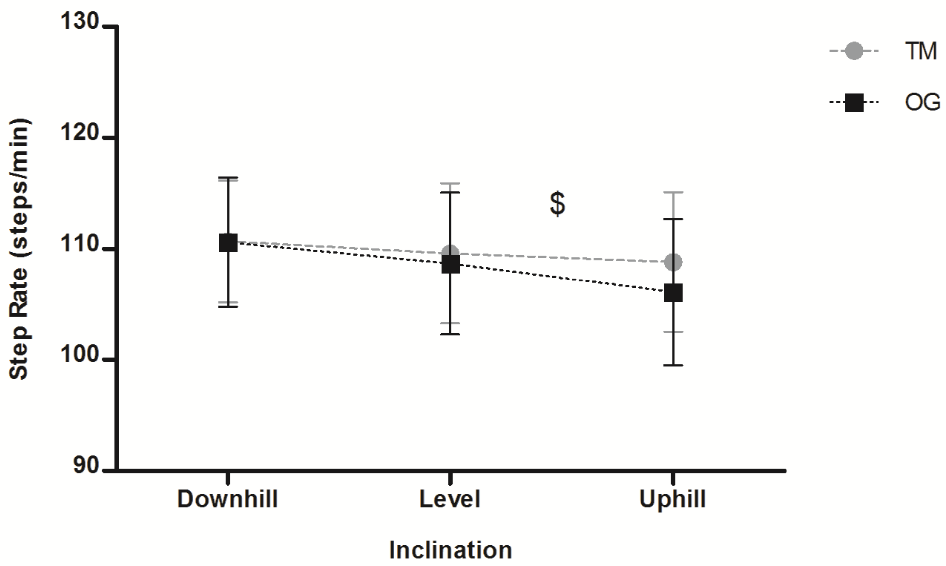

Figure 1
Changes in the Step Rate between Treadmill and Overground Walking
Step rate (mean ± standard deviation (SD)) illustration of interaction between inclination and the mode. Note the small magnitudes between the modes and inclinations. Significant interaction ($), with the step rate decreasing more during overground (OG) walking than treadmill (TM) walking between level and uphill inclinations.

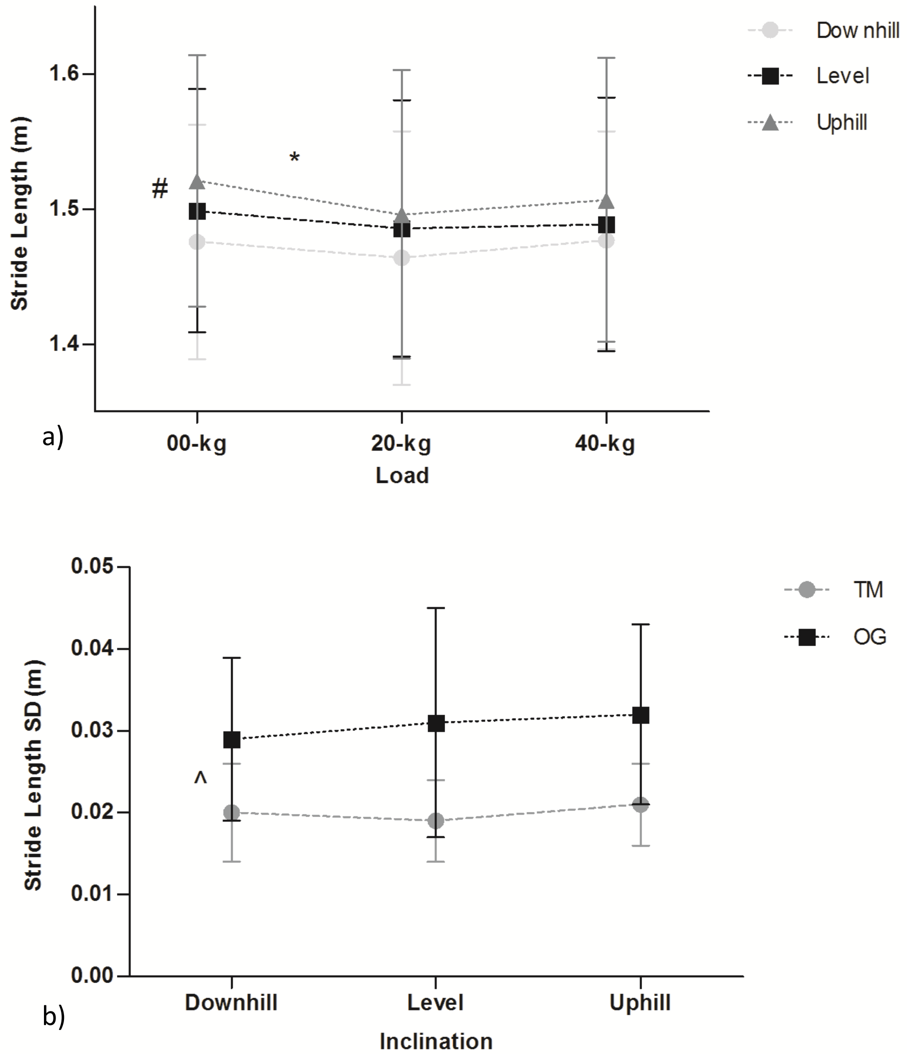

Figure 2

Changes in Stride Length with the Mode, Inclination and Load

a) Stride length (mean ± standard deviation (SD)) illustration of increased stride length as inclination increased from level to uphill (#) and decreased stride length as load increased from 00 kg to 20 kg (*).

b) Stride length SD (mean ± SD) illustration larger SD (^) during overground (OG) walking than treadmill (TM) walking.

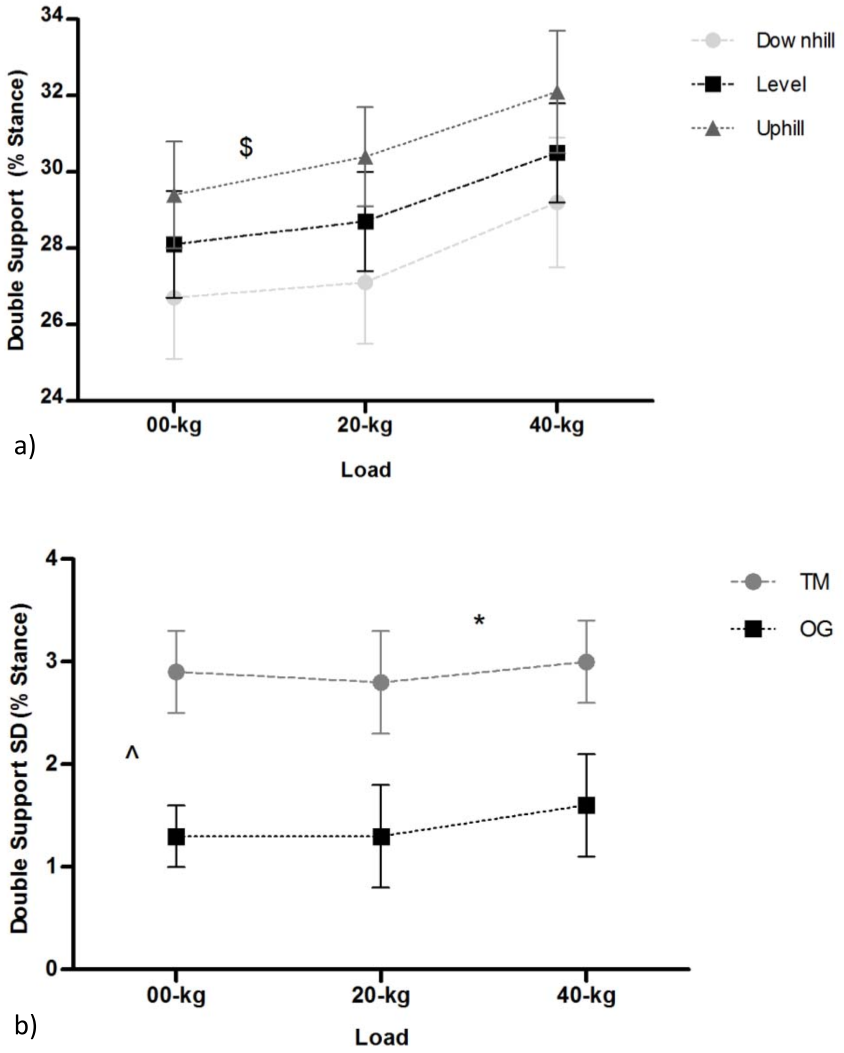

Figure 3
Changes in Double Support Percentage with the Mode, Inclination and Load
a) Double support percentage (mean ± standard deviation (SD)) illustration of interaction between inclination and the load. Significant interaction ($) of double support percentage increasing more during the 20 kg load condition than the 00 kg load condition between level and uphill inclinations. b) Double support percentage SD (mean ± SD), which indicates higher SD for treadmill (TM) than overground (OG) walking (^) and for the 40 kg condition compared to the 20 kg condition (*).

Discussion

The purpose of this study was to examine effects of the mode (TM, OG), inclination (uphill, flat, downhill) and a load condition (00 kg, 20 kg, 40kg) on spatiotemporal parameters during walking. Our statistical results indicated that the mode, inclination and/or the load condition influenced steps per min, double support percentage and stride length mean values and SD. However, these mean differences were all small, with the largest differences approximately 2% of the gait cycle, which likely do not have clinical meaning. Therefore, these combined results supported our first hypothesis of no difference between modes. Our second and third hypotheses of differences with inclination and the load were not supported. Overall, the results of this study indicated that while there were consistent, small differences due to the mode, inclination and the load, these spatiotemporal differences likely were not clinically meaningful. For our SD analysis, we hypothesized there would be no difference for inclination or the mode. We found no change larger than 1% of the gait cycle, which indicates there are small changes in SD between TM and OG and with an added load that likely are not clinically meaningful.

The gait parameters from this study were similar to those previously reported. Subjects walked at 1.36 m/s, which was similar to the 1.4 m/s reported by Riley and colleagues (Riley et al., 2007). The stride length results for this study during level walking were similar to those reported in the literature, 1.4-1.6m (Lay et al., 2006; McIntosh et al., 2006; Riley et al., 2007). The subjects' average step rate, 109 steps/min, was within the range of Army prescribed step rates of 106-120 steps per min (Army, 1986; Army, 1990) which was expected as all subjects were soldiers.

Although the differences detected by this study were likely not clinically meaningful due to their small magnitude, these small differences were similar to some previous research on inclination. The stride length change from level to uphill TM walking was approximately 0.01 m (Leroux et al., 2002) compared to the 0.017 m for both TM and OG walking reported in this study. As these differences were small, it was not surprising that previous research into the influence of inclination on the walking gait had yielded conflicting results.

The load configurations may have influenced these results due to changes in the system (subject plus equipment worn) centre of mass. With the 20 kg load, the majority of the load was placed on the front of the subject, which moved the system centre of mass anteriorly. With the addition of the 20 kg backpack to achieve the 40 kg load, the system centre of mass likely shifted back to a neutral position similar to where it was during the 00 kg condition. It was possible that the small differences in stride length between the 00kg and 20kg load conditions and lack of changes between 00 kg and 40 kg load conditions were due to the centre of mass location instead of load magnitude. Despite utilizing a backpack load only, two studies with large occupational loads, > 20 kg (Ghori and Luckwill, 1985; Harman et al., 2000) found small increases (<5%) in percentage of double support as the load increased, which were similar to the current findings concerning double support percentage. Occupational load distribution may be a factor influencing mechanics instead of only load magnitude. Furthermore, how these spatiotemporal changes cause alterations in injury risk and metabolic measures currently is unknown.

We hypothesized that the TM data would yield lower average variability, or standard deviation, than the OG data. Surprisingly, the SD results did not indicate a consistent lower SD during treadmill walking. The results demonstrated that variability between modes during OG was significantly lower in some instances (Figure 3b) and significantly higher in others (Figure 2b). These inconsistent results indicated that TM walking did not systematically influence the SD of spatiotemporal parameters compared to overground walking. Additionally, these differences in variability were extremely small.

The small sample size is one limitation of this study as we were not statistically powered to find less than a large effect (1.0). However, the sample size was large enough to detect small magnitude changes.

Changes in the load of up to 40 kg, inclination of 6 percent grade away from level (i.e., uphill or downhill) and the mode (treadmill and overground) produced small, yet statistically significant changes in spatiotemporal parameters. Due to the small magnitude of changes, treadmill walking appears to closely replicate the spatiotemporal parameters of overground walking. Variability, as assessed by standard deviations, was not systematically lower during treadmill walking compared to overground walking.

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