

DIFFERENCES IN FRONTAL PLANE STABILITY DURING TREADMILL AND OVERGROUND WALKING

Noah J. Rosenblatt and Mark D. Grabiner

Clinical Biomechanics Laboratory, University of Illinois at Chicago
email: nrosenbl@uic.edu, web: www.uic.edu/ahs/biomechanics

INTRODUCTION

Given the consequences of falling to the side by older adults, attention has focused on identifying gait-related variables associated with increased lateral stability and decreased fall risk. Step-width (SW) and step-width variability (SWV) have traditionally been associated with frontal plane stability [1, 2]. Recently the “margin of stability” (MOS) has also been adopted for this purpose [3]. Since its calculation includes both center of mass (COM) position and velocity relative to the foot it may better describe stability during locomotion.

Frontal plane stability may be influenced by the conditions during which gait occurs. In contrast to sagittal plane variables that vary little between treadmill and overground walking [4], Stolze et al. [5] showed a significant difference in SW between the two conditions. To the best of our knowledge the work by Stolze et al is the only within-subject study to describe SW during treadmill and overground walking. However, SWV and MOS were not considered.

The purpose of this study was to determine the extent to which overground and treadmill walking differ in regard to frontal plane stability of healthy, young subjects. We hypothesized that SW would increase during treadmill walking. We also tested the null that SWV would not differ between conditions. Lastly, we hypothesized that MOS would increase, in parallel, with SW, during treadmill walking.

METHODS

Ten healthy young subjects (age 24.4 ± 4.5 yr) participated. Subjects walked at a comfortable, self-selected speed, both overground and on a treadmill (Marquette Electronics, Marquette, WI). Treadmill walking lasted for 10 consecutive minutes. For each of 30 overground walking trials, subjects walked 8 m across the lab floor, while a

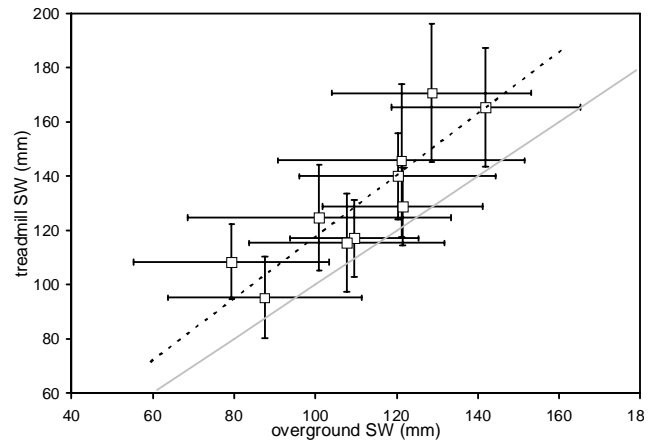


Figure 1: Overground SW significantly correlates with treadmill SW. Subject data points fell to the left of the line of unity (grey), suggesting subjects consistently walked with greater SW on the treadmill. Error bars represent SWV, which is significantly larger during overground walking. The best fit line (dotted black) has a slope of 1.13 and $R^2=0.79$

Polaris electronic wireless timer (FarmTek Inc, Wylie, TX) recorded walking speed, the values of which were averaged across all trials.

SW, SWV and MOS were computed from the motions of 23 passively reflective markers placed over specific body landmarks, and tracked using an eight camera motion capture system operating at 60 Hz (Motion Analysis, Santa Rosa, CA). SW was determined as the distance between the centroid of each foot segment at successive mid-stances. For each subject, SW was separately averaged over all left and right step. The standard deviations were used to represent SWV. MOS was measured as the distance between the extrapolated center of mass (XCOM) and the lateral border of the base of support (BOS_{lat}): $MOS = BOS_{lat} - XCOM$, where $XCOM = COM + \dot{COM} / \omega_0$, \dot{COM} is the velocity of the COM, ω_0 is the natural frequency of a pendulum with length 1.34 times trochanteric height [3], and BOS_{lat} is approximated from the position of markers over the metatarsal and heels. MOS was calculated from heel strike to contralateral toe-off. The

minimum value of MOS is reported (MOS_{min}). The more positive MOS_{min} the more stable the gait.

Walking speeds for the conditions were compared using a paired t-test. If a significant correlation existed between SW, SWV or MOS_{min} , and walking speed for both conditions then walking speed would be used as a covariate in the between-condition analyses. Between-condition analyses were performed using 2 (left vs. right limb) by 2 (overground vs. treadmill) repeated measures analyses of variance (ANOVA) for SW, SWV and MOS_{min} . For each main effect, a Pearson correlation was determined between the subject-specific values of the variable for the two cases. Analyses were performed using SPSS software (SPSS, Inc, Chicago, IL) with significance given for $p < 0.05$.

RESULTS AND DISCUSSION

Walking speed was significantly larger for overground compared to treadmill walking (1.41 ± 0.16 m/s vs. 1.09 ± 0.17 m/s, $p < 0.01$), and the correlation between the two values was significant ($r = 0.69$, $p = 0.028$). However the correlations between walking speed and SW, SWV or MOS_{min} were not significant. As a result walking speed was excluded from subsequent analyses.

Across all steps, SW during treadmill walking was ~15% larger than that during overground walking (131.2 ± 24.3 mm vs. 111.8 ± 18.9 mm, $p = 0.001$). The correlation between treadmill and overground SW was significant ($p = 0.001$, $r = 0.884$; Figure 1). Between limb differences were not significant.

Across all steps, SWV during treadmill walking was about ~23% smaller than that of overground walking (24.2 ± 4.7 mm vs. 18.7 ± 5.1 mm, $p = 0.001$; Figure 1). However the correlation between SWV during the two conditions was not significant. Between-limb differences were also not significant.

MOS_{min} was invariant between overground and treadmill walking (66.3 ± 8.9 mm and 62.9 ± 10.0 mm, respectively), but significantly correlated ($p < 0.002$, $r = 0.90$; Figure 2). Between-limb differences were not significant, although they were quite obvious for two of the subjects (Figure 2).

The constant MOS_{min} during conditions in which

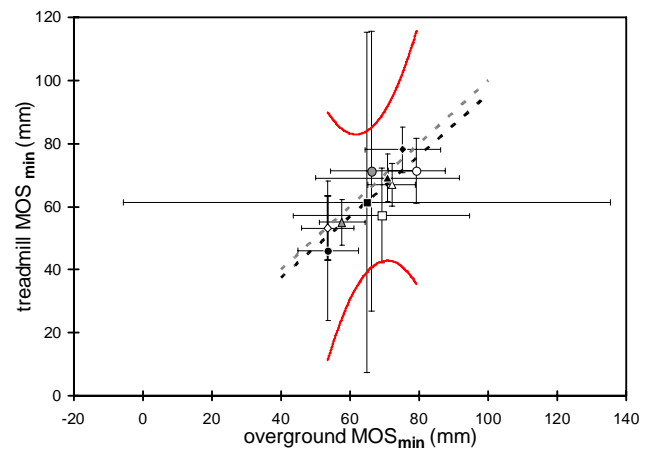


Figure 2: MOS_{min} is not affected during treadmill and overground walking. The best fitting straight line (dotted grey) to the data (subject means \pm SD) has a slope of 0.96, $R^2 = 0.738$, and a line of unity (dotted black) falls within the 95% confidence interval for the best fit line (red curved lines). Although on average there is little between-limb difference in MOS_{min} one subject had an approximately eight-fold between-limb difference for both conditions, resulting in large SD when the limbs were pooled together.

SW varied significantly suggests that during unperturbed overground walking, foot placement is chosen with the goal of attaining a desired value [3]. Alternatively, given the consequences of stepping off a raised, moving treadmill belt, it is possible that subjects voluntarily increase SW to potentially increase lateral stability. However, paradoxically, a larger SW is associated with increased trunk acceleration. The net result therefore can be an invariant MOS_{min} . In either case, the decreased SWV during treadmill walking reflects increased precision of foot control.

CONCLUSION

Kinematic parameters associated with frontal plane stability, particularly SW and SWV are significantly different, but meaningfully correlated, during treadmill and overground walking. However, MOS_{min} was insensitive to whether walking was on the treadmill or overground. Thus measures of SW and SWV only partially reflect frontal plane dynamic stability. The larger, more precise SW during treadmill walking may reflect an end goal of the central nervous system, to maintain a constant average MOS_{min} , regardless of the walking tasks.

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