

THE EFFECT OF BODY WEIGHT SUPPORT ON THE ANKLE-FOOT ROLL-OVER SHAPE

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INTRODUCTION

Body weight supported treadmill training (BSWTT) has emerged in the past two decades as method of gait rehabilitation for neurological injuries such as incomplete spinal cord injury and stroke. During this therapy, patients placed over a treadmill have a portion of their body weight supported with a harness, and trained therapists provide manual assistance as necessary to promote upright posture and lower-extremity trajectories associated with normal gait [1]. Despite its prevalence, much is still unknown about the effects on gait of key BWSTT parameters, such as the percentage of body weight support (BWS).

Successful rehabilitation depends on accurately replicating the forces and motions present during normal locomotion. A single measure that expresses the relationship between these terms is the ankle-foot (AF) roll-over shape, defined as the circular arc formed when the center of pressure (COP) is transformed into a shank-based coordinate system [2]. This shape is suggested to be clinically invariant under a variety of walking conditions [e.g., 2,3]. Thus, changes in the AF roll-over shape with BWS may indicate that the relationship between the forces and motions associated with normal walking is altered during BWSTT. This study seeks to determine the effect of BWS on the radius of the AF roll-over shape and the anterior and superior locations of its center.

METHODS

Nine neurologically unaffected subjects, 5 male and 4 female, participated in this study. The means and standard deviations of their heights and ages were 1.73 ± 0.09 m and 23.11 ± 2.47 years, respectively. Informed consent was obtained.

At the beginning of the study, the subjects walked overground at a comfortable speed, which became their self-selected speed for the duration of the

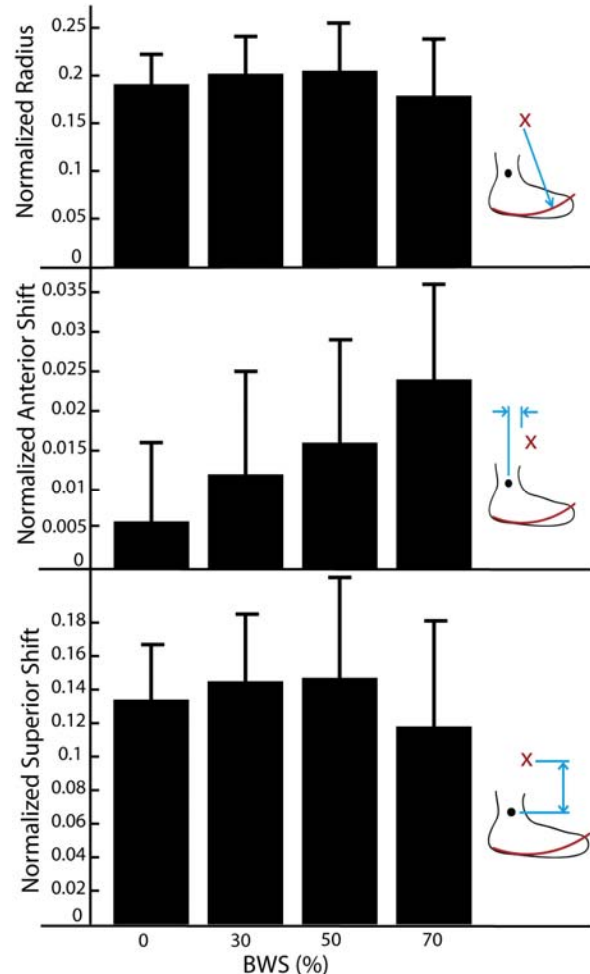


Figure 1: Mean roll-over shape parameters with increasing BWS. Each parameter, (a) radius, (b) anterior shift, and (c) superior shift, is normalized by subject height. The error bars represent one standard deviation.

trials. Four reflective markers were then placed on their left lateral malleolus, calcaneus, 5th metatarsal, and lateral epicondyle. Subjects walked on a split-belt instrumented treadmill (Bertec Corp., Columbus, OH) at their self-selected speed with four levels of BWS (0%, 30%, 50%, and 70%). Conditions were randomized for each subject. Ground reaction forces were collected at 200 Hz. A medical harness and a closed-loop pneumatic force control system (Vigor Equipment, Stevensville, MI;

Tescom, Elk River, MN) provided BWS. Kinematic gait data were collected using a seven camera VICON motion analysis system (Vicon Mx cameras, Vicon, Inc.). Data collection continued for approximately 20 seconds at each level of BWS to allow the gait to reach steady state. We analyzed nine consecutive steady-state gait cycles per condition for each subject.

We calculated the AF roll-over shapes by fitting a circle to the COP data after transforming it into a shank-based coordinate system [2]. The radius of this circle and the anterior and superior locations of its center were normalized by subject height (H). We investigated the effect of BWS on these normalized quantities using a repeated measures analysis of variance (ANOVA) and performed post-hoc tests using the Bonferoni correction factor.

RESULTS AND DISCUSSION

The radius, anterior location, and superior location of the AF roll-over shape were influenced by BWS ($p < 0.001$) (Figure 1). Post-hoc tests indicated that the anterior shift changed significantly between all BWS values and that all parameters changed significantly between 30% and 70% BWS (Table 1). Additionally, the variability in the radius and the superior shift increased with increasing BWS. Further investigation of individual subject responses to changes in BWS showed that different subjects employed different strategies to compensate for increased BWS, which may explain the observed increase in parameter variability.

The roll-over shape center shifts anteriorly with increased BWS at each level. Previous modeling results of asymmetrical gaits for transtibial

prosthesis users illustrated that an anterior shift of the prosthesis alignment results in reduced joint torque and larger stride lengths [4]. Similarly, with increasing amounts BWS, our subjects may have shifted their weight anteriorly and adjusted their torques and stride length. The mechanisms resulting in this anterior shift are a topic of future study.

Hansen et al. suggested that an anterior shift of the roll-over shape center of less than $0.005H$ was not meaningful in a clinical setting [2]. However, our data demonstrate changes in all three parameters between $0.01H$ and $0.03H$. These changes may be clinically meaningful, but further work is necessary to determine the threshold beyond which changes in the roll-over shape are clinically relevant.

CONCLUSIONS

This study investigates the effects of increasing BWS on the AF roll-over shape as a means to measure how well normal walking forces and motions are replicated in BWSTT. In contrast to previous work that identified it as an invariant of normal walking, our findings indicate that the AF roll-over shape radius and center location change with increased BWS in neurologically unaffected subjects. The true clinical utility of this result can only be determined through comparison with the AF roll-over shapes of neurologically impaired subjects obtained under similar training conditions.

REFERENCES

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Table 1: Change in mean roll-over parameters normalized by height for a given pair of BWS values. For instance, (0,30) is the change in means between 0% and 30% BWS. A “*” indicates statistical significance, which, due to multiple comparisons, occurs with $p < 0.008$.

| BWS | Radius/Height | | Anterior Shift/Height | | Superior Shift/Height | |
|-------|---------------|----------|-----------------------|----------|-----------------------|----------|
| | Change | p-value | Change | p-value | Change | p-value |
| 0,30 | -0.011 | 0.044 | -0.006 | <0.001 * | -0.011 | 0.056 |
| 0,50 | -0.014 | 0.041 | -0.010 | <0.001 * | -0.012 | 0.079 |
| 0,70 | 0.012 | 0.099 | -0.017 | <0.001 * | 0.017 | 0.029 |
| 30,50 | -0.003 | 0.652 | -0.004 | 0.001 * | -0.001 | 0.826 |
| 30,70 | 0.023 | 0.001 * | -0.012 | <0.001 * | 0.027 | <0.001 * |
| 50,70 | 0.026 | <0.001 * | -0.008 | <0.001 * | 0.029 | <0.001 * |