

Effective Rocker Shapes for Walking, Swaying, and Standing

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INTRODUCTION

The roll-over shape (ROS), which is the effective rocker that the ankle-foot system conforms to from heel contact to opposite heel contact in walking, may be a useful tool for design and evaluation of lower limb prostheses. During many activities of daily living, however, standing and swaying are also important. Walking ROSs have been found to be nearly circular in shape and unchanged with variations in walking speed, added weight to the torso, and shoe heel height [1-3]. However, it is unclear what the effective rocker shapes are for able-bodied persons during gentle swaying or quiet standing. We hypothesized that the effective shapes of swaying and standing would be flatter than walking ROSs, providing an inherently stable base.

METHODS

Ten able-bodied subjects were asked to walk at their freely self-selected speed, sway gently, and stand quietly. During swaying, the subjects were asked to perform low amplitude, low frequency sways, trying not to lift their heels or toes off the ground. All subjects wore Converse canvas sneakers provided by the lab because this shoe has a flat sole and does not restrict ankle motion.

Data were collected at the VA Chicago Motion Analysis Research Lab, equipped with six force plates and an eight-camera motion analysis system. A modified Helen Hayes marker system [4] was used to monitor joint kinematics. We also measured ground reaction forces (GRF) as they walked, swayed, and stood on the force plates. Commercial software, EVA Realtime and Orthotrak, was used to yield ankle kinematics and joint center coordinates.

A custom Matlab script was used to transform the center of pressure (COP) of the GRF under the shoe from a lab-based to a shank-based coordinate system, yielding the effective rocker shape [5]. Walking and swaying shapes were fit with second order polynomials:

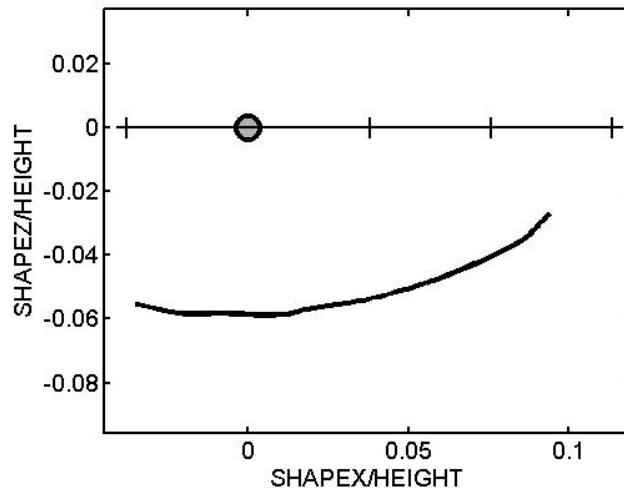


Figure 1: Walking roll-over shape (normalized by height) of a subject's right foot. The curve can be fitted to a circle and the mean \pm SD radius for all the subjects was $16.1 \pm 2.5\%$ of height or $30.4 \pm 4.6\%$ of leg length. The arc length was $13.2 \pm 1.0\%$ of height or $86.7 \pm 6.8\%$ of foot length (FL). The horizontal line is a FL and the ankle center (0,0) is at $\sim 25\%$ FL.

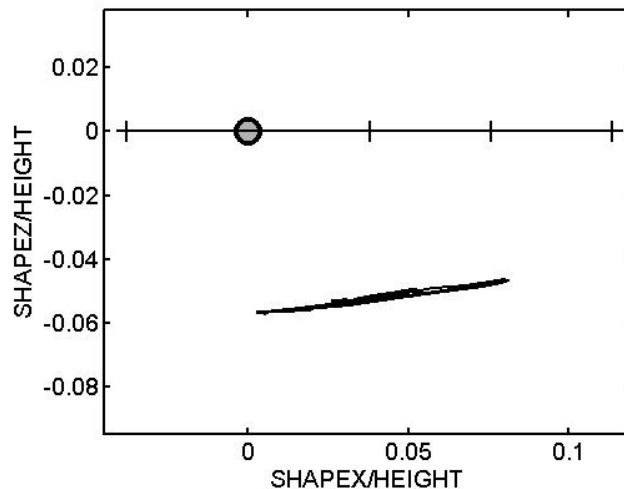


Figure 2: Swaying effective shape (normalized by height) of a subject's right foot. The curve is flat with a length of $7.2 \pm 1.3\%$ of height or $47.2 \pm 8.4\%$ of foot length (FL). The horizontal line is a FL and the ankle center (0,0) is at $\sim 25\%$ FL.

$$Z = a_2 X^2 + a_1 X + a_0 \quad (1)$$

where X and Z were the anterior and proximal components, respectively, of the effective rocker shapes. The hypothesis was that the a_2 coefficient would be reduced for swaying effective shapes compared with walking shapes, indicating a reduction in curvature. A one-tailed paired T-test was performed in SPSS to test this hypothesis. The arc length of the walking shape was calculated from its best-fit circle, using $L = \text{radius} * \text{central angle}$. The lengths of the flat shapes were calculated using $L = [(x_1-x_2)^2+(y_1-y_2)^2]^{1/2}$, where (x_1,y_1) and (x_2,y_2) are the coordinates of the ends of the shapes.

RESULTS AND DISCUSSION

The results shown are data collected from one subject, representative of the entire pool. Visual inspection shows that the walking ROS was circular and that the effective rocker shapes of swaying and standing were flatter, as hypothesized (Figures 1-3). The mean a_2 coefficient of all the subjects (Table 1), which is proportional to curvature, for the swaying shapes is significantly lower than those for walking ($p < 0.001$). The mean arc length (Table 1) indicate that the subjects utilized almost 87% of their foot length while walking, but kept their COP around the middle 50% of their feet while swaying and around the middle 5% while standing. Swaying keeps the COP within reported functional stability limits [6]. The standing COP is near the center of the functional stability limits and likely chosen to react to unexpected forward or backward perturbations.

Understanding standing and walking patterns of able-bodied gait can be important for prosthetic and orthotic designs. For example, the “flat” region in some prosthetic feet may be useful for prosthesis users with poor balance. The length of the “flat” region may determine the appropriate compromise between stability and mobility for each user. These results may also be applicable to walking

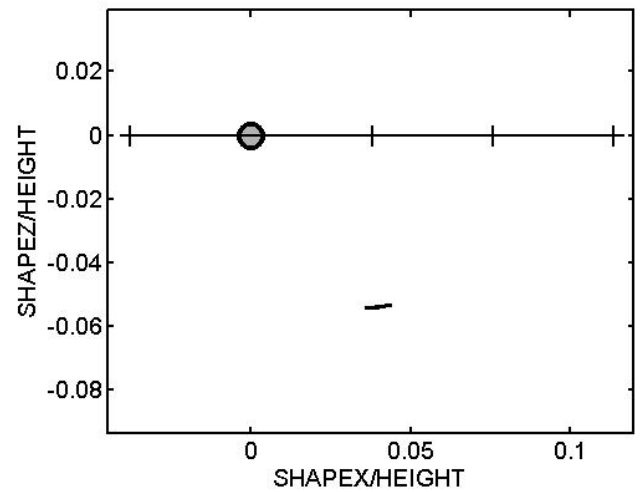


Figure 3: Standing effective shape (normalized by height) of a subject’s right foot. The curve is flat with a length of $0.7 \pm 0.3\%$ of height or $4.9 \pm 1.9\%$ of foot length (FL). The horizontal line is a FL and the ankle center (0,0) is at $\sim 25\%$ FL.

casts/boots and rockers for total contact casts. Additionally, the development of bi-modal ankle-foot prostheses that provide a curved effective shape during walking and a flat effective shape during standing may be warranted.

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Table 1: Characteristics of the three effective rocker shapes. The arc lengths show that the subjects used most of their feet during walking, about half during swaying, and only about 5% while standing. The a_2 coefficients show that swaying shapes were significantly flatter than walking shapes ($p < 0.001$).

Measurement	Walking	Swaying	Standing
Arc Length	$13.2 \pm 1.0\%$ H $86.7 \pm 6.8\%$ FL	$7.2 \pm 1.3\%$ H $47.2 \pm 8.4\%$ FL	$0.7 \pm 0.3\%$ H $4.9 \pm 1.9\%$ FL
a_2 Coefficient	3.53 ± 0.44	0.43 ± 0.31	N/A

Note: All values displayed are mean \pm SD of all ten subjects. H = height, FL = foot length.