INTRODUCTION
Able-bodied humans have been shown to walk with lower limb effective rocker shapes that are nearly circular and that stay consistent for different walking speeds (Hansen et al., 2004), when carrying different amounts of added weight (Hansen and Childress, 2005), for shoes of different heel heights (Hansen and Childress, 2004), and for rocker shoes of different radii (Wang and Hansen, in press). However, it is unclear whether these effective rocker shapes remain consistent for other functional tasks such as standing and swaying. Understanding biomimetic rockers for various functional tasks could improve design and assist in prescription of lower limb orthoses and prostheses.

METHOD
Subjects: Eleven young able-bodied subjects were involved in the study (age = 28±4 years; height = 176±10cm; and mass = 71±14kg).

Apparatus: A modified Helen Hayes marker set was used to construct a link segment model of the body. Markers were tracked with an 8-camera motion analysis system and the center of pressure (CoP) of the ground reaction force was determined using force platforms.

Procedures: Subjects walked at a freely selected pace, stood quietly, and performed fore-aft swaying. All participants wore flexible canvas high top shoes during the experiments.

Data Analysis: Effective shapes were found by transforming CoP data from a laboratory-based coordinate system to a coordinate system based on the lower leg (shank) (Hansen and Wang, 2010). CoP data in the shank reference frame provide a measurement of the effective rocker that the ankle-foot system conformed to during the task. A simple model (Figure 1) was used to determine the stiffness levels required of a prosthetic ankle to mimic the results from able-bodied persons.

RESULTS
Effective shapes for walking were circular and consistent with earlier measurements (mean radius = 0.33 times the leg length). Effective shapes for fore-aft swaying were significantly flatter (p = 0.003), with a mean radius of about 2.2 times the leg length. Although loading (W) during fore-aft swaying was assumed to be half of that during walking in the model, the stiffness required of a prosthetic ankle to mimic the able-bodied effective rockers was still over 3 times higher for fore-aft swaying than for walking. The effective shape for quiet standing was short and resided at the intersection of walking and fore-aft swaying shapes (Figure 2).

DISCUSSION & CONCLUSIONS
The results suggest that the complex lower limb systems of able-bodied persons act to create a circular rocker for walking and a flatter shape for standing and swaying. Both shapes could be mimicked with simple mechanisms, but modeling suggests that a bi-modal system (i.e. a system with two separate mechanical states) would be required to mimic the effective shapes used for walking and swaying. Work is ongoing to test the effectiveness of systems that offer various compromises between the optimal walking and swaying shapes. Future work will also focus on design and testing of bi-modal systems that will provide biomimetic behavior for walking and swaying (patent pending).

REFERENCES

Figure 1 – Drawing showing variables used in a model to determine the stiffness levels required of a prosthesis to obtain biomimetic rocker shapes for walking and swaying.

Figure 2 – Effective rocker shapes for walking (light gray), fore-aft swaying (dark gray), and quiet standing (black) for a representative subject.

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