Transfemoral Socket Project Summary and Figures

This report outlines some of the results from the Transfemoral Socket Project pilot study. The Transfemoral Socket Project has two goals:

(1) Examine the biomechanics and symmetry of people with unilateral, transfemoral amputations walking with two different prosthetic sockets across a range of slopes and speeds.

(2) Compare the socket pistoning during walking with two different prosthetic sockets across a range of slopes and speeds.

Methods

Three subjects with unilateral, transfemoral amputations walked on a split-belt treadmill using a suction prosthetic socket and an adjustable socket (Quatro socket, Quorum Prosthetics, Windsor, CO). Subjects first walked on a level treadmill at 0.75, 1.00, 1.25, and 1.50 m/s. Then, subjects walked at 1.25 m/s (one subject walked at 1.00 m/s) on the treadmill at +3, -3, +6, and -6 degrees. Motion capture cameras tracked markers placed on the feet, shanks, thighs, and pelvis. Force plates embedded into the treadmill measured ground reaction forces during walking at 1000 Hz. A magnet was taped onto the liner inside of the socket and another magnet was

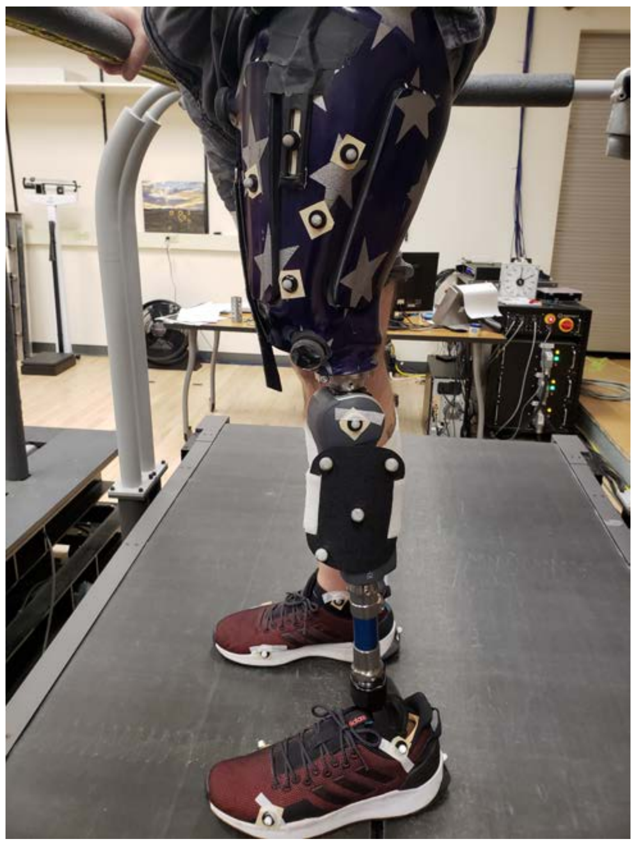


Figure 1. Lower-body marker set and socket pistoning sensor setup. A magnet was attached to the leg inside of the socket. Another magnet outside of the socket followed the magnet on the inside. Its motion was tracked using a marker on top of the magnet and from a touch potentiometer in order to estimate socket pistoning.

placed on the outside of the socket. To estimate socket pistoning, a marker was attached to the outside magnet and tracked as the outside magnet followed the inside magnet. Moreover, a touch potentiometer was taped between the outside marker and the socket in order to measure socket pistoning (**Figure 1**).

We calculated stance average vertical ground reaction force, first and second peak vertical ground reaction force, peak propulsive and braking fore-aft ground reaction force, and contact time during each trial. In addition, we calculated the symmetry index between the unaffected leg (UL) and affected leg (AL) for each of the parameters.

$$\mathrm{SI} = \left|\frac{X_{UL} - X_{AL}}{\frac{1}{2}(X_{UL} + X_{AL})}\right| \; x \; 100\% \qquad (1)$$

0% refers to perfect symmetry between the legs.

We calculated the individual leg work, defined as the positive and negative external mechanical work performed by each limb to redirect the body's center of mass, during the step-to-step transition. The step-to-step transition is the period when both legs are on the ground and refers to the transition from the unaffected leg to the affected leg or the affected leg to the unaffected leg.

Results

During walking across all speeds and slopes, subjects had two peaks in vertical ground reaction forces each stance phase (**Figure 2**). Additionally, during stance they had a negative peak followed by a positive peak in fore-aft vertical ground reaction corresponding to braking and propulsion, respectively (**Figure 2**).

Vertical Ground Reaction Forces

There was an increasing trend in stance average vertical ground reaction forces with increasing speed; however, there was not an obvious trend in stance average vertical ground reaction forces with changing slopes (**Figure 3**). For all of the configurations, the stance average vertical ground reaction forces of the affected leg were lower than the unaffected leg (**Figure 3**). Moreover, stance average vertical ground reaction forces in the unaffected leg were lower when the subjects walked with the Quatro socket compared to the suction socket (**Figure** 3). Subjects walked with more symmetric (lower symmetry index) stance average vertical ground reaction forces when wearing the Quatro socket (**Figure 3**). First peak vertical ground reaction forces generally increased with increasing speed (**Figure 4**). There did not seem to be an obvious trend in the first peak vertical ground reaction force between sockets or legs for the different configurations (**Figure 4**). There also were not any obvious trends in first peak symmetry index across speeds, but across slopes subjects had more symmetric first peak vertical ground reaction forces when wearing the Quatro socket (**Figure 4**). There was not an obvious trend in the second peak of the vertical ground reaction forces across speeds, but there was a general increasing trend of second peak vertical ground reaction forces with increasing slopes (**Figure 5**). Across the different slopes, the second peak vertical ground reaction forces were greater for the unaffected leg compared to the affected leg (**Figure 5**). Moreover, across the different slopes, second peak vertical ground reaction forces in the unaffected leg were lower when subjects wore the Quatro socket (**Figure 5**). Except for when walking on a level treadmill at 0.75 m/s, subjects had more symmetric second peak vertical ground reaction forces when they walked with the Quatro socket for all slopes and speeds (**Figure 5**).

Fore-aft Ground Reaction Forces

Peak propulsive ground reaction forces increased with increasing speed and increasing slope from level (increasing absolute value of angle) (**Figure 6**). For all speeds and slopes, peak propulsive ground reaction forces were greater for the unaffected leg compared to the affected leg (**Figure 6**). Furthermore, subjects had lower peak propulsive forces in the unaffected leg when using the Quatro prosthetic socket compared to the suction socket for every configuration (**Figure 6**). There was not any obvious trend in symmetry for peak propulsive forces (**Figure 6**). Across all speeds and slopes, peak braking ground reaction force was more negative for the unaffected leg compared to the affected leg (**Figure 7**). Moreover, peak braking force for both legs was more negative when wearing the suction socket compared to wearing the Quatro socket for all speeds and slopes except 6 degrees (**Figure 7**). Peak braking forces tended to decrease (become more negative) with increasing speed (**Figure 7**). Except when walking uphill and downhill at three degrees, subjects used more symmetric peak braking forces when wearing the Quatro socket for all speeds and slopes (**Figure 7**).

Contact Time

Contact time decreased with increasing speed (**Figure 8**). For all speeds and slopes, contact time for the unaffected leg was longer than the contact time for the affected leg (**Figure 8**). For every speed and slope except walking uphill at six degrees, subjects walked with more symmetrical contact time when they were using the Quatro socket compared to when they were using the suction socket (**Figure 8**).

Socket Pistoning

Unfortunately, there was not an obvious pattern of socket pistoning across strides (**Figure 9**). Perhaps, this could mean that there was not any appreciable socket pistoning and we were only measuring noise. However, it may mean that our measurement methods do not have high enough resolution to pick up accurate measurements of socket pistoning. Therefore, further research needs to be done to validate our socket pistoning measurements.

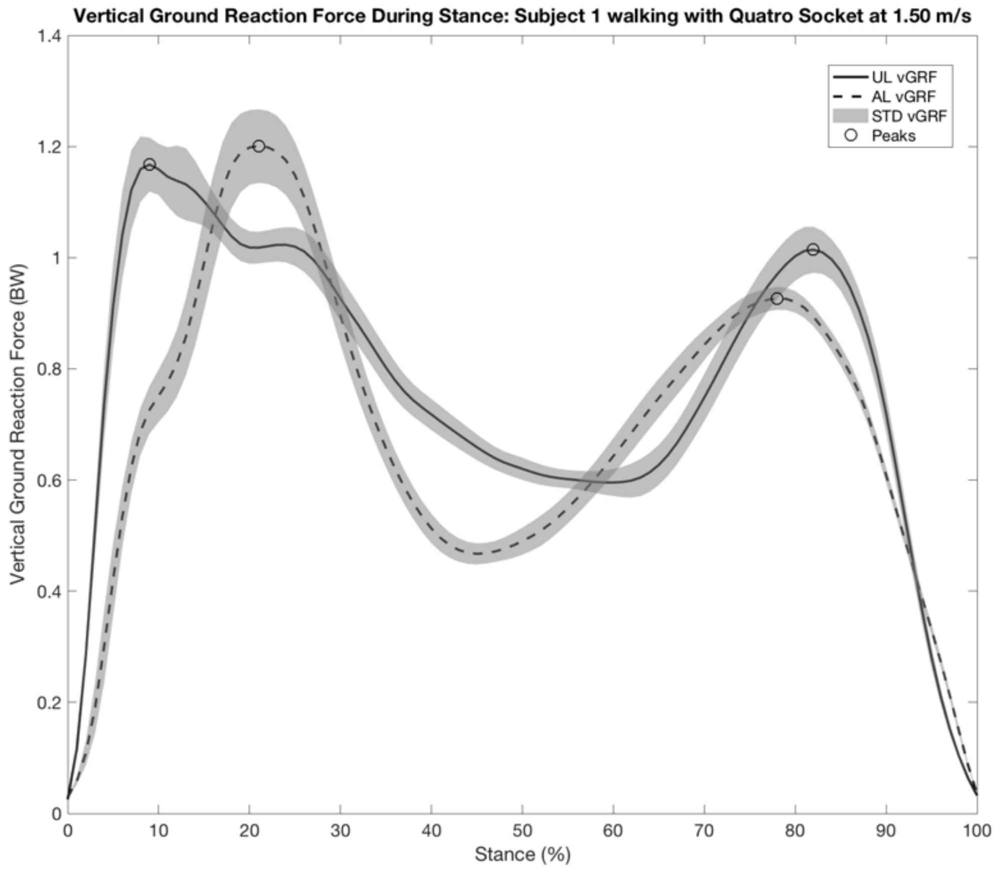
Individual Leg Work

For all speeds and slopes, positive individual leg work during the unaffected leg to affected leg transition was greater when the subjects wore the suction socket compared to when they wore the Quatro socket (**Figure 10**). For all speeds and slopes except when the subject walked down hill, positive individual leg work was greater during the transition from the unaffected leg to the affected leg compared to the transition from the affected leg to the unaffected leg (**Figure 10**). Negative individual leg work became increasingly negative with increasing speed (**Figure 11**). There was not an obvious trend between the two sockets for negative individual leg work during either the unaffected leg to affected leg transition or affected leg to unaffected leg transition (**Figure 11**).

<u>Key Takeaways</u>

1. Walking with the Quatro socket **improved** contact time symmetry (8/8 speeds and slopes), stance average vertical ground reaction force symmetry (8/8 speeds and slopes), first peak vertical ground reaction force symmetry (6/8 speeds and slopes), second peak vertical ground reaction force symmetry (7/8 speeds and slopes), and peak braking ground reaction forces symmetry (6/8 speeds and slopes) compared to walking with the suction socket
    a. Improved symmetry reduces overcompensation by the unaffected leg
    b. Improved symmetry may signify an increase in socket comfort
2. More work needs to be done to validate socket pistoning measurements

Ground Reaction Forces During Stance



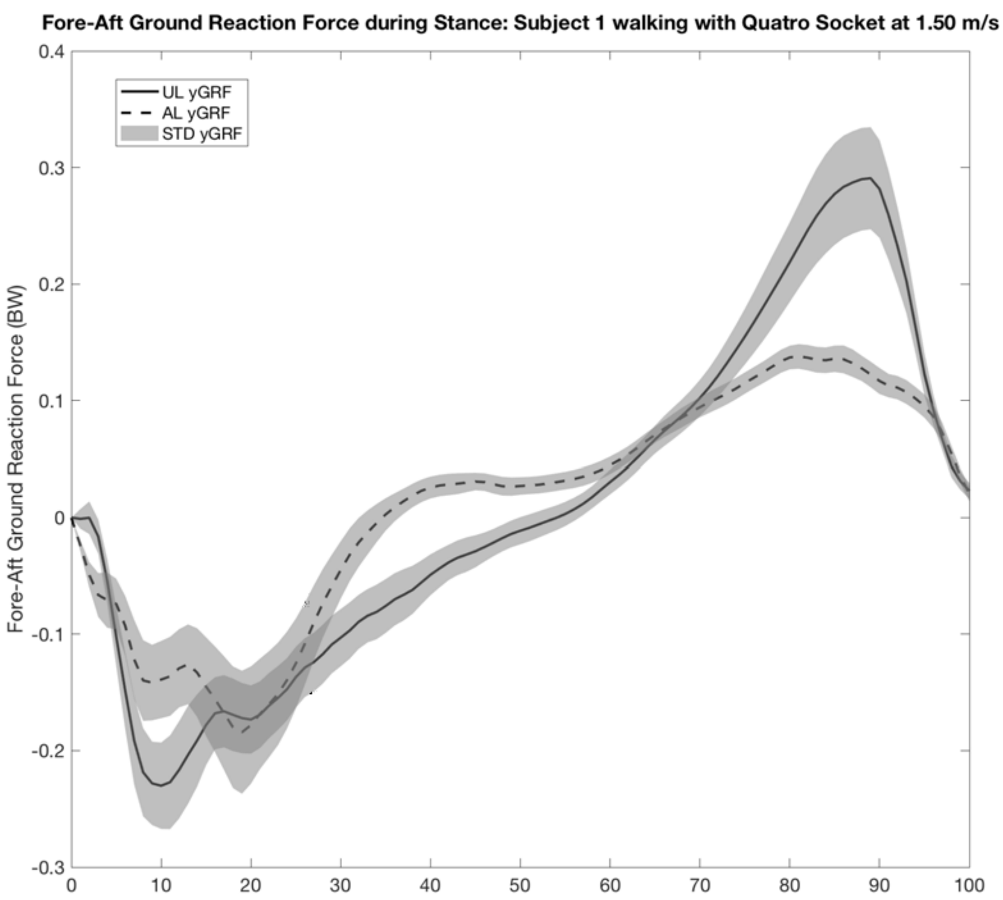


Figure 2. Subject 1 walking with Quatro socket at 1.50 m/s. UL: unaffected leg. AL: affected leg. STD: standard deviation. (top) Representative trace of vertical ground reaction force during stance. (bottom) Representative trace of fore-aft ground reaction force during stance.

Vertical Ground Reaction Forces

Stance Average Vertical Ground Reaction Force

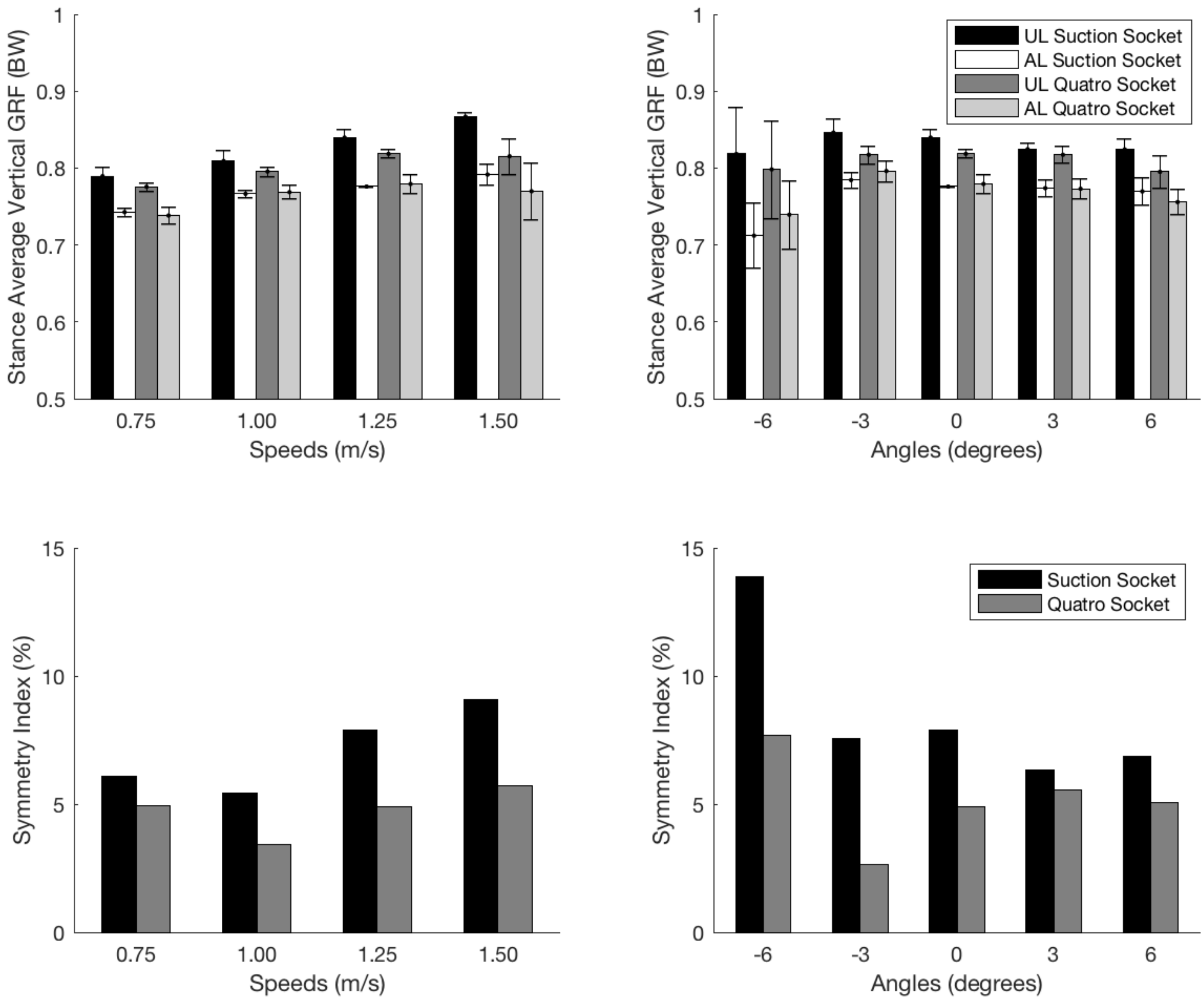


Figure 3. Stance average vertical ground reaction force and corresponding symmetry indices across slopes and speeds. Symmetry index is defined as the percent difference between the two legs. (top-left) Stance average vertical ground reaction force across speeds. (top-right) Stance average vertical ground reaction force across slopes. (bottom-left) Symmetry index of stance average vertical ground reaction force across speeds. (bottom-right) Symmetry index of stance average vertical ground reaction force across slopes. Error bars are standard error of the mean. UL: unaffected leg. AL: affected leg. N = 3.

First Peak Vertical Ground Reaction Force

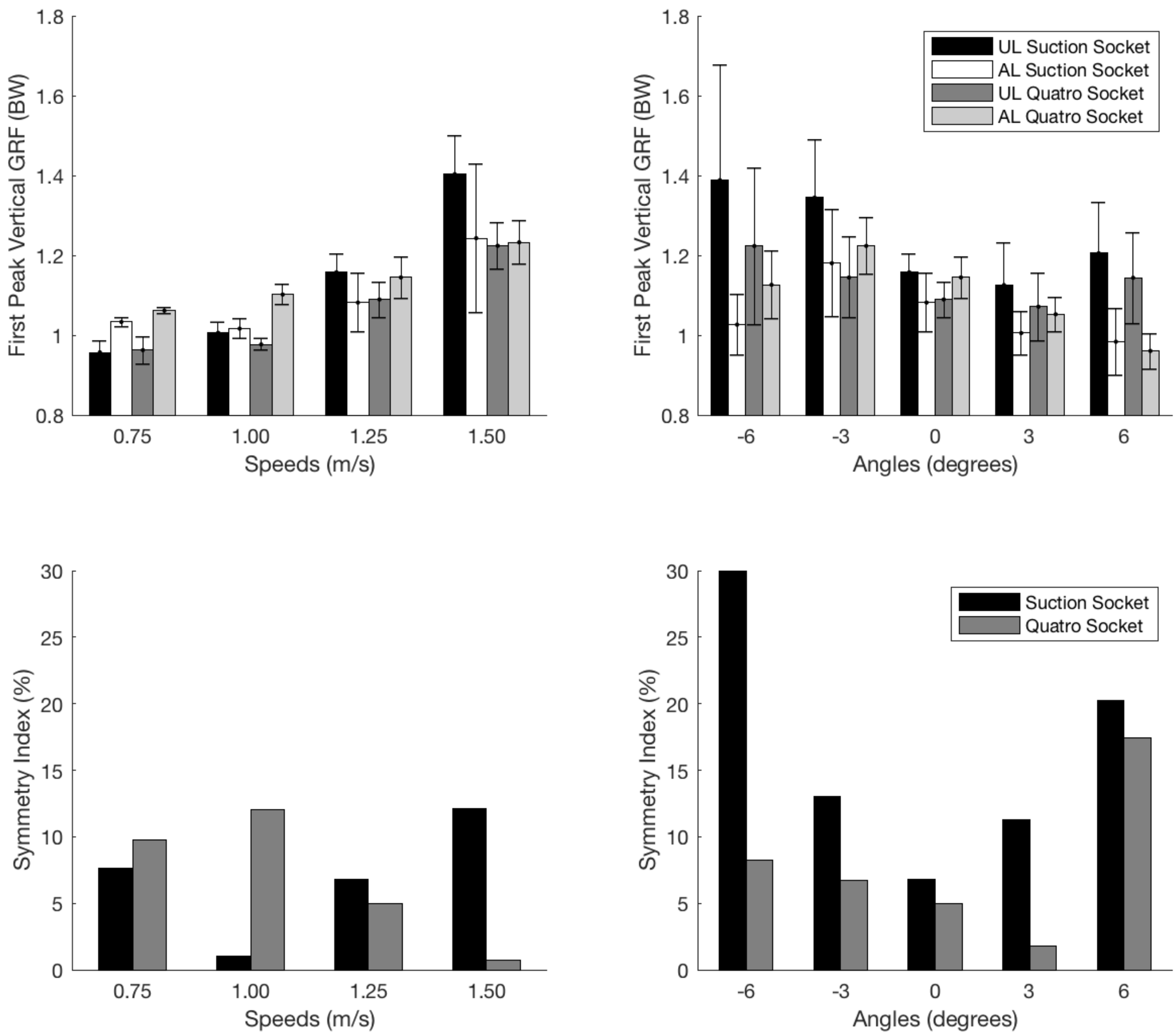


Figure 4. First peak vertical ground reaction force and corresponding symmetry indices across slopes and speeds. Symmetry index is defined as the percent difference between the two legs. (top-left) First peak vertical ground reaction force across speeds. (top-right) First peak vertical ground reaction force across slopes. (bottom-left) Symmetry index of first peak vertical ground reaction force across speeds. (bottom-right) Symmetry index of first peak vertical ground reaction force across slopes. Error bars are standard error of the mean. UL: unaffected leg. AL: affected leg. N = 3.

Second Peak Vertical Ground Reaction Force

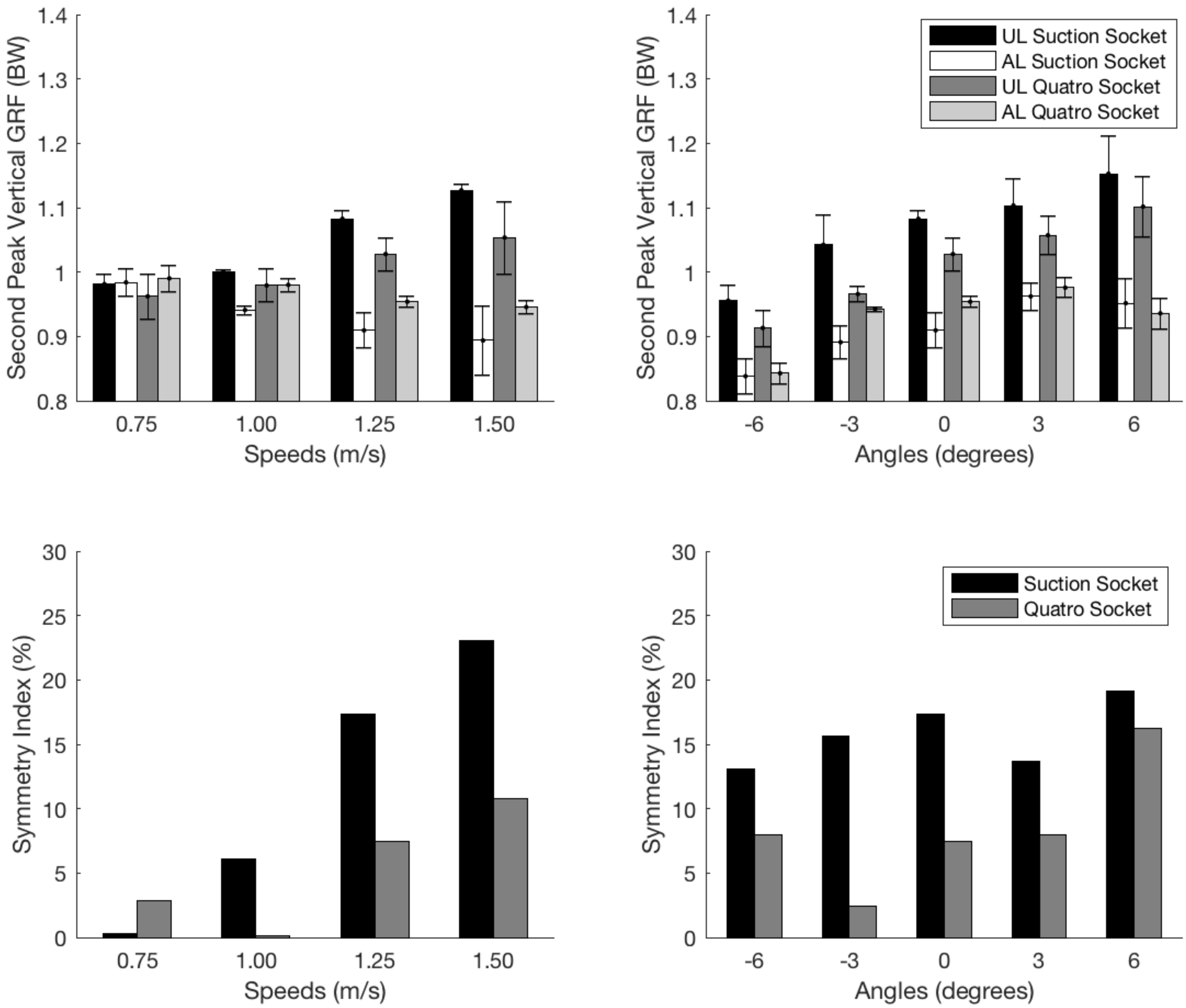


Figure 5. Second peak vertical ground reaction force and corresponding symmetry indices across slopes and speeds. Symmetry index is defined as the percent difference between the two legs. (top-left) Second peak vertical ground reaction force across speeds. (top-right) Second peak vertical ground reaction force across slopes. (bottom-left) Symmetry index of second peak vertical ground reaction force across speeds. (bottom-right) Symmetry index of second peak vertical ground reaction force across slopes. Error bars are standard error of the mean. UL: unaffected leg. AL: affected leg. N = 3.

Fore-aft Ground Reaction Forces

Peak Propulsive Ground Reaction Force

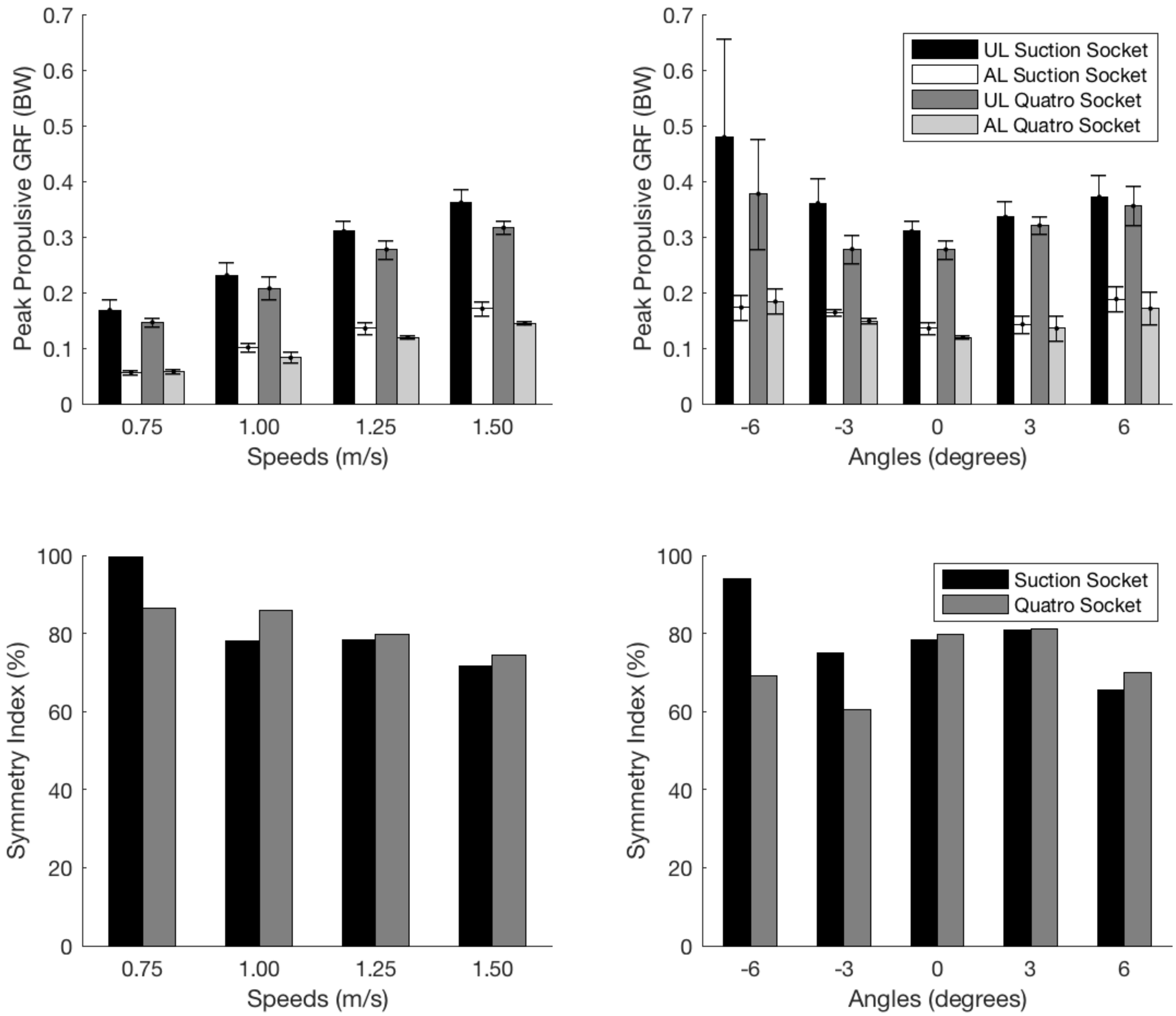


Figure 6. Peak propulsive fore-aft ground reaction force and corresponding symmetry indices across slopes and speeds. Symmetry index is defined as the percent difference between the two legs. (top-left) Peak propulsive fore-aft ground reaction force across speeds. (top-right) Peak propulsive fore-aft ground reaction force across slopes. (bottom-left) Symmetry index of peak propulsive fore-aft ground reaction force across speeds. (bottom-right) Symmetry index of peak propulsive fore-aft ground reaction force across slopes. Error bars are standard error of the mean. UL: unaffected leg. AL: affected leg. N = 3.

Peak Braking Ground Reaction Force

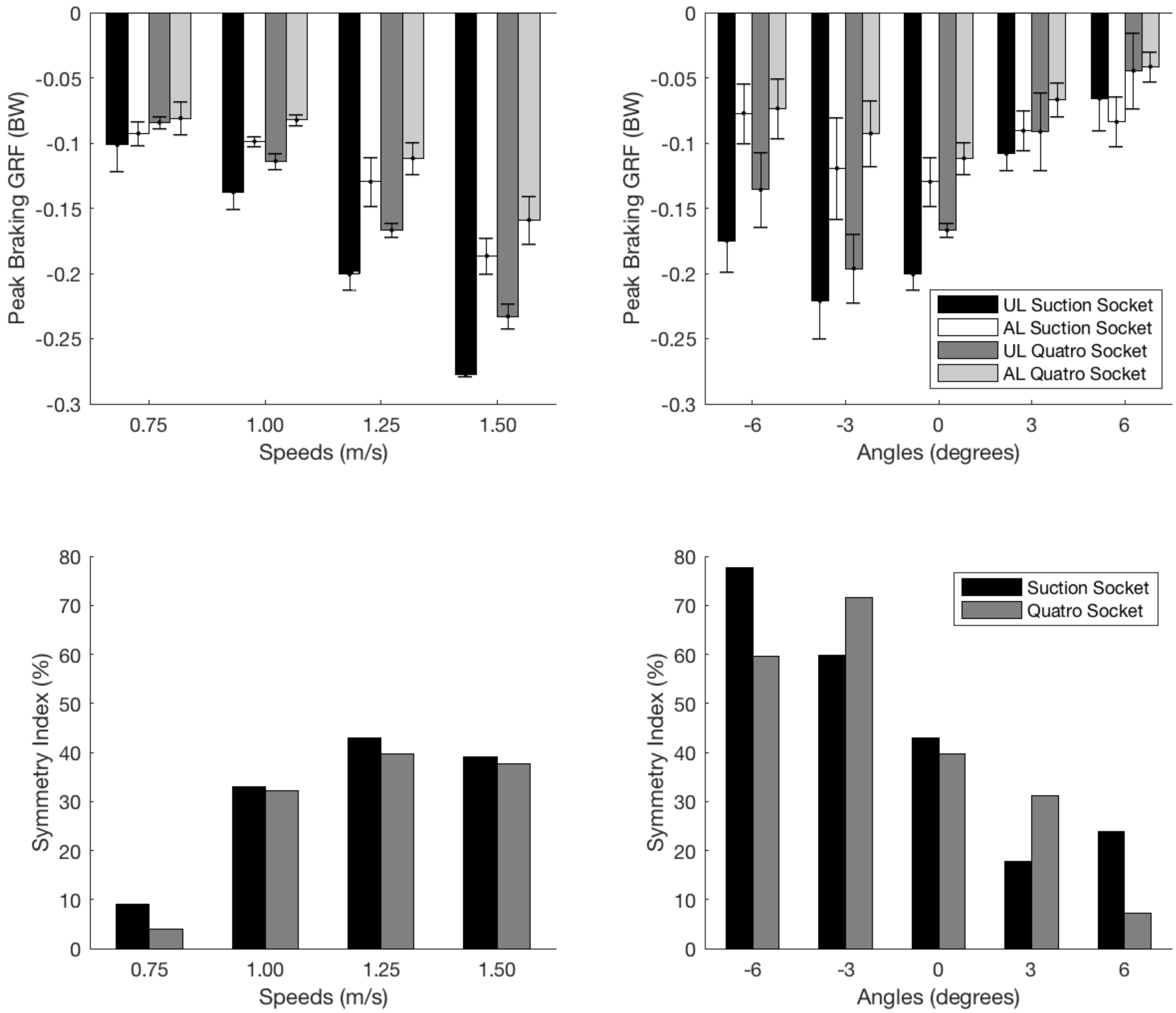


Figure 7. Peak braking fore-aft ground reaction force and corresponding symmetry indices across slopes and speeds. Symmetry index is defined as the percent difference between the two legs. (top-left) Peak braking fore-aft ground reaction force across speeds. (top-right) Peak braking fore-aft ground reaction force across slopes. (bottom-left) Symmetry index of peak braking fore-aft ground reaction force across speeds. (bottom-right) Symmetry index of peak braking fore-aft ground reaction force across slopes. Error bars are standard error of the mean. UL: unaffected leg. AL: affected leg. N = 3.

Contact Time

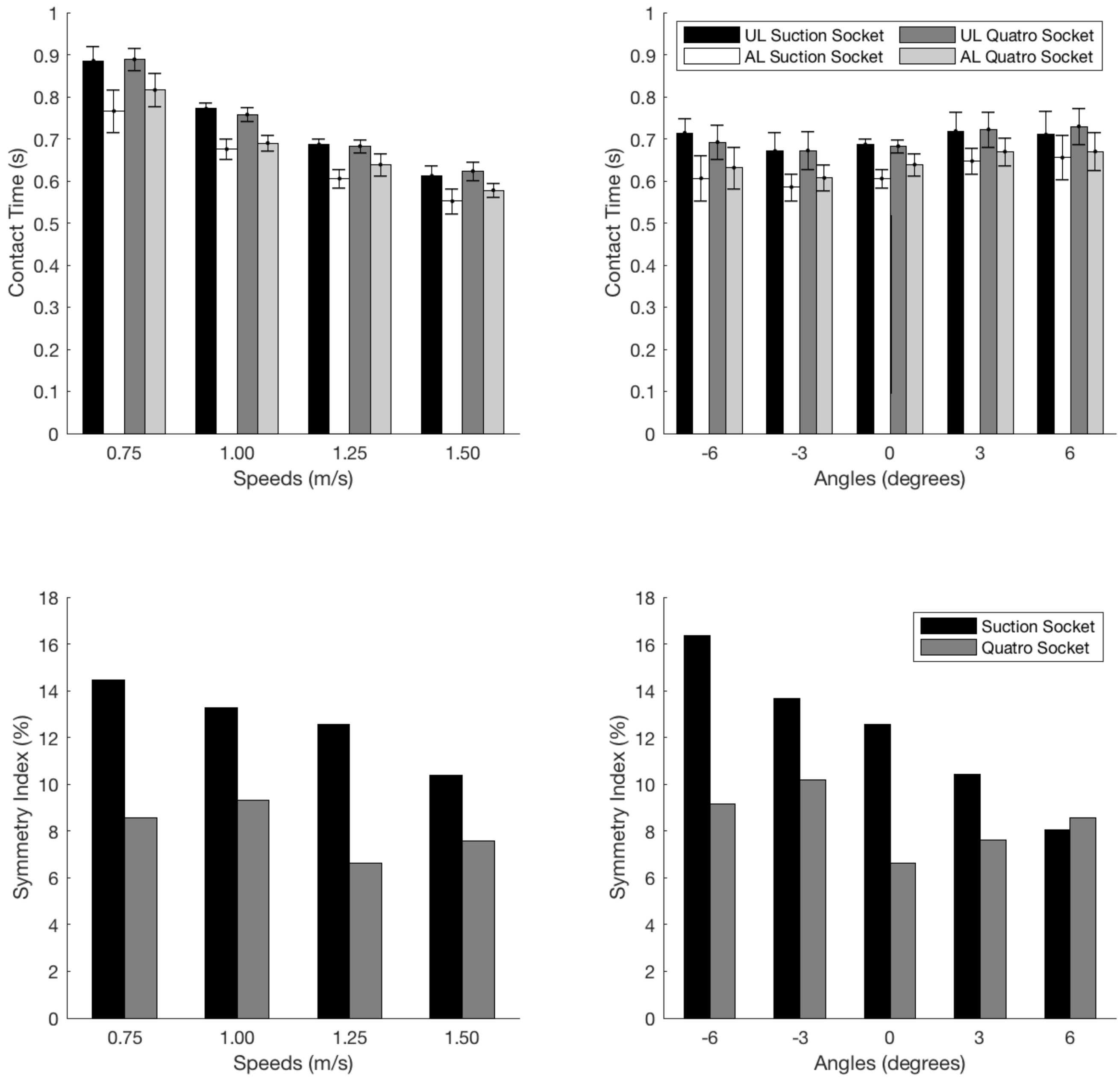


Figure 8. Contact time and corresponding symmetry indices across slopes and speeds. Symmetry index is defined as the percent difference between the two legs. (top-left) Contact time across speeds. (top-right) Contact time across slopes. (bottom-left) Symmetry index of contact across speeds. (bottom-right) Symmetry index of contact time across slopes. Error bars are standard error of the mean. UL: unaffected leg. AL: affected leg. N = 3.

Socket Pistoning

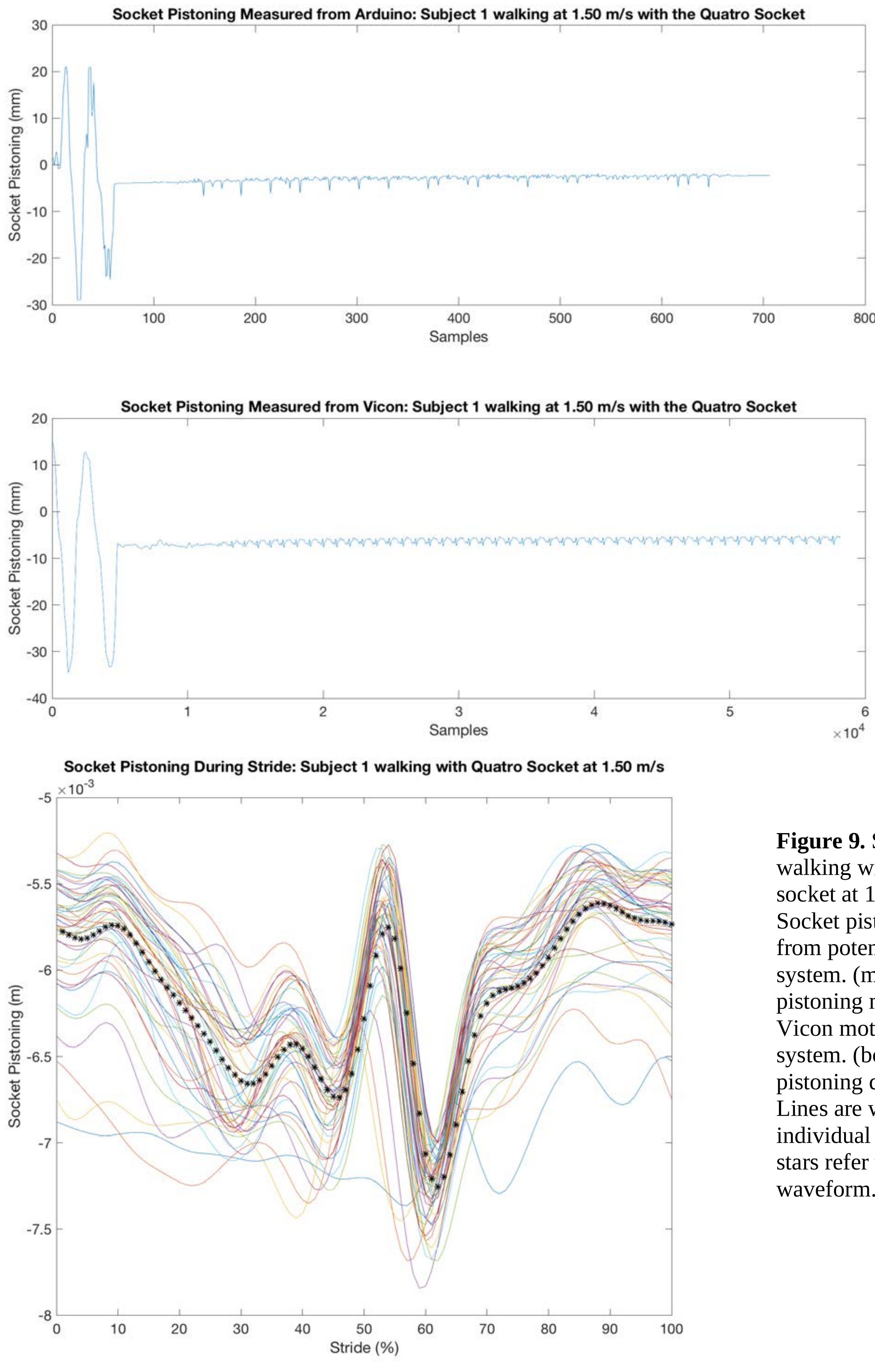
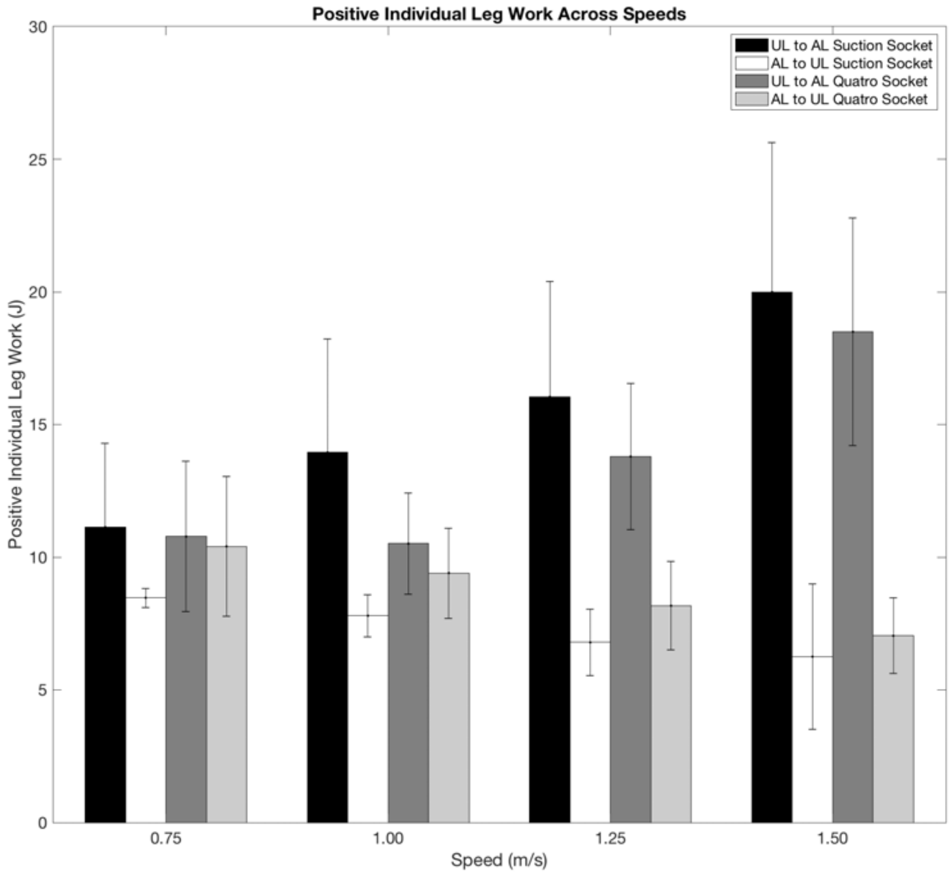


Figure 9. Subject 1 walking with Quatro socket at 1.50 m/s. (top) Socket pistoning measured from potentiometer system. (middle) Socket pistoning measured from Vicon motion capture system. (bottom) Socket pistoning during stride. Lines are waveforms from individual stride and black stars refer to the mean waveform.

Individual Leg Work

Positive Individual Leg Work



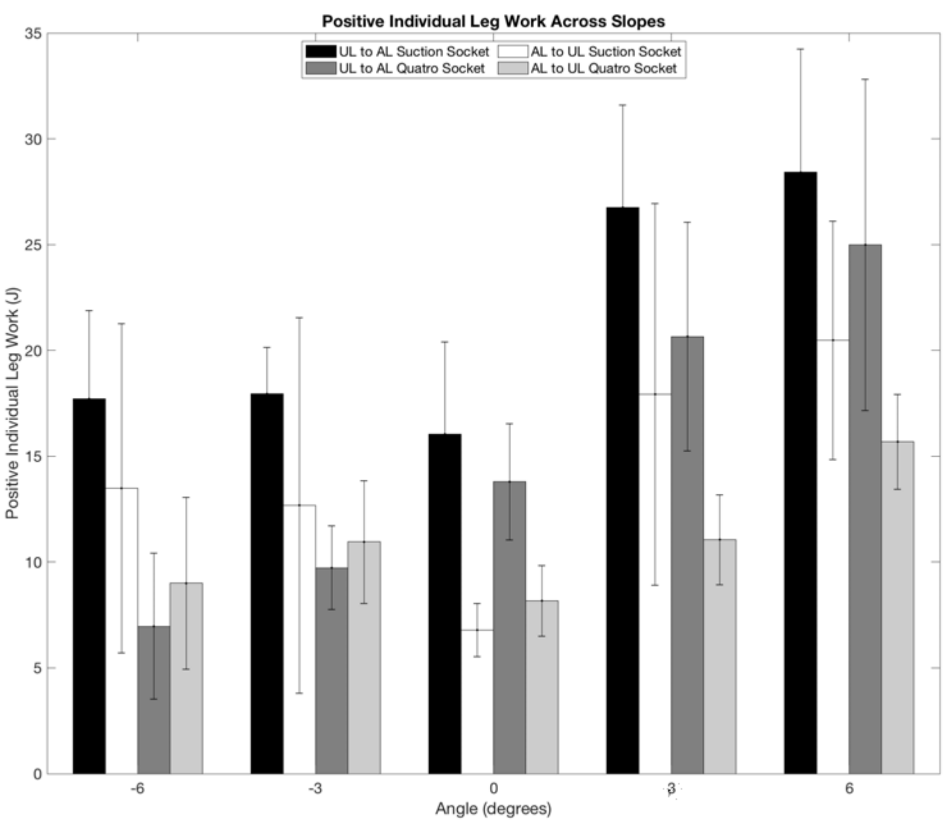


Figure 10. Positive individual leg work during the step-to-step transition (top) Positive individual leg work across speeds (bottom) Positive individual leg work across slopes. Error bars are standard error of the mean. UL to AL: unaffected leg to affected leg transition. AL to UL: affected leg to unaffected leg transition. N = 3.

Negative Individual Leg Work

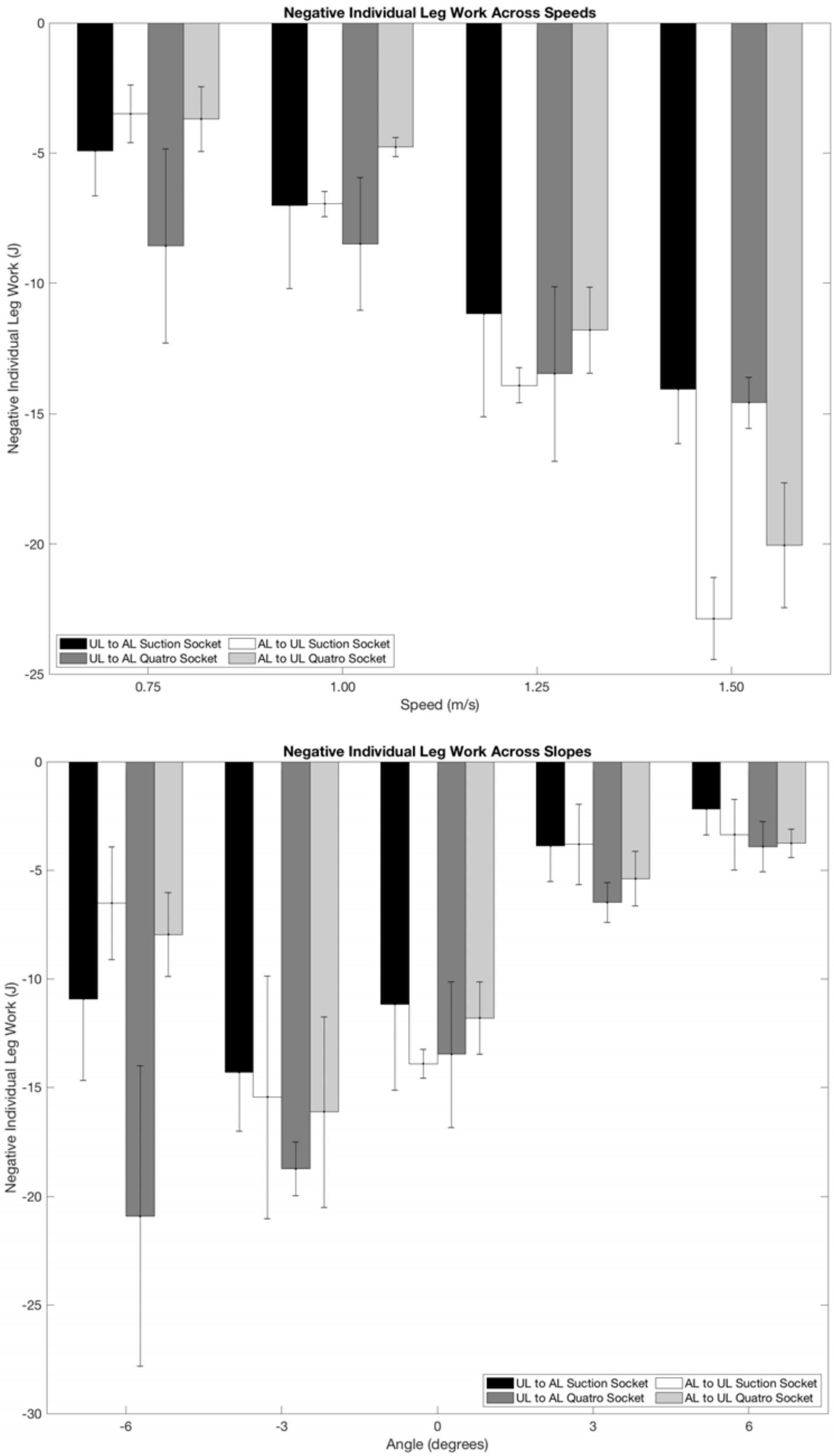


Figure 11. Negative individual leg work during the step-to-step transition (top) Negative individual leg work across speeds (bottom) Negative individual leg work across slopes. Error bars are standard error of the mean. UL to AL: unaffected leg to affected leg transition. AL to UL: affected leg to unaffected leg transition. N = 3.