The Time of Slip Onset During Stance Influences the Characteristics of the Unconstrained Perturbation

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Figure 1: Slips that occur at different points of stance may elicit unique conditions compared to those that happen at heel-strike.

Figure 2: An assembled WASP device mounted to a shod prosthetic foot. Upon receiving a trigger signal sent via Bluetooth connection, power is supplied to an internal electric motor that releases the outsole. This exposes the wearer to a low friction surface on top of the outsole, thereby causing a slip.

Figure 3: An illustration of the three slip variables described above.

Figure 4: Scatter plots relating slip onset with the three observed slip variables.

Figure 5: An assembled WASP device mounted to a shod prosthetic foot. Upon receiving a trigger signal sent via Bluetooth connection, power is supplied to an internal electric motor that releases the outsole. This exposes the wearer to a low friction surface on top of the outsole, thereby causing a slip.

Figure 6: An illustration of the three slip variables described above.

BACKGROUND & AIMS

- Lab-induced perturbations are a popular strategy to study balance and prevent falls [1]
- Research has focused exclusively on slips that occur at heel-strike, leaving the result of slips at other onset times unknown (Fig. 1)
- Our Wearable Apparatus for Slip Perturbations (WASP) can administer unpredictable, unconstrained slips at any point during stance
- The aim of this work was to examine the effect of slip timing on the mechanics of the perturbations

METHODS

- 10 healthy, young adults participated in the following study
- All subjects wore a compression suit, athletic shoes, a safety harness, a pair of WASP devices (Fig. 2), and a full-body reflective marker set that was recorded at 120 Hz by a 17-camera motion capture system (Motion Analysis Corp.; Santa Rosa, CA)
- Each participant performed 12 trials, during which they walked back and forth across an 8-meter walkway at their self-selected comfortable pace until a slip was delivered
- Slips targeted either early (0-33%), mid (34-67%), or late (68-100%) stance phase to obtain a broad distribution of onset times (Fig. 1)
- Trial durations, slip onset phases, and perturbed foot were randomized prior to the session

DATA & STATISTICAL ANALYSIS

- Gait events were determined using a kinematic-based method [2]
- Slip onset was the instant that the perturbed foot’s horizontal velocity began to increase after WASP activation, while slip cessation was either the instant that this velocity returned to zero or the following toe-off (i.e. for late stance slips)
- All slip mechanics were computed in a body center of mass (CoM) based coordinate system
- Slip directions are the angles between the sliding foot’s CoM motion vector and the subject’s heading (Fig. 3)
- Slip distances are the difference between the perturbed foot’s CoM at slip onset and cessation, while slip velocities are the peak horizontal velocities within this same period (Fig. 3)
- Spearman’s rank correlation coefficients were calculated to quantify the relationship between the three slip attributes and slip onset time

ONSET TIME IMPACTS SLIP MECHANICS

A. Slip Direction vs. Onset

B. Slip Distance vs. Onset

C. Slip Velocity vs. Onset

CONCLUSIONS

- A significant strong, positive relationship was found between slip onset time and slip direction ($\rho(89)=0.659$, $p<0.001$; Fig. 4A)
- A significant strong, negative association exists between slip onset and slip distance ($\rho(89)=-0.609$, $p<0.001$; Fig. 4B)
- A weak, negative correlation between onset time and slip velocity was observed, however this relationship was still significant ($\rho(89)=-0.246$, $p=0.019$; Fig. 4C)
- As slips occur later in stance phase, the sliding foot tends to slow and travel a shorter distance in a direction that becomes increasingly lateral to and eventually opposite to the direction of walking

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REFERENCES