COMPARISON OF KINEMATIC METHODS FOR DETERMINING FOOTSTRIKE AND TOE-OFF DURING OVERGROUND RUNNING

Rebecca E Fellin [1] and Irene S Davis [1, 2]

[1] University of Delaware, Newark, DE, USA
[2] Drayer Physical Therapy Institute, Hummelstown, PA, USA
Email: fellin@udel.edu

INTRODUCTION

The study of gait often requires the identification of footstrike and toe-off. This is typically accomplished with the use of force plates, an instrumented walkway or footswitches. However, when these devices are not available, an alternative method is needed.

Several kinematic methods to determine footstrike and toe-off have emerged in the literature. For running Hreljac and Stergiou (2000) used sagittal plane foot and shank angular velocities. The timing of peak knee extension has been used to separated running strides (Dingwell et al, 2001). In addition the vertical position of the ankle marker (Alton et al, 1998) and the vertical velocity and displacement of the foot markers (Schache et al, 2001) have also been used to define stance. A study by Zeni et al. (2007) suggested using relative displacement between the sacral and foot markers to determine stance during walking. However, to date these methods have not been compared to each other. Therefore, the purpose of this study was to compare these kinematic methods of determining footstrike and toe-off with a force platform. We hypothesized the Hreljac and Stergiou method would be the most accurate method since it was the only running method validated with force platform data.

METHODS

This is an ongoing study of recreational runners ages 18-45, running at least 10 mpw. To date, two female and three male runners (31.8 ± 7.1 years and rearfoot strikers) have been studied. Retroreflective markers were applied to the right lower extremity. Subjects ran at 3.35m/s along a 25m runway striking a force plate at the center. Kinematic data sampled at 120 Hz with a VICON (Oxford, UK) system and filtered at 12Hz. Kinetic data were sampled at 1080 Hz with a Bertec (Ohio, USA) force plate and filtered at 50 Hz. Five trials were averaged for each subject.

Stance was first determined using the force plate data (FP). Footstrike was identified when the vertical ground reaction force exceeded 10 N. Toe-off was determined when the force dropped below 10N. Stance was then determined using 5 kinematic methods reported in the literature.
1. *Angular Velocity Method (ANGV)* Footstrike was defined as the time coincident with the local minimum of sagittal plane foot angular velocity. Toe-off was defined as the local minimum of the shank angular velocity. 2) *Peak Knee Extension (PKEXT)* The time of peak knee extension was used to identify footstrike, while the second peak knee extension was used to identify toe-off. 3) *Foot Vertical Displacement (FPOSZ)* The minimum vertical position (z) of the distal heel marker was used to identify footstrike. The minimum vertical position (z) of the 2nd metatarsal head marker was used to find toe-off. 4) *Foot Vertical Velocity (FVELZ)* The change in vertical velocities from negative to positive of the distal heel and second

metatarsal head markers to determine footstrike and toe-off, respectively. 5) *Foot-Sacrum Y Displacement (FSDISY)* Footstrike was defined at the time of maximum positive displacement in the direction of progression (y) between the sacrum and distal heel marker: $T_{hs}=(Y_{heel} - Y_{sacrum})_{max}$. Toe-off was defined as the minimum displacement in y between the second metatarsal head marker and the sacrum marker: $T_{to}=(Y_{toe} - Y_{sacrum})_{min}$

Absolute and rms errors (in ms) were computed for each subject and averaged across subjects.

RESULTS AND DISCUSSION

The absolute and rms errors are presented in Table 1 and Figure 1, respectively. Based on these preliminary results, footstrike was most accurately determined using the FVELZ method which, on average, was determined within 1.33 ms (rms = 5 ms) of that measured with the force plate. However, the FPOSZ method also accurately determined footstrike, within 3.83 ms (rms = 6.67 ms) of the force plate time. In general, there was more error in determining toe-off. However, the PKEXT method identified it within 1.67 ms (rms= 6.33 ms) of that of the force platform. In all of these cases, footstrike and toe-off were identified within one video frame (8.33ms) of the force plate data.

Interestingly, the ANGV method resulted in the greatest amount of error. The angular acceleration curves had multiple minima, some occurring in the middle of stance, which caused toe-off to be detected consistently early. Both PKEXT and FSDISY methods consistently detected footstrike about 5 frames early. This is most likely due to people fully extending their leg shortly prior to footstrike and then flexing their leg slightly before footstrike.

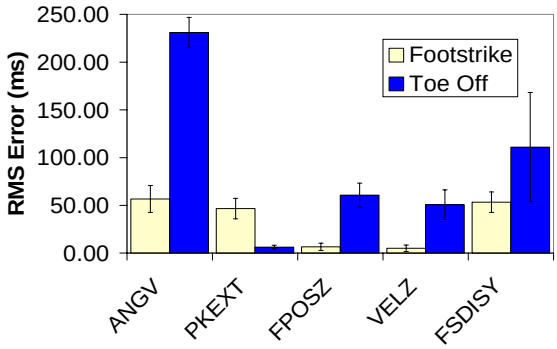

Figure 1: Stance determination RMS errors

These results begin to suggest utilizing different kinematic methods to accurately determine footstrike and toe-off during running may be best.

SUMMARY/CONCLUSIONS

The distal heel marker vertical velocity was the most valid measure for determining footstrike. However, toe-off was best determined by the peak knee extension method.

REFERENCES

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Table 1: Absolute error (in ms) of stance determination methods (mean ± SD)

Event	ANGV	FSDISY	PKEXT	FPOSZ	FVELZ
Footstrike	-47.33 ± 14.1	-52.00 ± 10.8	-46.67 ± 10.8	3.83 ± 6.0	1.33 ± 5.8
Toe-off	-231 ± 15.8	111 ± 150.7	1.67 ± 3.6	-60.67 ± 12.7	-50.67 ± 15.5

Negative values indicate early event estimation, positive values indicate late event estimation