Validation of a Kinematic Protocol for the Determination of Gait Events During Overground and Treadmill Running

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Introduction
The accurate division of the gait cycle into its component stance and swing phases is important in gait analysis. Use of force platforms to indicate when the foot is in contact with the ground is the 'gold standard' method of determining foot strike (FS) and toe off (TO). However force platforms may not be available, particularly during treadmill locomotion. Methods of determining these gait events using additional instrumentation (e.g. foot switches [1]) exist, but further encumber the subject and may be limited by the number of analogue channels available. A method of identifying FS and TO from standard kinematic data alone, without additional instrumentation or markers, has been devised and validated for overground walking [2]. The aim of this study was to extend this technique to overground and treadmill running.

Statement of Clinical Significance
A technique for the accurate and objective determination of foot strike and toe off during treadmill and overground running from kinematic data alone is a valuable addition to the gait analyst's repertoire, as it does not depend on the presence of force platforms or additional instrumentation to identify these key events in the gait cycle.

Methodology
Three-dimensional kinematic data and ground reaction force data were collected from 16 subjects during 5 trials of overground and 15 s of treadmill running at 3.8 $m.s^{-1}$ using an eight camera motion capture system collecting at 120 Hz (Motion Analysis Corporation, Santa Rosa, CA, USA) and a force platform at 1200 Hz (Kistler, Winterthur, Switzerland). All subjects gave written informed consent and all procedures were approved by the University's Ethics Committee. Kinematic data were collected for four foot/ shoe markers commonly used in gait analysis: tip of second toe (TOE), fifth metatarsal head (5MTH), posterior heel (HEEL) and lateral calcaneus (CALC).

Six of the datasets were used to develop rules for the location of FS and TO on plots of the vertical displacement and velocity of the marker concerned, based on the location of these events determined by the vertical component of the ground reaction force. Custom Matlab software (Mathworks, Natick, MA, USA) was developed to display graphs for interactive rating of FS and TO location using kinematic data alone. A cohort of raters (n = 5) identified FS and TO for all trials of the 10 datasets that were not used in the rule development. Inter-rater reliability was tested using intra-class correlation coefficient and the validity of the

technique was assessed using 95% limits of agreement (95% LOA) were determined for each marker in each condition.

Results
All 95% LOA for the treadmill condition were within ± 0.06 s. TOE exhibited the smallest 95% LOA of approximately ± 0.02 s and 5MTH the largest. Qualitatively, there is also noteworthy consistency between raters. Similarly, in the overground condition, 5MTH exhibited the largest 95% LOA and TOE displayed the smallest. With the exception of 5MTH, the 95% LOA were again within ± 0.06 s. As with the treadmill condition, qualitative assessment indicated consistency between raters for all markers. The qualitative observations of consistency between raters were confirmed by the test of inter-rater reliability. The intra-class correlations revealed extremely high correlation coefficients ($R > 0.99$) for all markers in both conditions.

Table 1: Approximate 95% Limits of Agreement for the four markers used to determine either foot strike (FS) or toe off (TO)

Condition	TO: TOE (s)	TO: 5MTH (s)	FS: HEEL (s)	FS: CALC (s)
Treadmill	0.02	0.04	0.02	0.03
Overground	0.02	0.10	0.04	0.04

Discussion
Inter-rater reliability was very high, indicating that the method is objective and robust to the rating being carried out by different individuals and does not require skilled users.
The 95% LOA were lower in the treadmill condition than overground for all markers. This is consistent with previous studies that have indicated reduced levels of kinematic variability during treadmill locomotion [3-5].
With the exception of 5MTH in the overground condition, all markers located gait events more accurately than a previously validated field counting technique [6]. Similarly, the 95% LOA fall within the ranges cited by Mickelborough et al. [2] in their application of this technique to overground walking. Since events occur more quickly during running, this is a particularly positive result.
Further work is required to determine whether the technique is valid for pathological subjects. The development of this technique using a single-case design approach may be necessary for these more variable populations.

References
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