IDENTIFICATION OF INSTANTS OF TOUCHDOWN AND TAKE-OFF IN SPRINT RUNNING USING AN AUTOMATIC MOTION ANALYSIS SYSTEM

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The identification of the instants of touchdown and take-off are important in determining step characteristics during the biomechanical analysis of sprinting. Six athletes performed 20 sprint trials each in which a single foot contact was made with a force plate, and kinematic data were gathered with five toe markers. Criterion event times taken from the force plate were compared to event times calculated using vertical displacement thresholds from standing trials and peak vertical acceleration values. The lowest RMS differences between the criterion value and the standing trial thresholds were between 0.003 and 0.005 s, whilst the lowest RMS differences for vertical acceleration ranged between 0.005 and 0.007 s. These results revealed that accurate touchdown and take-off events in sprinting could be determined using an automatic motion analysis system.

KEY WORDS: event detection, timing, kinematics, track and field athletics

INTRODUCTION:

The identification of the instants of touchdown and take-off are important in defining step characteristics in sprinting. As well as being events of interest in their own right, the time difference between touchdown and take-off gives the duration of the support phase and the identification of a specific repeatable instant in consecutive step cycles enables the calculation of step frequency, a key determinant of running velocity. Furthermore, previous studies of sprinting have identified the magnitude of key kinematic variables at touchdown and take-off as being important indicators of performance. Examples include high knee flexion velocity at touchdown (Mann & Herman, 1985) and reduced hip extension angle at take-off (Kunz & Kaufmann, 1981).

Motion analysis using conventional 50 Hz video cameras (or 60 Hz in NTSC format) has been suggested to be limiting for the calculation of timing variables, such as touchdown and take-off (Salo & Grimshaw, 1998). The use of contemporary automatic motion analysis systems facilitates the collection of data at greater sampling frequencies in comparison to conventional video cameras. However, the identification of key events such as touchdown and take-off are difficult to achieve when using automatic motion analysis. In an attempt to overcome this problem, Hunter et al. (2004) recorded sprint performance with an automatic motion analysis system at 240 Hz. They used the method of Hreljac & Marshall (2000), which had been developed on walking, to identify the instant of peak vertical acceleration of the head of the second metatarsal, and were able to identify ground contact to the exact frame or one frame late, 93% of the time. To date, no investigations, that have accommodated laboratory-based data collections in which a unilateral scanner has been used to track the bilateral sagittal plane motion of sprinting, have been conducted. The purpose of this study was to evaluate the accuracy in determining the instants of touchdown and take-off during a sprint run using a unilateral scanner, based on (i) the vertical displacement of toe markers from a standing trial and (ii) the peak vertical acceleration as a threshold value for ground contact.

METHODS:

Data collection: Six athletes (5 male, 1 female; age 22.8 ± 1.6 years, body mass 75.5 ± 9.4 kg; height 1.78 ± 0.06 m) participated in the study. A force plate (9287BA, Kistler Instruments Ltd., Switzerland) operating at 1000 Hz was located in a customised housing in the centre of a 110m track and securely covered with a Mondo track surface. The force plate was synchronised with a CODA CX1 Motion Analysis System (Charnwood Dynamics, UK) sampling at 800 Hz. The CODA scanner unit was positioned perpendicular to the plane of motion and 4 m from the centre of the force plate. As illustrated in Figure 1a, active markers were positioned on the lateral aspect of each subject's left sprinting shoe, at five sites: superior to the distal end of the first toe [A]; lateral to the distal end of the third toe [B]; superior to the first inter-phalangeal joint of the second toe [C]; lateral to the distal end of the fifth toe [D] and lateral to the fifth metatarsophalangeal joint [E]. Markers and battery packs were securely fixed to the shoes using double-sided adhesive tape. Two static trials, where position data were collected whilst the subject maintained a stationary, standing position were acquired for each subject (capture time: 10 s). The first trial required the subject to maintain a standing position with feet flat on the ground. Subjects were asked to raise their foot into a stationary tip-toe position in the second trial to mimic the position of the foot at touchdown during the contact phase of sprinting. Subjects then completed ten running trials, in which a single foot contact was made with the force plate. Subjects initiated the trials from a location 10 m posterior to the centre of the force plate, and were instructed to accelerate maximally and adopt a foot-strike pattern on the force plate similar to that achieved during sprint running. Synchronised force and coordinate data were gathered for five seconds, with foot-strike on the force plate typically occurring approximately one second after triggering. A trial was rejected if the subject consciously or noticeably adjusted their step pattern in order to contact the force plate. A second series of ten sprint trials was performed in which markers were attached to the medial aspect of the right shoe. As illustrated in Figure 1b, markers were positioned at five locations: superior to the distal end of the first toe [F]; medial to the distal end of the first toe [G]; superior to the first inter-phalangeal joint of the second toe [H]; medial to the first inter-phalangeal joint of the first toe [J] and medial to the first metatarsophalangeal joint [K]).

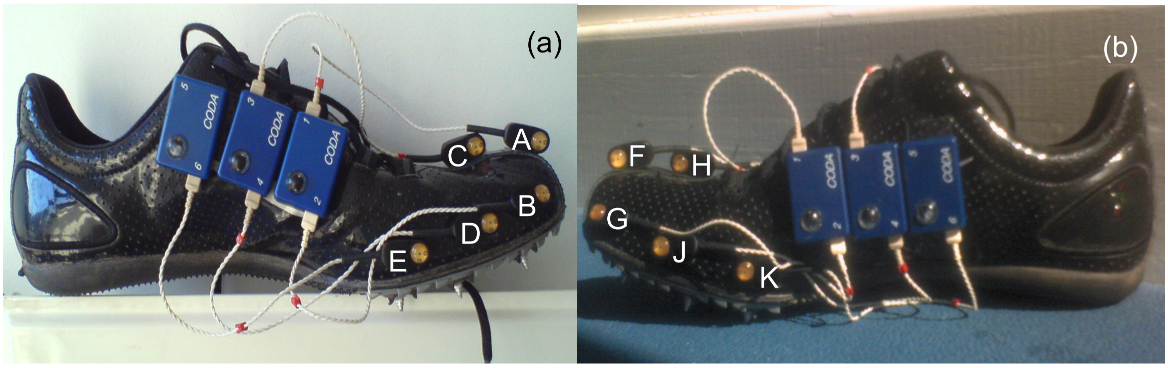

Figure 1: The lateral (a) and medial (b) locations of the CODA markers on the sprinting shoe

Data processing: Vertical ground reaction force, marker position and marker acceleration data for all static and sprint running trials were exported at 800 Hz for further analysis, prior to which acceleration data were low pass filtered at 20 Hz. The mean plus two standard deviations of the last 2801 samples (three and a half seconds) of vertical ground reaction force data were calculated for each running trial. There was zero load on the force plate during this time, and this value was taken as the threshold for contact with the force platform, and defined as the criterion measure. The first data point at which the vertical force increased above the pre-defined threshold was defined as touchdown, and the first subsequent data point at which the force decreased below the threshold was defined as take-off. For each static trial, the mean plus two standard deviations of the vertical coordinate of all 8001 samples (ten seconds) of each marker were calculated, and this value was taken to be the threshold for contact with the track for each individual. Two thresholds for each lateral and medial marker set were subsequently obtained for each individual using the flat-footed and tip-toed standing trials. For each marker the instant of touchdown was defined as the first data point in which the vertical coordinate of the marker dropped below the marker-defined threshold, and take-off was defined as the first in which the vertical coordinate of the marker was raised above the marker-defined threshold. Finally, the instant of peak vertical

acceleration of each marker around touchdown and take-off was identified, and the time of this data point noted as a third measure of touchdown and take-off for each marker.
The root mean squared (RMS) differences between the criterion times of touchdown and take-off, derived using the force data, and the event times, derived using the standing flat-footed and tip-toed thresholds and peak vertical accelerations, were calculated for each marker on each subject across the ten trials. The mean RMS values across the six subjects were calculated for touchdown and take-off for the ten markers under the three calculation conditions.

RESULTS:

Mean RMS differences across six subjects for each condition are displayed in Table 1. RMS differences between the criterion measure and marker-derived event time were most consistently low when calculated using peak vertical acceleration. However, the lowest values for specific individual markers for touchdown and take-off, with lateral and medial marker sets, occurred when the thresholds taken from the coordinates in the standing trials were adopted. Marker D produced the lowest RMS value for the lateral marker set for touchdown when using the flat-footed standing trial as a threshold (0.003 s), whilst marker C produced the lowest RMS value for take-off when using the tip-toed standing trial as a threshold (0.004 s). The lowest RMS difference for the medial marker set for touchdown was produced by marker F using the flat-footed standing trial as a threshold (0.005 s). The lowest RMS value for take-off, also using the flat-footed standing trial as a threshold, was seen for Marker H (0.005 s).

Table 1 - Mean RMS Differences in Touch down (TD) and Take-off (TO) Times between Force Plate Criterion and Marker-Derived Criterion Obtained from Three Experimental Conditions across Six Subjects.

Marker		Marker RMS Differences with respect to Force Plate Criterion [s]					
		Flat-footed Coordinate		Tip-toed Coordinate		Vertical Acceleration	
		TD	TO	TD	TO	TD	TO
Lateral	A	0.007	0.015	0.026	0.012	0.006	0.009
	B	0.005	0.008	0.047	0.008	0.005	0.017
	C	0.015	0.006	0.033	0.004	0.007	0.007
	D	0.003	0.012	0.023	0.024	0.005	0.022
	E	0.004	0.048	0.004	0.040	0.005	0.009
Medial	F	0.005	0.015	0.031	0.011	0.007	0.009
	G	0.047	0.009	0.025	0.006	0.007	0.008
	H	0.013	0.005	0.035	0.009	0.007	0.007
	J	0.007	0.009	0.019	0.015	0.007	0.006
	K	0.017	0.030	0.013	0.026	0.007	0.008

DISCUSSION:

The results of this study revealed that when using coordinate data of lateral and medial foot markers the instants of touchdown and take-off during sprint running contacts could be determined to between 0.003 and 0.005 s of the force data-derived criterion measure. The RMS differences derived in this investigation were equivalent to a resolution of measurement of at least 200 Hz, and provided a similar level of accuracy to that reported by Hunter et al. (2004), who identified the instant on touchdown to within one field at 240 Hz in 93% of trials. However, Hunter et al. (2004) did not identify the instant of take-off. The findings of this study suggested that two markers located on each of the lateral and medial aspects of the foot could be used to identify the instants of touchdown and take-off in a sprint run. Markers located superior to the first inter-phalangeal joint of the second toe, lateral to the distal end of the fifth toe, lateral and superior to the distal end of the first toe and superior to the first inter-phalangeal joint of the second toe [H], medially produced the highest level of agreement between marker-derived event times and force data-derived times.

Investigations of lateral and medial marker sets of the foot were necessary to accommodate laboratory-based data collections in which a unilateral scanner was used to track bilateral sagittal plane motions. For example, markers located on the lateral aspect of one foot and the medial aspect of the second foot are necessary to quantify right and left lower body kinematics. Individuals also potentially produce ground contact with varying foot positions. Six subjects were therefore used in this study to ensure that the defined marker locations produced consistently small RMS differences between the criterion and experimental values in order that a standard marker protocol could be employed in future data collections.

The standing trial thresholds yielded the lowest RMS values. However, the peak vertical acceleration threshold also produced low RMS differences of between 0.005 to 0.007 s for touchdown and take-off with the lateral and medial marker sets, which suggested that the peak vertical acceleration threshold could be used when the collection of a standing trial is not possible. For example, the vertical displacement threshold for sprint contacts on a banked curve may be difficult to derive. The peak vertical acceleration approach may subsequently be applied as an alternative approach to deriving event times in sprinting.

CONCLUSION:

When using vertical displacements of lateral and medial foot markers produced during a standing trial, touchdown and take-off events in sprinting could be accurately identified to between 0.003 and 0.005 s of a force data-derived criterion measure. The identification of the occurrence of touchdown and take-off are important during biomechanical analyses of sprinting for the calculation of step characteristics and the identification of performance-related kinematics such as joint angles and angular velocities at these key events in the sprint cycle.

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