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Short communication

A kinematic method to detect foot contact during running for all foot strike patterns

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ABSTRACT

The biomechanics of distance running are studied in relation to both understanding injury mechanisms and improving performance. Kinematic methods must be used to identify the stance phase of running when data are recorded during running on a standard treadmill or outside the laboratory. Recently, a focus on foot strike patterns has emerged in the field. Thus, there is a need for a kinematic method to identify foot contact that is equally effective for both rearfoot and non-rearfoot strike patterns. The purpose of this study was to determine whether a new kinematic method could accurately determine foot contact during running in both rearfoot and non-rearfoot strikers. Overground gait data were collected at on 22 runners, 11 with a rearfoot strike pattern and 11 with a non-rearfoot strike pattern. Data were processed to identify foot contact from: vertical ground reaction force, two previously published kinematic methods, and our new kinematic method. Limits of agreement were used to determine bias and random error of each kinematic method compared to ground reaction force onset. The new method had comparable random error at 200 Hz sampling frequency (5 ms per frame) to the previous methods (7 frames vs 6–9 frames) and produced the same offset for both strike patterns (3 frames), while the existing methods had different offsets for different strike patterns (4 or 7 frames). Study findings support use of this new method, as it can be applied to all running strike patterns without adjusting the frame offset, simplifying data processing.

1. Introduction

The biomechanics of distance running are studied in relation to both understanding injury mechanisms and improving performance. Typically, previous studies of running biomechanics have included only rearfoot strikers, which represent the majority of distance runners (de Almeida et al., in press). However, a recent focus on non-rearfoot strikers has emerged in the field. The stance phase of running is often of interest and is usually determined from force platform contact during laboratory studies. However, kinematic methods to identify the stance phase must be used when data are recorded during running on a standard treadmill or outside the laboratory environment.

There are several published methods for determining foot contact during gait from kinematic data. However, these were developed primarily for walking and may not be as effective for running gait given fundamental differences between the two, such as presence of a flight phase in running. A recent study tested several previously published kinematic methods for either walking or running that assessed data collected from rearfoot striking runners (Fellin et al., 2010). These authors reported that two of the methods were also suitable for determining foot contact in rearfoot striking runners. These were: (1) the time of minimum vertical position of the distal heel marker; and (2) the change in vertical velocity of this marker from negative to positive. However, given the focus of these methods on heel motion, it is unclear whether they would also be effective in identifying foot contact in non-rearfoot striking runners. It may be that different methods give the best results for rearfoot strikers and non-rearfoot strikers. If so, this would add an additional step of identifying foot strike pattern using kinematic methods prior to implementing a specific foot contact algorithm. This extra step would necessitate either collection of video data or pre-evaluation of kinematic data. Several kinematic methods for determining foot contact have been compared in a group of runners with rearfoot, midfoot, and forefoot strike patterns (Smith et al., 2015). Unfortunately, different error magnitudes were found for the best algorithm among strike patterns, which may hinder its use with non-rearfoot strikers. Recently, a kinematic method which can identify foot contact for

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all strike patterns has been reported (Osis et al., 2014). However, it uses a principal components analysis technique, which is computationally demanding to implement. With the recent interest in the effects of different strike patterns on running biomechanics, there is a need for a kinematic method to identify foot contact that is both simple to implement and equally effective for all strike patterns during running.

Existing kinematic methods for identifying foot contact incorporate some aspect of foot kinematics into their algorithm. This may be a limiting factor, as there are large differences in foot kinematics at contact across foot strike patterns. A method that focuses on the common kinematics of a more proximal segment may be equally effective across all strike patterns. The center of mass moves downwards during terminal swing phase, from its peak height during the flight phase at midswing (Novacheck, 1998). We anticipated that movement of the pelvis would closely track the center of mass in moving downwards rapidly from midswing to foot contact. Since this occurs during the swing phase, pelvis vertical velocity would likely be independent of footstrike pattern. Thus, we propose that the peak downward velocity of the pelvis may be a consistent feature of foot contact in all strike patterns. The purpose of this study was to determine whether our new method could be used to determine foot contact accurately during running in both rearfoot strikers and non-rearfoot strikers. The new method and two previously published methods were compared to the gold standard of onset of vertical ground reaction force. We hypothesized that the new method was as effective as previous methods in identifying foot contact, and that it was equally effective for rearfoot and non-rearfoot strikers.

2. Methods

As part of a larger study of foot strike patterns, 22 runners were recruited. Participants were currently healthy runners between 18 and 45 years of age who reported at least 10 miles per week of running for the last year or more. Participants were excluded if they were currently injured, reported a lower extremity injury during the past 6 months, or had any history of major lower extremity injury. Half of the sample were rearfoot strikers (age 29 ± 7 y; height 1.75 ± 0.11 m; mass 65.9 ± 12.5 kg; weekly mileage 37 ± 21 miles; 4 women) and the other half non-rearfoot strikers (age 30 ± 7 y; height 1.76 ± 0.09 m; mass 68.2 ± 13.0 kg; weekly mileage 35 ± 16 miles; 3 women). Non-rearfoot strikers were 2 forefoot strikers and 9 midfoot strikers. All procedures were approved by the local Institutional Review Board. All participants provided written informed consent prior to participation in the study. Foot strike pattern was determined by strike index (Cavanagh and Lafortune, 1980). As per Cavanagh and Lafortune (1980), runners with an initial stance phase center of pressure location in the rearmost third of the foot were classified as rearfoot strikers. Runners with a more anterior initial center of pressure location were classified as non-rearfoot strikers.

Retro-reflective markers were attached to the right lower extremity and pelvis on anatomical landmarks and thermoplastic shells (Brindle et al., 2014). Briefly, anatomical markers used to define joint centers were placed on the malleoli, first and fifth metatarsal heads, femoral epicondyles, greater trochanters, and iliac crests. Thermoplastic shells mounted with four non-collinear tracking markers were attached using neoprene underwraps and hook and loop tape to the pelvis, thigh, and shank (Manal et al., 2000). Three non-collinear markers were attached to the heel. All participants wore standard laboratory footwear which allowed access to the heel. Following a standing calibration trial to establish segment coordinate systems and joint centers, anatomical markers were removed. Participants ran at 3.7 m/s ± 5% across the laboratory, making contact with a force platform embedded in the middle of the floor. Five successful trials were collected, in which participants made contact with the foot fully on the force platform without visual targeting. This yielded 110 trials for analysis. Data were recorded with a motion capture system sampling at 200 Hz and synchronized force platform sampling at 1000 Hz.

Data were processed using Visual3D software (C-Motion Inc., Germantown, MD) for rigid body analysis using joint coordinate systems (Grood and Suntay, 1983). Segment coordinate systems were defined according to published standards (Cole et al., 1993). The variables of interest were the frame of foot contact determined according to two previously published methods (Fellin et al., 2010), a new method, and the gold standard of onset of vertical ground reaction force (20 N threshold). The published methods were the frame of minimum vertical position of the heel marker and the frame when the heel marker vertical velocity changed from negative to positive. The new method was the frame of maximum downward velocity of the pelvis center of mass. The 95% limits of agreement (Bland and Altman, 1986) were used to determine bias and random error in each method compared to the gold standard. Root mean square error was also calculated to enable comparison with previous work.

3. Results

The 95% limits of agreement were comparable among techniques and ranged between seven and nine frames, with an offset of three to five frames for the sample as a whole (Figs. 1–3). However, when rearfoot and non-rearfoot groups were considered separately, differences between the new method and the published methods became apparent (Table 1). In particular, the offset was the same for both foot strike patterns with the new method, but differed between foot strike patterns for both published methods. When the three frame offset was incorporated into the new method, foot strike for 99% of the trials was identified within four frames (20 ms) of force plate contact. Furthermore, 95% of the trials were identified within 3 frames (15 ms) of force plate contact. Root mean square (RMS) error was 1.3 frames (6.5 ms).

4. Discussion

The purpose of this study was to determine whether a new method and two published methods to determine foot contact were able to identify foot contact in both rearfoot and non-rearfoot striking runners. Results were comparable among methods

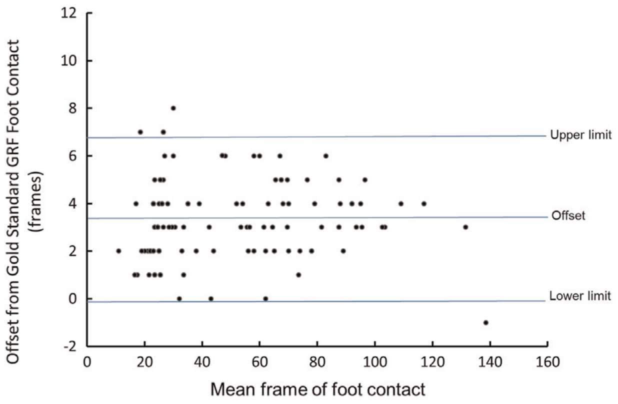

Fig. 1. Bland–Altman plot for the proposed method of identifying foot contact (frame of maximum pelvis downward velocity), illustrating the bias (offset), and the 95% limits of agreement (random error).

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