Journal of Biomechanics 47 (2014) 1588–1593

Contents lists available at ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

A simple field method to identify foot strike pattern during running

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ARTICLE INFO

Article history:
Accepted 3 March 2014

Keywords:
Accelerometers
Running pattern
Incline running
Field
Classification

ABSTRACT

Identifying foot strike patterns in running is an important issue for sport clinicians, coaches and footwear industrials. Current methods allow the monitoring of either many steps in laboratory conditions or only a few steps in the field. Because measuring running biomechanics during actual practice is critical, our purpose is to validate a method aiming at identifying foot strike patterns during continuous field measurements. Based on heel and metatarsal accelerations, this method requires two uniaxial accelerometers. The time between heel and metatarsal acceleration peaks (THM) was compared to the foot strike angle in the sagittal plane (α_{foot}) obtained by 2D video analysis for various conditions of speed, slope, footwear, foot strike and state of fatigue. Acceleration and kinematic measurements were performed at 1000 Hz and 120 Hz, respectively, during 2-min treadmill running bouts. Significant correlations were observed between THM and α_{foot} for 14 out of 15 conditions. The overall correlation coefficient was $r=0.916$ ($P<0.0001$, $n=288$). The THM method is thus highly reliable for a wide range of speeds and slopes, and for all types of foot strike except for extreme forefoot strike during which the heel rarely or never strikes the ground, and for different footwears and states of fatigue. We proposed a classification based on THM: FFS < -5.49 ms $<$ MFS < 15.2 ms $<$ RFS. With only a few precautions being necessary to ensure appropriate use of this method, it is reliable for distinguishing rearfoot and non-rearfoot strikers in situ.

1. Introduction

Among the biomechanical features of running locomotion, three foot strikes have been identified: a rearfoot strike (RFS) in which the heel lands before the ball of the foot, a midfoot strike (MFS) in which the heel and the ball of the foot land quasi-simultaneously, and a forefoot strike (FFS) in which the ball of the foot lands before the heel. Foot strike may be influenced (or not) by ethnic group (Hatala et al., 2013; Lieberman et al., 2010), footwear (Horvais and Samozino, 2013; Squadrone and Gallozzi, 2009; Warne and Warrington, 2012; Willy and Davis, 2013), speed or the athlete's level of performance (Hasegawa et al., 2007; Hayes and Caplan, 2012; Kasmer et al., 2013; Larson et al., 2011). Many recent studies have investigated whether or not foot strike influences impact (Giandolini et al., 2013a; Lieberman et al., 2010), running economy (Gruber et al., 2013; Perl et al., 2012; Warne and Warrington, 2012), or the risk of running-related injuries (Daoud et al., 2012; Giuliani et al., 2011). From an epidemiological standpoint, studies have aimed to classify foot strikes among different populations of runners (Hasegawa et al., 2007; Hayes and Caplan, 2012; Kasmer et al., 2013; Larson et al., 2011).

Most of the studies aiming to identify running patterns have hitherto used 2D motion analysis. In some of them, using high-speed cameras, markers were set on the subject and/or shoes in order to assess the foot strike angle, i.e. angle between the running surface and the plantar surface (Daoud et al., 2012; Lieberman et al., 2010). A positive angle indicates a RFS, a negative angle indicates an FFS and an $\sim 0°$ indicates an MFS. Daoud et al. (2012) used a 500-Hz camera and declared the MFS when the metatarsals and heel stroke were within two consecutive milliseconds. Other studies classified patterns according to their point of initial contact during races in larger samples using a frame-by-frame analysis (Hasegawa et al., 2007; Kasmer et al., 2013; Larson et al., 2011). These studies typically used 120 to 300-Hz cameras, and such a video analysis presents some inevitable drawbacks. First, a frame-by-frame analysis is necessary to accurately detect the exact moment of contact, a

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http://dx.doi.org/10.1016/j.jbiomech.2014.03.002
0021-9290/

method of uncertain accuracy and operator-dependent. It is therefore quite subjective, and requires high-frequency cameras and/or analysis by several experimenters (Kasmer et al., 2013; Lieberman et al., 2010). Second, there are limitations in terms of the number of steps analyzed and the measurement conditions. To date, experimenters have either recorded many steps on a treadmill, or have investigated running patterns in field conditions but have recorded only one to four steps for each subject and trial. However, intra-individual step variability should not be neglected (Belli et al., 1995),

Measurements of vertical ground reaction force (VGRF) with a force platform or an instrumented treadmill can also be used to identify RFS, MFS and FFS. Whereas RFS generates an impact peak ~25 ms after foot strike, this impact peak does not usually occur with FFS and is often absent in MFS (Cavanagh and Lafortune, 1980; Dickinson et al., 1985; Giandolini et al., 2013a; Lieberman et al., 2010). Impact peak is therefore used as a practical kinetic indicator to distinguish between patterns. However, no study directly supports this relationship and the presence or absence of an impact peak may be related to many other parameters (e.g. footwear, step frequency, and speed). Force plates are also used to determine the foot strike index, defined as the position of the center of pressure at landing relative to the foot length (Cavanagh and Lafortune, 1980). According to these authors, RFS is described by a foot strike index lower than 33%, MFS by an index ranging between 34% and 66%, and FFS by an index higher than 67%. However, since FFS is defined by an initial strike on the metatarsals, the 4th and 5th metatarsal heads are often located below 67%, which lead to confusion between MFS and FFS (Lieberman, 2012). Note that the foot strike index, assessed by force plate, and the foot strike angle are strongly correlated (Altman and Davis, 2012). Nevertheless, these kinetic methods also present some limitations. Field measurements are hardly feasible, and although using a force platform may facilitate this, experimenters typically measure only one step per trial.

Considering the aforementioned limits of existing methods, our purpose was to validate a simple method using continuous measurements to identify the running pattern in situ. This method is based on acceleration measurements through accelerometers located on the heel and metatarsals. In addition to being simple and inexpensive, these devices are light, small and wireless. It thus causes no inconvenience to the runner and consequently can easily be used in the field.

2. Methods

This study was divided into two protocols (Fig. 1): *validation*, to test the influence of slope, speed and foot strike on the method; and *application*, to test the effects of footwear, speed and fatigue on the method's reliability. Data analysis was the same for both protocols. Subjects were recruited after giving their informed written consent for the study, which was approved by the local ethics committee and conducted in agreement with the Declaration of Helsinki (Clinical trial NCT01602146).

2.1. *Validation protocol*

2.1.1. *Subjects*

Fourteen experienced runners (11 males and 3 females, 24.6 ± 10.3 years, 177 ± 6 cm, 68.1 ± 8.9 kg) were recruited. They wore the same running shoes (Salomon XR Mission CS™, mass: 325 g, heel height: 20 mm, drop: 11 mm). Naturally, 61% of the subjects were rearfoot strikers, 31% midfoot strikers and 8% forefoot strikers (according to video analysis of their preferred running speed).

2.1.2. *Experimental design*

Two weeks before the experiment, the preferred running speed (PRS) of each subject was assessed during a 10-min level treadmill running bout as previously proposed (Giandolini et al., 2013a, 2013b). The average PRS obtained was 12.3 ± 2.8 km h^{-1}. On the day of the experiment, after a standardized warm-up, subjects performed 2-min running bouts in ten randomized conditions (Fig. 1A). In level running, the subjects performed eight conditions: at their PRS with their natural foot strike pattern (no instruction), with a RFS, an MFS, and an FFS; they repeated these four conditions at 14 km h^{-1} for females and 16 km h^{-1} for males.

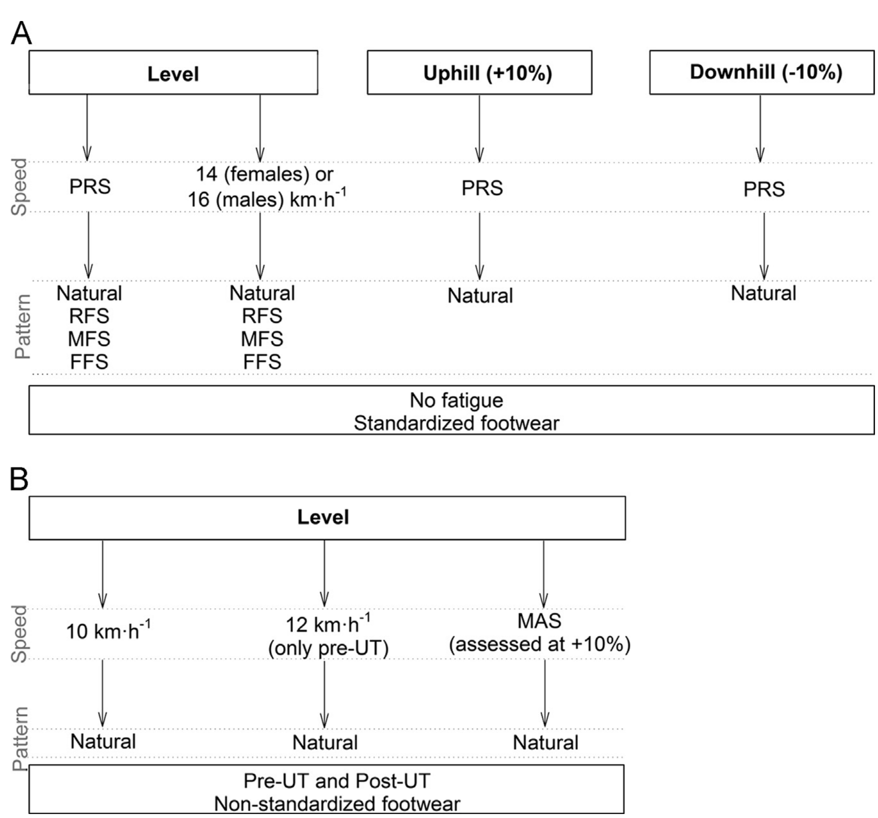

Fig. 1. Description of *validation* (panel A) and *application* (panel B) protocols. In *validation*, each subject performs ten conditions: eight with different speeds and foot strike patterns in level running, one in uphill and one in downhill running. In *application*, three conditions are completed: one before the race and two after the race.