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Short communication

Comparison of accelerometry stride time calculation methods

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ABSTRACT

Inertial sensors such as accelerometers and gyroscopes can provide a multitude of information on running gait. Running parameters such as stride time and ground contact time can all be identified within tibial accelerometry data. Within this, stride time is a popular parameter of interest, possibly due to its role in running economy. However, there are multiple methods utilised to derive stride time from tibial accelerometry data, some of which may offer complications when implemented on larger data files. Therefore, the purpose of this study was to compare previously utilised methods of stride time derivation to an original proposed method, utilising medio-lateral tibial acceleration data filtered at 2 Hz, allowing for greater efficiency in stride time output. Tibial accelerometry data from six participants training for a half marathon were utilised. One right leg run was randomly selected for each participant, in which five consecutive running stride times were calculated. Four calculation methods were employed to derive stride time. A repeated measures analysis of variance (ANOVA) identified no significant difference in stride time between stride time calculation methods ($p=1.00$), whilst intra-class coefficient values (all >0.95) and coefficient of variance values (all $<1.5\%$) indicate good reliability. Results indicate that the proposed method possibly offers a simplified technique for stride time output during running gait analysis. This method may be less influenced by "double peak" error and minor fluctuations within the data, allowing for accurate and efficient automated data output in both real time and post processing.

1. Introduction

The use of low cost portable sensors, such as accelerometers and gyroscopes, has become increasingly popular in running gait analysis over the last number of years (Higginson, 2009). Their decreased size and lightweight nature allows easy, ecologically valid attachment whilst still uncovering a multitude of information in a natural environment. Within running gait analysis tibial sensor attachment has been identified as superior in identifying lower limb acceleration patterns as it is close to the area of interest, this being the lower limb (Mathie et al., 2004). This attachment allows for identification of running gait parameters such as stride frequency (Mercer et al., 2002) and ground contact time (Purcell et al., 2006). Of these parameters, stride frequency, and therefore stride time, has been identified as a major contributing factor to running economy and overall run outcome, making it a parameter of great interest (Mercer et al., 2008). Stride time is defined as "time elapsed between the first contacts of two consecutive foot falls of the same foot expressed in milliseconds" (Beauchet et al., 2011), and numerous methods have been previously utilised to identify initial ground contact during running within tibial accelerometer data. Mercer et al. (2003) identified the minimum value before the absolute maximum value in the longitudinal axis as the beginning of foot strike. Mizrahi et al. (2000) identified the absolute maximum value in the longitudinal axis as the point of heel strike. However, there are numerous factors which may affect the ability to accurately and efficiently identify stride time from longitudinal accelerometer data streams utilising these, and similar, methods. Firstly, many studies which have utilised previous stride time calculation methods have done so during treadmill running protocols (Mercer et al., 2003; Mizrahi et al., 2000), taking out any possible effect of alternate terrains on foot strike pattern and stride time calculation. Secondly, previous research (Mizrahi et al., 2000) has used secondary manual confirmation of heel strike through visual observation of data to avoid the inclusion of any "bad" data. These "bad data" may be representative of a stumble or fall, or may be due to sensor movement causing a "double peak" at heel strike. Manual confirmation to confirm the time of heel strike would be inefficient on longitudinal data sets, and where there are "double peak" error it is not possible to correctly distinguish the impact peak from the rebound peak, even using automated processes (Panther and Bradshaw, 2013). Thirdly, running patterns have been found to vary between individuals with different striking patterns, rearfoot and forefoot (Laughton et al., 2003), and may be altered by gait retraining

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programmes and shoe variation (Giandolini et al., 2013). This may affect the validity of using stride time calculation methods utilising heel strike (Mizrahi et al., 2000), across groups of runners. Lastly, peak tibial acceleration during impact has been found to reach up to 147.2 m/s^2 in running studies (Crowell et al., 2010; Flynn et al., 2004), and this may vary during self-paced running on various terrains (Giandolini et al., 2015). This may affect stride time calculation methods using thresholds (Meardon et al., 2011) in tibial acceleration peaks. The current study sought to investigate if stride time derived from 2 Hz filtered, medio-lateral tibial accelerometry data is comparable to previous methods. It is proposed 2 Hz filtered data may produce accurate and comparable results to previous methods, whilst being more efficient due to lack of manual intervention in producing stride time series in expansive, longitudinal data sets. It is also proposed that filtering running data at 2 Hz will retain the dynamics of stride time, whilst being less influenced by "double peak" error, individual foot strike patterns or various running terrains. The proposed method is not reliant on distinct peak acceleration values or individualised acceleration value threshold selection, associated with individual running styles. Lastly, the use of the medio-lateral axis to derive the beginning of ground contact has been previously validated (Purcell et al., 2006) and therefore the current authors wish to ascertain if, when filtered at 2 Hz, it provides comparable results. If valid, our novel method would provide an efficient, robust method of stride time calculation in longitudinal accelerometry data, without the need for manual intervention and/or stride time confirmation, or individualised acceleration thresholds. This would allow for efficient stride time calculation across groups of runners, providing valid results regardless of running style, terrain or pace.

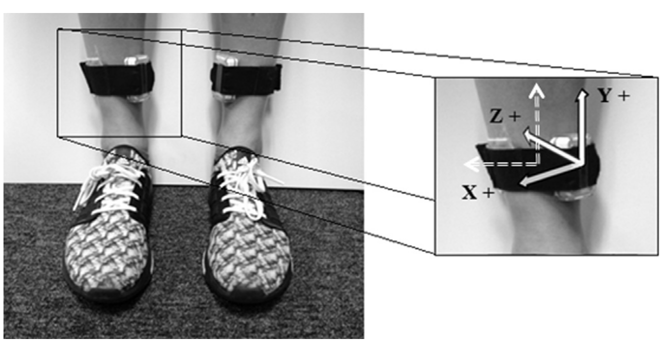

Fig. 1. Bi-lateral accelerometer attachment to the anterio-medial distal tibia. Only data collected from the accelerometer attached to the right tibia was used in this investigation. On a concentrated section of the right tibia, positive axial directions of the accelerometer local coordinate system when attached are superimposed in bold arrows, with vertical and lateral directions of the lower limb global coordinate system superimposed in dashed arrows.

2. Methods

2.1. Participants and instrumentation

Accelerometry data from six (one male, five female) recreational runners (age: 33.5 ± 5.8 years, stature: 1.66 ± 0.08 m, mass: 71.1 ± 12.2 kg) undertaking a half marathon training programme were utilised. During this half marathon training programme participants ran at a self-paced speed, which they could alter as they wished through alterations in stride time and stride frequency. Participants also ran on freely chosen terrain. This resulted in the extracted accelerometry data representing recreational running in its most natural, uncontrolled form, with variance between participants providing a range of tibial accelerometry data. Informed consent was collected prior to data collection. Participants were required to attach a tri-axial Shimmer 2r sensor (SHIMMER, Dublin, Ireland) to their anterio-medial distal tibia bi-laterally for each training run (n=48), and the event itself (total distance covered +340 km) (Fig. 1). Accelerometers were self-attached by the participants via a purpose built elastic strap (accelerometer mass: 28 g, combined accelerometer and strap mass: 48 g) with the sensor placed inward, toward the tibia, to prevent further movement. Prior to distribution a demonstration of sensor attachment was provided and sensors underwent static calibration every three weeks, following manufacturer 9DOF application methods. As sensor attachment is medial on the anterior tibia, the static calibration resulted in a local sensor coordinate system not directly aligned with the global coordinate system of the lower limb. Therefore, when attached the sensor allowed for the collection of an approximate estimate of tibial medio-lateral acceleration in the x axis, tibial vertical acceleration in the y axis and tibial anterior-posterior acceleration in the z axis. When attached to the tibia a positive vertical acceleration was directed proximally, positive medio-lateral acceleration was directed laterally and positive anterio-posterior acceleration directed posteriorly. Data were sampled at 204.8 Hz (±6 g, sensitivity=200 mV/g). Training comprised of four runs per week for twelve weeks of a popular Hal Higdon (Hal Higdon 2014) half-marathon 'novice' programme.

2.2. Data analysis

For this analysis accelerometry data collected from the Shimmer 2r sensor attached to each participants right leg were chosen from one randomly selected run (containing up to 7 million data points). Standing periods performed by the participants pre- and post each run indicated run start and completion. Accelerometer run data were corrected for static tilt, calculated during the standing period, with x and z axis corrected to 0 m/s^2 and y corrected to +9.81 m/s^2. Preliminary data processing was performed for all files using a custom built LabView (National Instruments, Newbury, UK) programme. Data containing six consecutive impact peaks were chosen at random from the file, resulting in the calculation of 5 strides for each participant. The number of strides derived was chosen due to manual calculation of strides in methods 2–4, and also as previous research (Wixted et al., 2010) has utilised similar amounts of running data in accelerometer

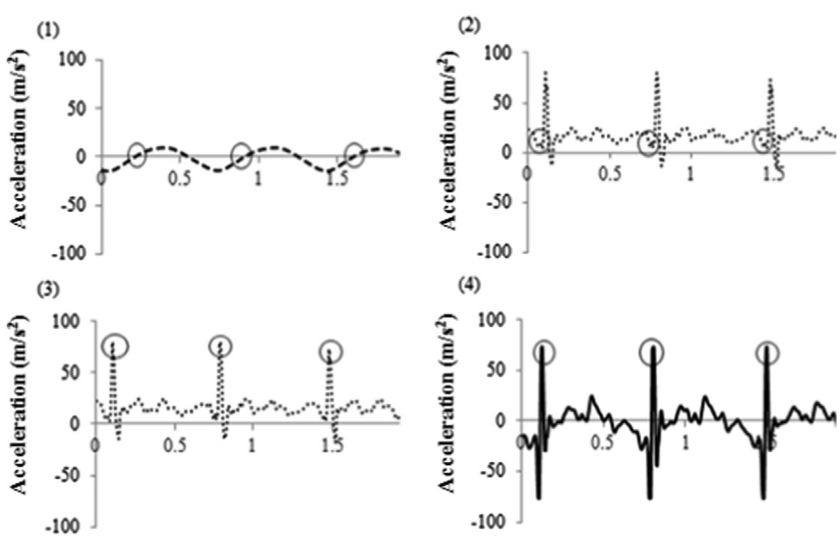

Fig. 2. Acceleration patterns (m/s^2) for a representative two second running trial. Identification of beginning/end of stride times for M1–M4 as identified by the circle.