Extraction of running stance phase using tibial acceleration

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Introduction: The running cycle is defined by two phases: the stance phase, when the foot is in contact with the ground, and the swing phase that brings the leg forward. These two phases are delimited by two events: the Initial Contact (IC) and the Toe-Off (TO) when the foot hit and leave the ground respectively. The Stance Time (ST) is the duration from IC to TO. Accurate identification of these events is essential for gait phases description. Using Vertical Ground Reaction Force (VGRF) is a common method for identification [1], but it is primarily constrained to limited space and are generally used in laboratory settings. Wearable technology, particularly accelerometers, has become one of the viable alternatives to outdoor environments [2]. However, the actual methodology requires several sensors for proper extraction, and the locations of the sensors does not always allow the extraction of repeatable signals (i.e. on the shoe or on the tibia). The purpose of this study was to extract the stance time using only the tibial acceleration.

Method: This study was approved by a local ethical committee. One volunteer was asked to run at a constant speed 100 trials on a straight line instrumented with 3D force platforms to collect the VGRF (used as reference). Two 3D accelerometers were placed at the distal extremity of the medial surface of both tibias to collect the acceleration signals. The IC and TO are defined when the VGRF first rose above 10 N and then reduce to 25 N respectively [1]. As the occurrence of impact peak (IP) is restricted to a specific range during the running cycle, the positions of IC and TO were deduced from the position of IP. First, a Region Of Interest (ROI) was defined to localize IC and TO events based on the trials, the ROI for the IC was defined between 6 and 6.5 % of the step duration before the IP, the ROI for the TO was defined between 48 and 50 % of the step duration after the IP.

Then, events were detected with a computer algorythm based on the defined ROI. For IC, if there was only one maximum in the ROI (which is the IP), IC was detected as the nearest extremum before the beginning of the ROI. If there were two maxima in the ROI, IC was assumed as the midpoint between the nearest extremum before the beginning of the ROI and the first maximum. If more than two maxima existed in the ROI, IC was the point counting backward two maxima from the IP. For TO was detected as the minima before the beginning of the ROI.

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In this study, right and left data were mixted as a 200 sample dataset. The relative error of event detection was calculated between the IC, TO and ST extracted from the longitudinal acceleration signals and the VGRF signals to assess the extraction performance. Good extraction was considered if the error is 5 % or less. The whole method was considered as valid only if the percentage of good extraction is 95 % of the 200 extractions or more. Figure 1 shows a good extraction. In this case errors were 0.95 %, 1.58 % and 2.53 % for IC, TO and ST detection respectively.

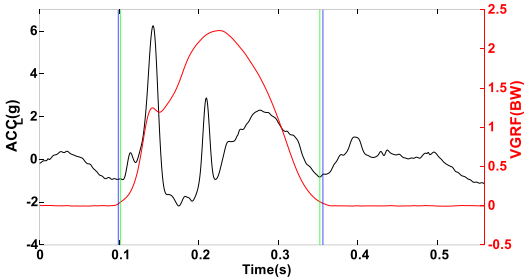

Fig. 1: Acceleration signal of a running step (black curve) and for force signal (red curve). Good extraction of IC and TO from the longitudinal acceleration (green line) compared to the one from the VGRF (blue line)

Results: The results showed that the detection of IC and TO were good with low errors (Table 1). In these cases at least 95% of the extraction were considered as good. For ST, if the mean error was relatively low (3.01 ± 2.18 %) the percentage of good extraction remained under the criteria and did not validate the methodology.

Table 1: Relative error for IC, TO and ST instants detection.

	Max error (%)	Mean error ± SD (%)	Good extraction (%)
IC	4.98	1.51 ± 1.50	100
TO	8.93	2.09 ± 1.09	95
ST	9.38	3.01 ± 2.18	82

Discussion: The methodology proposed in this study was able to detect IC and TO using only one accelerometer on the tibia during running. If the number of good extraction is still to improve for ST, as it cumulates the errors of IC and TO, the mean results were smilar to the literature using several sensors [2]. Perspective work should focus on the detection of false positive or negative to classify the error, and investigate whether different subjects and the running variations (speed, technics…) impact on the detection.

1. Hunter JP, Marshall RN, McNair PJ (2015) Relationships between ground reaction force impulse and kinematics of sprint-running acceleration. J. Appl. Biomech 21: 31–43.
2. Mo S, Chow DHK (2018) Accuracy of three methods in gait event detection during overground running. Gait Posture 59:93-98.

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