Development and Validation of an Algorithm for Foot Contact Detection in High-Dynamic Movements using Inertial Measurement Units

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Summary

This study developed an algorithm based on Inertial Measurement Units (IMUs) for foot contact detection (FCD) during high-dynamic sports movements. Data were collected using a force plate and IMU sensors. Two algorithms, one based on pelvis vertical velocity (PVV) and one on resultant foot acceleration (RFA), were tested to detect initial contact (IC) and toe-off (TO) during changes of direction and sprints with deceleration tasks. Both algorithms were compared to force plate data, used as the ground truth. Optimal results were achieved by combining the two algorithms, resulting in minimal error for both IC and TO (median=15.67ms, IQR<90ms). This hybrid approach provides a reliable alternative to force plates for analysing complex, sport-specific movements in real-world settings through IMUs.

Introduction

Wearable IMUs offer a promising alternative to traditional laboratory-based motion capture systems in biomechanical studies, providing more reliable insights under real-world, sport-specific conditions [1]. The proper detection of foot contact is pivotal to provide accurate IMU-based biomechanics when force plate is not available. [2]. However, FCD algorithms have mostly been explored in the context of gait analysis, leaving a gap in understanding their reliability for high-dynamic movements, such as changes of direction and sprints with deceleration. These movements, common in sports, are associated with a greater risk of musculoskeletal injuries, such as anterior cruciate ligament (ACL) ruptures [3]. This study aimed to develop a FCD algorithm to identify a reliable IMU-based solution suitable for application in sport-specific and high-dynamic movements, in real-world settings.

Methods

Thirty-four healthy athletes were involved in the study and asked to perform two high-dynamic movements, a 90° change of direction and a sprint with deceleration task. Data were collected using a force plate (1000Hz, Vicon Motion Systems Ltd.) and 8 wearable IMUs (60Hz, MTw Awinda, Xsens) placed on the lower limbs and trunk (Figure 1). A total of 302 trials were acquired (164 changes of direction, 138 sprints with deceleration), out of which 47 were excluded from the analysis due to errors in manual triggering during acquisition. Two different algorithms were developed to identify IC and TO events for accurate FCD using IMUs. The first algorithm was based on PVV, while the second one used RFA. Both approaches aimed to detect all foot contact windows within a trial, selecting the largest window as the target one. The two algorithms were evaluated by comparing the detected IC and TO events with those derived from the analysis of force plate measurements, which served as a reference. To assess the accuracy of the newly developed algorithms, the median offset and interquartile range (IQR) between the windows detected by the reference system and those identified by PVV and RFA, respectively, were calculated.

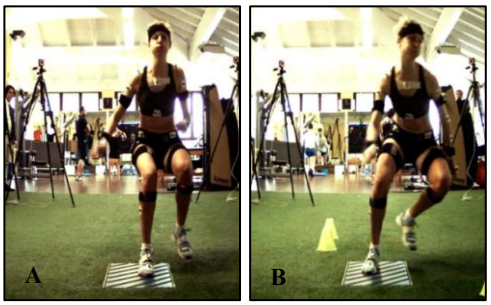

Figure 1: Athlete equipped with IMUs, performing sprint with deceleration (A) and change of direction (B), with force platform and motion capture cameras included in the setup.

Results and Discussion

For IC detection, the PVV algorithm achieved a median offset of -16.67ms (IQR = 77.83), while the RFA algorithm showed a median offset of 11.17ms (IQR = 166.67). For TO detection, the PVV algorithm had a median offset of 102.83ms (IQR = 83.33), compared to 15.67ms offset (IQR = 88.83) for the RFA algorithm. Both algorithms failed to detect IC and TO in one file due to unrecognized patterns. Based on these results, a mixed algorithm was developed, combining IC detection from PVV and TO detection from RFA. The mixed algorithm achieved a median offset of -15.67ms (IQR = 77.83) for IC and 15.67ms (IQR = 88.83) for TO. Bland-Altman plots revealed 38 outliers (14.9%), primarily linked to complexity in pattern recognition and inconsistencies between the ground truth and the PVV and RFA curves.

Conclusions

An IMU-based algorithm combining PVV and RFA were developed and validated for FCD during high-dynamic and sports movements. This algorithm offers a robust solution for clinical applications by accurately identifying multiple footsteps in ecological scenario.

References

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