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# Agreement of Gait Events Detection by Inertial Measurement Units and an open source Markerless End-to-End Workflow?

Ahmed Yacine LARDJANE \*

LAMIH, CNRS, UMR 8201, Univ. Polytechnique Hauts-de-France, Valenciennes, France.

IRT Railenium, Valenciennes, France.

Mathias BLANDEAU

LAMIH, CNRS, UMR 8201, Univ. Polytechnique Hauts-de-France, Valenciennes, France

Laura WALLARD

LAMIH, CNRS, UMR 8201, Univ. Polytechnique Hauts-de-France, Valenciennes, France

Christopher PAGLIA

IRT Railenium, Valenciennes, France.

Christophe GILLET

LAMIH, CNRS, UMR 8201, Univ. Polytechnique Hauts-de-France, Valenciennes, France

Sébastien LETENEUR

LAMIH, CNRS, UMR 8201, Univ. Polytechnique Hauts-de-France, Valenciennes, France

Emilie SIMONEAU-BUESSINGER

LAMIH, CNRS, UMR 8201, Univ. Polytechnique Hauts-de-France, Valenciennes, France

\*Corresponding author. Email: [AhmedYacine.Lardjane@uphf.fr](mailto:AhmedYacine.Lardjane@uphf.fr)

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## 1. Introduction

Precise spatiotemporal calculation and proper analysis of kinematic and kinetic variables during walking depend on gait cycle events, usually detected by force plates. Those variables are widely used by clinicians, but also in urban planning, particularly for pedestrian crossing where walking speed is investigated in different environments, such as roads or railways stations (Grison et al. 2022). Motion capture outside laboratories is challenging, leading to the rise of accelerometer-based Inertial Measurement Units (IMUs) as a popular alternative. Markerless motion analysis technologies have emerged, with numerous commercial systems available. However, these

systems can be costly and often rely on proprietary code and datasets for their training (Wade et al. 2022). Pose2Sim represents a recent breakthrough in markerless motion capture. This open source workflow uses 2D pose estimation data from videos, leveraging validated open source pose estimation models such as OpenPose and AlphaPose, as well as custom-trained models through open source tools like DeepLabCut. Pose2Sim identifies and associates individuals, accurately triangulates joint positions, and integrates with an OpenSim model (Pagnon et al. 2022). It supports any type of camera, broadening its applicability across various study settings. Despite extensive research in IMU and kinematics for walking event estimation, literature lacks a comparative analysis between open source, markerless motion capture solutions and gold standards. This study aims to evaluate the agreement of three open source algorithms for walking events detection from force plates, IMU and videos.

## 2. Methods

### 2.1 Protocol

Four Kistler Type 9286 force plates (500Hz), 4 Delsys Trigno IMUs (370Hz) and 5 Miquis video cameras (25 Hz), mounted on the wall, ensuring a full view of the entire walkway were used in this study. All devices were synchronized by Qualisys software. IMUs were attached to the participants' first metatarsals and the lateral aspects of their heels. The study included one healthy young male (age: 31 yrs, 1.73 m, 71 kg) who walked on a 5-meters corridor equipped with the force platforms, turned around, and returned. A valid trial required a complete foot contact per force plate. The participant kept a forward gaze, avoiding force plate targeting. A total of 125 shoed and 125 barefoot walks were completed. Rest periods were given every 15 trials, and a 5-minutes break after 45 trials.

### 2.2 Data analysis

For both conditions, reference events were identified using force platform data on Matlab, with heel strikes (HS) and toe-offs (TO) when the vertical force exceeded or dropped below 20N, respectively (Blandeau et al. 2023). For the IMU, a first-order low-pass Butterworth filter with a 10Hz cutoff was applied to acceleration data, while a first-order band-pass Butterworth filter, spanning 0.001 to 5Hz was applied to gyroscope data. Then both acceleration and gyroscope data were smoothed using a Savitzky-Golay filter on the flexion axes. Maximum and minimum points of these filtered signals were identified as HS and TO, respectively (Gottlieb et al. 2020). For videos processing, body's keypoints were identified using the opensource BODY\_25B OpenPose model as it is the

most accessible pre-trained model (Stenum et al. 2023) and were processed using Pose2Sim end-to-end workflow. Events were then identified as proposed in Zeni, et al. (2008). All codes are open source and available on <https://github.com/yacine1007/imu-pose2sim-fp>

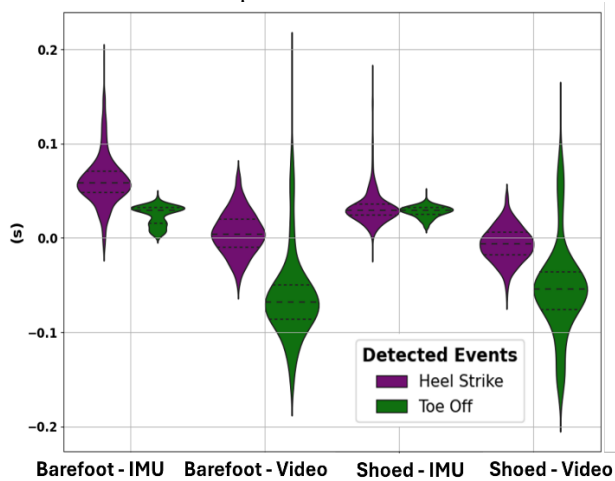
### 3. Results and discussion

In total, 305 and 350 footsteps were validated in barefoot and shoed conditions, respectively. The mean error results are presented in Table 1 and Figure 1.

**Table 1.** Mean error and SD (in seconds) between IMU and video algorithms and force platforms.

	Heel Strike		Toe-Off	
	IMU	Video	IMU	Video
<b>Barefoot</b>	0.060*	0.005*	0.024*	-0.068*
	±0.020	±0.022	±0.010	±0.047
<b>Shoed</b>	0.030*	-0.006*	0.028*	-0.050*
	±0.020*	±0.018	±0.006	±0.050

\* Represents a significant difference ( $p < 0.05$ ) in gait event detection between IMU or Video and force platforms



**Figure 1.** Mean errors distributions (in seconds) between algorithms and force platforms

A Shapiro-wilk test was applied to verify the normality of the data, followed by a non-parametric Friedman ANOVA in all conditions. For both barefoot and shoed conditions, the applied tests revealed a significant difference between gait event detection for both HS and TO obtained with IMU and video compared to data obtained with force platforms, ( $p < 0.001$ ). Our results are in line with the studies of Blandeau et al. (2023) and Stenum et al. (2023). In both shoed and barefoot conditions, IMUs errors were less dispersed than videos' errors (Figure1), this might be due to optimal IMU placement on the metatarsal and their higher

capture rate (Gottlieb et al. 2020). The distribution of video errors was mostly negative, suggesting a detection that occurred after the event happened. This could be attributed to a misdetection by the model and to the low recording rate. Improving the recording rate might enhance the model accuracy.

### 4. Conclusions

This study aimed to evaluate the agreement among open source algorithms using force plate data, video analysis and IMU for gait event detection. All three methods detected walking events (HS and TO). Although errors were detected, results align with previous studies, encouraging the use of open source models. However, it must nevertheless be done carefully. Further investigations should be conducted on larger samples under different conditions.

### 5. Conflict of Interest Statement

The authors declare no conflict of interest.

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