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# Validation of on-board algorithms for detecting walking events during Nordic walking

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## 1. Introduction

Over the past 15 years, Nordic Walking has become increasingly popular due to its enjoyable nature and ease of access. This physical practice is recommended during rehabilitation for its social and psychological benefits (Wallard et al. 2023), but also its ability to improve gait patterns or reduce gait deterioration (Ben Mansour et al 2018). The biomechanical analysis of any clinical activity such as Nordic walking is based on the detection of gait events (heel strike (HS) and toe-off (TO)), making it possible to normalize motion over strides (Perry 1992). Gait events are generally detected in the laboratory using a force platform or using algorithms based on kinematic data from optoelectronic systems. Few articles have investigated the accuracy of these algorithms in Nordic walking (Blandeau et al. 2023), despite the fact that this movement is different from conventional walking, in particular due to the synchronization of foot and wrist movements by the poles. In addition, these articles are incompatible with the ecological situation required for Nordic walking practice. However, the development of inertial measurement units (IMUs) in the field embedded event detection represents an interesting alternative for this practice. The aim of this study is therefore to test and validate the accuracy of an on-board algorithm for detecting walking events (measured at the feet and wrists) during Nordic walking.

## 2. Methods

### 2.1 Participants

Eleven subjects (4 women and 7 men; Age:  $48.8 \pm 25.1$  years; Weight:  $69.4 \pm 5.4$  kg) practicing a regular physical activity and with no pathologies limiting the practice of Nordic walking took part in the study. Each subject participated voluntarily in the study, which received a favorable opinion from the CER STAPS n°IRB00012476-2023-19-12-285.

### 2.2 Protocol

Forty-nine markers were positioned on the participants according to the IOR model. The 3D trajectories of the markers were recorded using a QUALISYS motion capture camera system. Four IMUs (Xsens Awinda) were positioned on each participant's wrist and foot (dorsal surface). Participants had to complete 3 passages in a straight line in a ten meters long corridor, using Nordic walking poles. Participants were given a familiarization period of 5 minutes to test their ability to walk with poles, so as not to bias the results of participants who were not familiar with Nordic walking.

### 2.3 Data Analysis

The kinematic data from the foot and pelvis markers were used to detect walking events according to the well-known Zeni's algorithm (Zeni et al. 2008) and serve here as a reference tool for our study because this algorithm was validated in Nordic walking in a previous study (Blandeau et al. 2023). Ensink's detection algorithm (Ensink et al. 2023) was used with data from IMUs placed on each foot. The flexion angular velocity of ankle was used to define mid-swings around which the HS (by a maximum of vertical acceleration) and the TO (by zero-crossing of the angular velocity) were defined. Walking events at the wrists were calculated using the acceleration vector norm filtered by a low-pass Butterworth filter with a cut-off frequency of 1Hz. The HS corresponded to the local maximum jerk and the TO to the local maximum acceleration between 2 HS. The average time difference in the detection of HS and TO between the Zeni's algorithm and the IMUs worn on the feet and wrists was calculated for each event. Data processing and statistical calculations were carried out using Matlab software (R2022B).

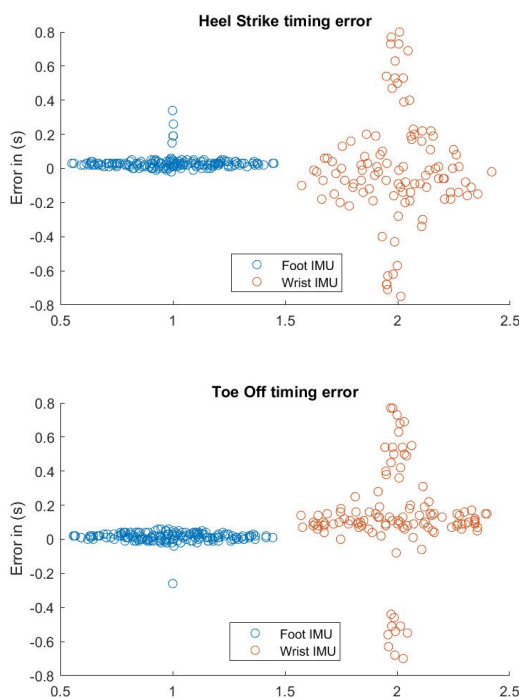
## 3. Results and discussion

A total of 33 acquisitions were collected for all subjects, representing 440 separate walking events. All of the walking events were detected by the IMUs located on the feet, whereas only half of the events were detected by the IMUs positioned on the wrists. The mean error and standard deviation between the Zeni's kinematic algorithm and the on-board algorithms as a function of HS and TO events were calculated (cf. Table 1).

	HS		TO	
Algo	Foot	Wrist	Foot	Wrist
Mean / SD	$31 \pm 39$	$-3 \pm 310$	$14 \pm 29$	$120 \pm 275$

**Table 1.** Mean error and standard deviation (in ms) of HS and TO detection between IMU algorithms and Zeni's algorithm

The mean event detection error (HS and TO) is low relatively to the sampling frequency in both sensor conditions, but the error variability is much higher for events detected at the wrist compared to the foot. After a negative Shapiro-Wilk test, Wilcoxon tests were carried out to observe any significant differences between laterality (left, right) and sensor placement (feet, wrists). The results are not significant for laterality, meaning that the algorithms are not sensitive to laterality. A significant difference was found between placement for the detection of HS ( $p < 0.005$ ) and TO ( $p < 0.001$ ).



**Figure 1.** Timing error for HS and TO depending on the two algorithms

A qualitative analysis of the data measured by the IMUs at wrist level was carried out in order to understand the source of this significant variability. It appears that not all subjects use the same Nordic walking technique. Some people prefer hitting the ground with their poles (Japan nordic walking style), creating a highly variable accelerometric profile that can be detected by the proposed algorithm. Other subjects adopt an arm swinging strategy (European Nordic walking style) creating a very smooth accelerometric signal that is difficult to detect with our algorithm (Homma et al. 2016).

## 4. Conclusions

The aim of this study was to test the ability of 2 on-board algorithms to detect walking events during Nordic walking. The algorithms succeeded in detecting walking events (HS and TO), with better results for the algorithm using foot IMUs. The ability to detect a Nordic walking method using on-board sensors represents a clinical interest in the ecological practice of Nordic walking, with future quantitative applications in rehabilitation and learning of this physical activity.

## Conflict of Interest Statement

The authors declare no conflict of interest.

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