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Validation of walking events detecting algorithm during Nordic walking of healthy subjects

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1. Introduction

Nordic walking popularity as a physical activity has increased in last 15 years due to its playfulness and easy accessibility. Nordic walking is more and more considered as a physical practice during rehabilitation to improve gait patterns or counteract the deterioration of walking quality (e.g. Ben Mansour et al. 2018). Moreover, Nordic walking is known for its social and psychological benefits (Zurawik 2020) and differs to normal walking both in kinematics and tool usage (poles). Nevertheless, because of its practice in ecological situations, carrying out a classical analysis of Nordic walking through the detection of walking events is a challenge.

Detection of walking events is at the core of gait analysis. Gait can be broken down into cycles defined by walking events, Heel Strike (HS) and Toe Off (TO) (Perry 2010). They are usually detected in biomechanics studies using forces platform or through the use of algorithms based on kinematics data from optoelectronic systems (Fonseca et al. 2022). Despite a very large number of articles dedicated to estimating walking events through kinematics, no articles were found on the specific practice of Nordic walking.

Hence, the purpose of this study is to test the ability of three classical algorithms for detecting walking events on a practice of walking as well as Nordic walking.

2. Methods

2.1. Participants

Seventeen subjects without known osteoarticular pathologies and engaged in regular physical activity gave their voluntarily consent to participate in this study (age: 26.4 ± 5.9 years; height: 172.18 ± 7.2 cm; mass: 74.47 ± 15.2 kg).

2.2. Protocol

A total of 49 reflective markers were placed on each subjects following the recommendation of the IOR Full Body Model. Markers' 3D trajectories were

recorded with a 12 cameras motion capture system (VICON) with a framerate of 200 Hz.

Each participant was asked to walk over a 10-m corridor on which were placed 4 Kistler forces platform Type 9286 A. In order to prevent subjects from targeting their gait at the force platform, subjects walked as many times as required to step 10 times exactly on at least one platform. To do this, one of the experimenters took care of observing the walking of subjects on the force platforms in contact with feet.

The first passage was done in normal walking, the second in fast walking and the third in Nordic walking with poles (all conditions were at self-selected speed). Concerning the passage in Nordic walking, the participants had a period of familiarization with walking in sticks of about 5 min in order not to distort the results of participants not initiated to the practice.

2.3. Data analysis

Two different datasets were used to compute the walking events. Reference events were computed with the force platform data. Reference HS and TO were defined when the vertical force reached a value respectively above or below 20 N (Fonseca et al. 2022). Kinematics based events were computed *via* the 3D trajectories of marker which were processed according to the event detection algorithms proposed in (Zeni et al. 2008) [Zeni 1] and [Zeni 2], and (Hreljac and Marshall 2000) [HMA]. The [Zeni 1], [Zeni 2] and [HMA] algorithms are respectively based on positions, velocities and accelerations of foot and sacrum markers.

Reference timing was subtracted to the three other algorithms to obtain the average time difference in HS and TO detection between algorithms and forces platforms according to the 3 walking conditions. After verification of the normality, repeated measures two-ways ANOVA were performed on both HS and TO errors depending on the 3 algorithms and walking conditions. A Post Hoc test was carried out in order to verify these significant differences by pairing *T*-test with Bonferroni corrections.

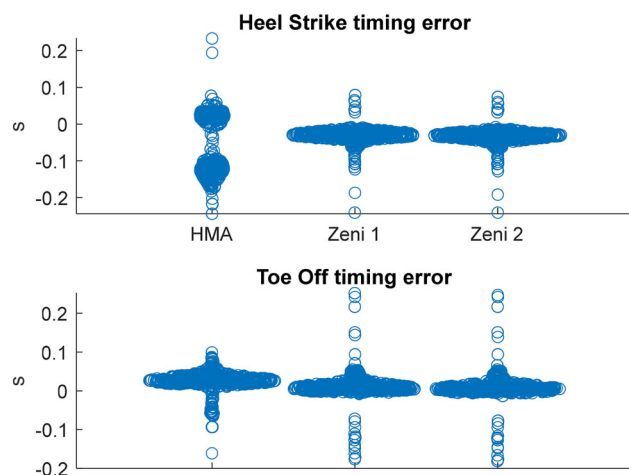
Data processing and statistical computation were carried out on Matlab software. Statistical tests were performed using the 0D SPM toolbox to investigate potential effect of walking condition on the mean detection error of HS and TO events.

3. Results and discussion

Fifty-one acquisitions were collected for all subjects who walked between 3 and 10 times over the corridor

Table 1. Mean error and standard deviation (in sec) of HS and to detection between algorithms and forces platform for each gait condition.

	HS			TO		
	HMA	Zeni 1	Zeni 2	HMA	Zeni 1	Zeni 2
Normal	-0.08 ± 0.08	-0.04 ± 0.02	-0.04 ± 0.02	0.03 ± 0.03	0.01 ± 0.03	0.01 ± 0.04
Fast	-0.05 ± 0.07	-0.03 ± 0.01	-0.03 ± 0.01	0.03 ± 0.01	0.01 ± 0.01	0.01 ± 0.01
Nordic	-0.02 ± 0.07	-0.03 ± 0.01	-0.03 ± 0.01	0.02 ± 0.02	0.01 ± 0.03	0.01 ± 0.03

**Figure 1.** Timing error for HS and to depending on the three algorithms for all conditions.

for each condition. A total of 223 walking events were identified for normal walking, 153 for Fast walking and 183 for Nordic walking. Mean error and standard deviation between the force platform data and the [Zeni 1], [Zeni 2] and [HMA] algorithms according to the gait conditions for HS and TO detection has been carried out (cf. Table 1).

The [HMA] algorithm presents an average error between 0.08 s and 0.02 s depending on the gait conditions. On the other hand, the [Zeni 1] and [Zeni 2] algorithms show an error between 0.04 and 0.01 s. Moreover, for each algorithm, the Nordic walking condition represents the lowest average error. Finally, for the 3 algorithms, the lowest average error was in the detection of TO compared to HS, and that whatever the gait condition.

The 2-ways RM ANOVA yielded significant results for both HS and TO detection according to gait condition.

For HS detection event (cf. Figure 1), the results showed a significant difference both on the algorithm and walking condition ($p=0.002$). Significant differences were found between [HMA] and [Zeni 1] and

between [HMA] and [Zeni 2] ($p<0.001$) but not between [Zeni 1] and [Zeni 2] on all walking conditions. Similarly, all algorithms result significantly changed their timing error depending on the walking condition ($p<0.001$).

For TO detection event (cf. Figure 1), the results showed a significant difference only on the algorithm choice ($p=0.002$). Post-hoc analysis yielded a significant difference between [HMA] and [Zeni 1] and between [HMA] and [Zeni 2] ($p<0.001$) but not between [Zeni 1] and [Zeni 2] on all walking conditions

Interestingly, the [HMA] HS estimation precision improves with gait speed increase whereas [Zeni 1] and [Zeni 2] stay constant. It might be due to the content of the [HMA] algorithm based on acceleration and jerk; quicker kinematics could improve the precision of event detection. These results shows that both Zeni algorithm seem more appropriate for the study of nordic walking.

4. Conclusion

The aim of this study was to test the ability of three classical algorithms for detecting walking events on 3 gait conditions (normal walking, fast walking and Nordic walking). All algorithms were successful in detecting walking events (HS and TO), with better results for [Zeni 1] and [Zeni 2] especially for HS. Moreover, [Zeni 1] and [Zeni 2] appears to be more robust related to walking speed.

Despite the presence of significant differences between the algorithms for each condition, all three algorithms obtained accurate average errors in the Nordic walking condition compared to other conditions for either HS or TO. These results encourage the feasibility of detecting walking events on a Nordic walking practice with embedded motion capture systems.

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