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A comparative study of two commercial IMU-based systems to assess gait spatiotemporal parameters

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1. Introduction

Gait spatiotemporal characteristics are classically used to assess physical and cognitive abilities and potential impairments (e.g., an increased risk of fall) due to disease or ageing. Systems using a few inertial measurement units (IMU) have been developed to perform such assessments. Compared to classical quantitative gait analysis set-up based on optoelectronic cameras and force plates, these systems are relatively cheap, simple to use, and they also allow performing this assessment in a less controlled environment. Some of them even allow ambulatory assessment in real-life settings.

Several studies focused on the validity of these systems for assessing gait spatiotemporal parameters. However, they rarely compare the system to each other or evaluate them in real-life situations. A review from Godinho et al. (2016) compared several systems for Parkinson's disease patients regarding different criteria (availability, use, reliability, validity, sensitivity to change). The GaitUp (GU) and Mobility Lab from APDM (ML) were ranked among the “highly recommended” systems (Godinho et al. 2016). Recently, Rudisch et al. (2021) performed a

comparative assessment of these two systems, together with overground measurement systems. They showed that GU and ML provided similar results for temporal parameters (almost no bias for the stride duration) but a small bias for spatial parameters (about 12 cm less for the ML compared to GU and the three other overground measurement systems). Yet, these results were obtained at one single speed and in a standard overground walking configuration.

The aim of this study is thus to complement the evaluation of these two highly recommended systems based on inertial sensors: GU and ML. The effect of gait speed will be considered, using an instrumented treadmill, and a preliminary assessment during free ambulation will be presented.

2. Methods

2.1 Participants & Procedure

For this experiment, 7 participants (4 females, 24 ± 5 years old, 170 ± 5 cm, 61 ± 10 kg) walked on a double-band instrumented treadmill. Each participant walked at six different speeds (0.6 / 0.8 / 1.0 / 1.2 / 1.4 / 1.6m/s) with an increment of 0.2m/s every 30 seconds. They also performed a small jump at the beginning and the end of the recording for synchronization purposes.

Two force plates integrated into the treadmill recorded ground reaction force (GRF) at 1000 Hz. Additionally, inertial sensors were placed on each foot: two Physiolog^{®5} sampling at 128 Hz for the GU and two Opal[™] sensors sampling at 128 for the ML. Sensors were placed according to manufacturers' recommendations.

On the other hand, one subject carried out an ambulatory test for about ten minutes with the same sensors on his feet. The subject's lower limb was filmed so that the number of cycles performed could be recorded on video.

2.2 Data analysis

We extracted the number of strides detected, their duration (Gait cycle time, GCT), and length (SL) for each detected stride. For the GU and ML, this was performed directly on the raw accelerometric data using the associated software (software 5.0 and Mobility Lab). For the treadmill, GRF were first low pass filtered at 10 Hz with a zero lag critically damped filter. Then, ground contacts were determined when the vertical component of the ground reaction force exceeded 10% of body weight. GCT were computed as the durations between two successive ground contacts of the same foot. Stride length was obtained as the product of the treadmill's velocity and the GCT, corrected by the distance between the center of pressure positions at the cycle's initial and final ground contacts. Outputs from the different systems were then time synchronized using the peak of acceleration and vertical force created by the jumps. It allowed matching strides detected by both systems. For the treadmill experiment, data were analyzed for the 20

middle seconds of each speed increment. For the ambulatory experiments, the whole 10-minute recording was analyzed.

GCT and SL for the different measurement systems were compared with a Bland-Altman approach.

3. Results and discussion

Table 1 shows the bias and limit of agreement (LoA) obtained for the treadmill experiment. Overall, biases remained small, except for the estimation of SL by the ML, which is about 10 cm (i.e., about 10%) shorter than the treadmill and the GU. LoA showed moderate variability for both ML and GU: about 70 ms for GCT and 10 to 15 cm for SL, i.e. 6% and 10-15% respectively. The walking velocity did not have any influence (no trend) on the bias but seemed to increase the LoA.

Table 1. Results of the Bland-Altman analyses for the treadmill experiments

	Systems	GCT (ms)	SL (cm)
Bias	Treadmill - GU	0	0.6
	Treadmill - ML	0	9.4
	GU - ML	-1	10.1
LoA	Treadmill - GU	58	21.1
	Treadmill - ML	49	18.8
	GU - ML	72	13.7

During the ambulatory test, the results showed a difference in the number of cycles found between the two systems (108 cycles for ML vs. 141 cycles for GU), the number of cycles found with GU being close to the reference video value (143 cycles). Figure 1 shows the Bland-Altman graph for the GU vs ML system on the SL for strides correctly detected by both systems. Results were similar to those obtained on the treadmill: relatively large bias of 8.50 cm and LoA of about 10 cm.

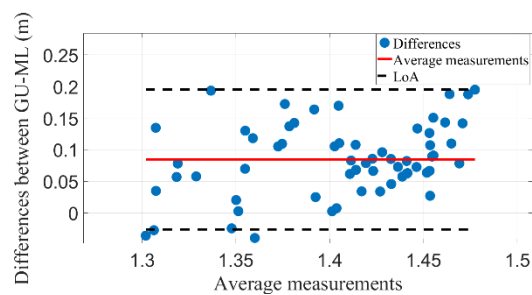


Figure 1. Bland-Altman graph comparing stride length between two systems during an ambulatory test.

Results obtained extended those from Rudisch et al. (2021) to a larger range of walking velocity and treadmill walking (instead of overground): GCT are accurately estimated by both systems, but ML seems to present a systematic bias for SL of about 10 cm. This could be explained by the fact that ML was initially

designed for studying Parkinsonian gait, but not the unaltered population considered here. This systematic bias could be corrected for future measurements of the same population. Yet, checking if it remains similar for other populations could be interesting. The fact that walking speed doesn't seem to affect these results is interesting as it shows that both systems could be used for a wide range of populations displaying relatively standard gait patterns (young adults but also the elderly). Finally, ML seems less sensitive and more specific than GU, with fewer strides detected during an ambulatory test.

4. Conclusions

GaitUp and Mobility Lab IMU-based systems were found equally accurate for assessing the Gait Cycle Time in a controlled test on a healthy population. However, the Mobility Lab displayed a systematic bias for the Stride length. Preliminary results on ambulation showed similar results, although the Mobility Lab detected less stride than the GaitUp.

Conflict of Interest Statement

None.

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