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Short communication

Validation of an ambient system for the measurement of gait parameters

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ABSTRACT

Fall risk in elderly people is usually assessed using clinical tests. These tests consist in a subjective evaluation of gait performed by healthcare professionals, most of the time shortly after the first fall occurrence. We propose to complement this one-time, subjective evaluation, by a more quantitative analysis of the gait pattern using a Microsoft Kinect. To evaluate the potential of the Kinect sensor for such a quantitative gait analysis, we benchmarked its performance against that of a gold-standard motion capture system, namely the OptiTrack. The "Kinect" analysis relied on a home-made algorithm specifically developed for this sensor, whereas the OptiTrack analysis relied on the "built-in" OptiTrack algorithm. We measured different gait parameters as step length, step duration, cadence, and gait speed in twenty-five subjects, and compared the results respectively provided by the Kinect and OptiTrack systems. These comparisons were performed using Bland-Altman plot (95% bias and limits of agreement), percentage error, Spearman's correlation coefficient, concordance correlation coefficient and intra-class correlation. The agreement between the measurements made with the two motion capture systems was very high, demonstrating that associated with the right algorithm, the Kinect is a very reliable and valuable tool to analyze gait. Importantly, the measured spatio-temporal parameters varied significantly between age groups, step length and gait speed proving the most effective discriminating parameters. Kinect-monitoring and quantitative gait pattern analysis could therefore be routinely used to complete subjective clinical evaluation in order to improve fall risk assessment during rehabilitation.

1. Introduction

Falls in elderly people very often have dramatic consequences, such as fractures, trauma, hospitalization, or even death (World Health Organization, 2008). Most of these falls result from established impairments of gait and balance stability. Devices quantifying gait and balance, such as force platforms, motion capture systems, or actimetric carpets, exist. However, they are often costly, and they require time and space to be set up, which considerably limit their use for clinical testing. We think that providing an automatic and efficient quantitative method coupled to a simple motion capture system would allow healthcare professionals to circumvent this limitation. In line with this, we propose a system based on the Microsoft Kinect, a low cost and non-intrusive ambient sensor, to extract gait parameters identified in the geriatric literature as the most relevant to assess fall risk (Hausdorff et al., 2001; Auvinet et al., 2003; Studenski et al., 2003).

Several studies showed that the Kinect is accurate to extract spatiotemporal parameters (see Springer and Yogev Seligmann, 2016 for a review), and thereby well-suited for gait assessment. Some studies compared the Kinect with a marker-based three-dimensional motion analysis (by using one Kinect version 1 sensor: Chang et al., 2012; Clark et al., 2013; Stone and Skubic, 2011; Xu et al., 2015; Galna et al., 2014; four Kinect v2: Geerse et al., 2015; one Kinect v2 Mentiplay et al., 2015; one Kinect v2 and markers Ye et al., 2016). Regarding marker-less systems, Gabel et al. (2012) compared Kinect v1 with pressure sensors placed inside the shoe, whereas other authors compared the Kinect v1 to an actimetric carpet (Motiian et al., 2015; Baldewijns et al., 2014).

Here we compared gait parameters extracted using a single Kinect sensor with those extracted using a twelve cameras OptiTrack system as reference. We also assessed which gait parameters differed significantly between age groups, because those were likely the best predictors of fall risk (World Health Organization, 2008; Gryfe et al., 1977; Lord et al., 2001). All above-mentioned studies, and more generally most of the studies on gait analysis with the Kinect sensor are based on the Microsoft SDK (with the exception of Stone and Skubic Stone and Skubic, 2011). We relied

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instead on an algorithm developed by Dubois and Charpillet (2017). The reason was that an accurate representation of the skeleton and the body segments is not necessary to extract the spatio-temporal parameters of gait. In our study, the parameters were extracted from the vertical displacement of the geometric center of the body. This approach has two main advantages. First, parameters can be extracted even if the feet of the walking person are occluded, which is likely to occur in a furnished room. Second, the performance of the analysis is relatively unaffected by the angle of view of the sensor.

2. Method

Participants of three different age groups participated in the experiment: eight young individuals (five women, three men) aged 23–28 (mean = 25 years), nine older participants (five women, four men) aged 67–73 (mean = 69 years), whose gait is often considered as "normal", and eight senior individuals (five women, three men) aged 76 to 89 (mean = 81 years) who are potentially more affected by "abnormal" modifications of the gait pattern (Gryfe et al., 1977). Additional information regarding the participants is provided in Table S1 in the supplementary materials. The study was conducted in accordance with the Declaration of Helsinki and approved by the local ethics committee.

The experiment took place in a 6 m × 8 m room equipped with twelve OptiTrack cameras (Prime 17 W model) and a single Kinect v2 sensor. The participants wore a suit with 41 reflective markers for the OptiTrack system and walked perpendicularly to and at a distance of 4 m from the Kinect sensor. Subjects performed ten back and forth gait trials at a comfortable speed. At the beginning of each sequence, participants raised the arm in order for the experimenter to synchronize the two systems.

Our processing method was only based on the depth images provided by the Kinect sensor. From the depth information, we extracted the silhouette of the walker using the background subtraction method. The trajectory of the centroid along the vertical axis was used to calculate the different gait parameters as described in Dubois and Charpillet (2017). Regarding the OptiTrack

Table 2
Bland-Altman bias (limits of agreement), and percentage error (PE) (computed as $100\times(2\ \text{SD of bias}))/((Mean_{Kinect} + Mean_{OptiTrack})/2)$ for the two systems.

	Bias (95 % LoA)	PE (%)
Step length (cm)	1.95 (−2.10 to 6.01)	6.28
Step duration (s)	−0.003 (−0.044 to 0.039)	7.17
Cadence (step/s)	0.000 (−0.124 to 0.124)	7.05
Gait speed (cm/s)	4.00 (−6.134 to 14.145)	8.96

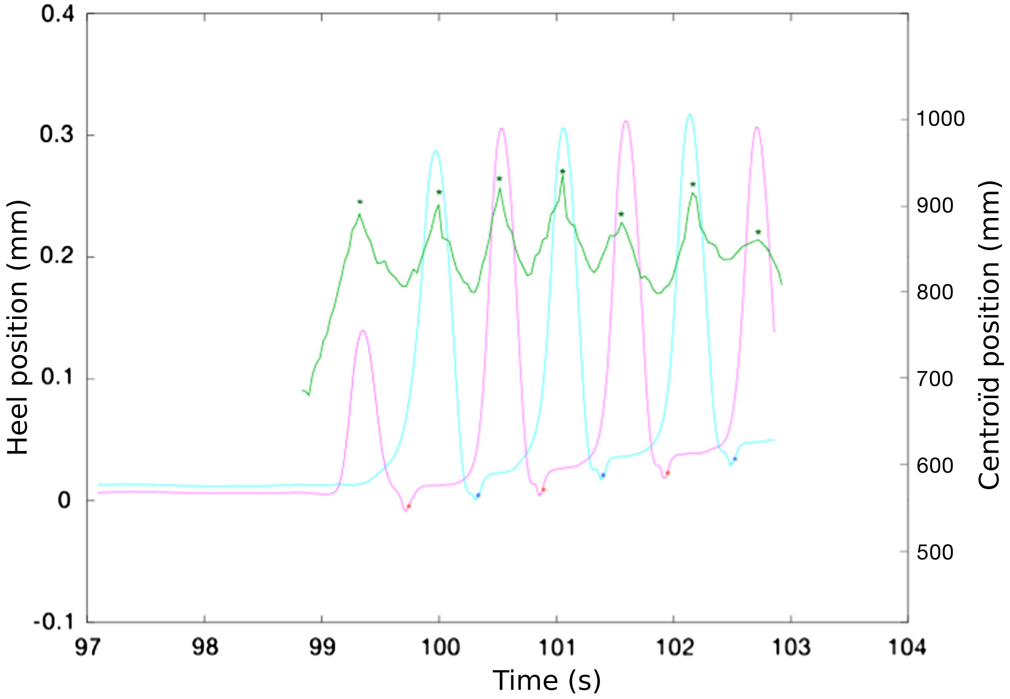

Fig. 1. Trajectories extracted with the Kinect and OptiTrack system during a walking sequence. The green line represents the Kinect centroid along the vertical axis, with green stars indicating the local maxima. The pink and blue lines represent the trajectories of the right and left heel, respectively, as measured by the OptiTrack system. The local minima are represented by the pink and blue stars. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 1
Gait parameters and their method of estimation using the OptiTrack and Kinect system.

Variables	OptiTrack	Kinect
Step length (cm)	The distance between the local minima of the left and right heel	The distance between two local maxima
Step duration (s)	The duration between the local minima of the left and right heel	The duration between two local maxima
Cadence (step/s)	1 divided by step duration	1 divided by step duration
Gait speed (cm/s)	Sum of the step lengths divided by the sum of step durations	Sum of step lengths divided by the sum of step durations