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Short communication

Reliability and comparison of Kinect-based methods for estimating spatiotemporal gait parameters of healthy and post-stroke individuals

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ABSTRACT

Different studies have analyzed the potential of the off-the-shelf Microsoft Kinect, in its different versions, to estimate spatiotemporal gait parameters as a portable markerless low-cost alternative to laboratory grade systems. However, variability in populations, measures, and methodologies prevents accurate comparison of the results. The objective of this study was to determine and compare the reliability of the existing Kinect-based methods to estimate spatiotemporal gait parameters in healthy and post-stroke adults. Forty-five healthy individuals and thirty-eight stroke survivors participated in this study. Participants walked five meters at a comfortable speed and their spatiotemporal gait parameters were estimated from the data retrieved by a Kinect v2, using the most common methods in the literature, and by visual inspection of the videotaped performance. Errors between both estimations were computed. For both healthy and post-stroke participants, highest accuracy was obtained when using the speed of the ankles to estimate gait speed (3.6–5.5 cm/s), stride length (2.5–5.5 cm), and stride time (about 45 ms), and when using the distance between the sacrum and the ankles and toes to estimate double support time (about 65 ms) and swing time (60–90 ms). Although the accuracy of these methods is limited, these measures could occasionally complement traditional tools.

1. Introduction

Alterations in gait are a common sequelae after stroke (Goldie et al., 1996). Assessment of gait-related impairments is commonly performed through standardized clinical scales and tests, such as the 6-Minute Walk Test (Dunn et al., 2015), the 10-Meter Walk Test, (Bohannon et al., 1996), or the Dynamic Gait Index (Whitney et al., 2000), which are usually easy to administer and not time-consuming. In contrast, traditional tools usually provide global scores, and may have limited sensitivity and be biased.

Kinematic and spatiotemporal analysis of gait enables identification of abnormal patterns and behavior in the different phases. Most widely used solutions for gait analysis use multicamera marker-based motion tracking to detect body segments during walking (Carse et al., 2013). Kinematic and spatiotemporal parameters can also be estimated from wearable inertial sensors (Sprager and Juric, 2015) or instrumented walkways (Wong et al., 2014), respectively. Although many solutions are available, they present common limitations, such as the high cost and required space, that may limit their clinical use.

Recently, the off-the-shelf Microsoft Kinect (Microsoft, Redmond, WA), in its different versions, has enabled human motion tracking by estimating the 3D position of the main joints without using markers and with higher portability, which has motivated its use for gait analysis. Different studies have reported the reliability of different methods of estimating spatiotemporal gait parameters in healthy population with comparable results to laboratory-grade systems, with both the first (Clark et al., 2013; Pfister et al., 2014; Stone et al., 2011; Xu et al., 2015; Baldewijns et al., 2014) and second version of the Kinect (Dolatabadi et al., 2016; Mentiplay et al., 2015; Eltoukhy et al. 2017a, 2017b; Müller et al., 2017; Geerse et al., 2015). The second version of the device improves some features of the previous version. Specifically, it has wider field of view and depth range and higher camera and depth resolution. Besides, Kinect v2 has shown better global performance regarding accuracy and stable data (Gonzalez-Jorge et al., 2015). An increasing number of studies have focused on spatiotemporal gait analysis with these devices in post-stroke individuals (Vernon et al., 2015; Clark et al., 2012; Cao et al., 2017).

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However, variability in populations, measures, and methodologies prevents adequate comparison of the results. Consequently, the real strengths and weaknesses of each method remain unclear.

The objective of this study was to determine and compare the reliability of the most common methods in the literature to estimate spatiotemporal gait parameters using the Kinect v2 in healthy and post-stroke adults.

2. Methods

2.1. Participants

Individuals from 18 to 80 years old with no known musculoskeletal or vestibular disease and/or prosthetic surgery were recruited from the student body and staff of Universitat Politècnica de València. Post-stroke individuals were recruited from the outpatient service of Servicio de Neurorrehabilitación y Daño Cerebral of Hospitales Vithas-NISA. The stroke group included stroke survivors from 18 to 80 years old, able to walk ten meters and follow instructions (Mississippi Aphasia Screening Test >45) (Romero et al., 2012), with fairly good cognitive condition (Mini-Mental State Examination >23) (Folstein et al., 1975) and without fixed contracture, arthritic or orthopedic conditions in the legs.

The healthy group consisted of 45 participants (31 men, 14 women) with a mean age of 30.6 ± 7.6 years old. The stroke group consisted of 38 participants (22 men, 16 women), with a mean age of 56.1 ± 13.2 years old, a mean chronicity of 14.7 ± 8.5 months, and a mean score in the gait sub-scale of the Tinetti Performance-Oriented Mobility Assessment (Tinetti 1986) of 10.5 ± 1.5.

Ethical approval for the study was granted by the Institutional Review Board of Vithas-NISA Valencia al Mar Hospital. All eligible candidates who agreed to take part in the study provided informed consent.

2.2. Instrumentation

Position of the 25 main joints were obtained from a Kinect v2 at 30 Hz, using the Kinect for Windows Software Development Kit 2.0, and a high-performance PC that incorporated an 8-core Intel® Core™ i7-3632QM @3.60 GHz and 8 GB of RAM. A video camera Sony HXR-MC50E (Sony Corporation, Tokyo, Japan) was used to film the trials at 1920 × 1080 pixel resolution and 30 fps. A 6-m long and 1-m wide measuring walkway with an accuracy of 0.5 cm was used to estimate distances. The measuring walkway consisted of a printed vinyl with multiple transversal lines, each separated 0.5 cm from the others (Fig. 1).

2.3. Procedure

The experiment took place in a dedicated space free of obstacles and distractors. The Kinect v2 was fixed on a standing platform at 80 cm of height, oriented parallel to the floor. The measuring walkway was fixed to the floor along the sagittal axis of the Kinect v2. The video camera was fixed at 70 cm of height, also oriented parallel to the floor in a transversal axis to the measuring walkway.

All the participants were initially positioned five meters away from the Kinect v2 and were briefly introduced to the purpose of the study. Participants were required to wear close-fitting, pale, and non-reflective clothes to avoid additional tracking errors. An experimenter indicated them to walk on the walkway towards the device with a comfortable speed until they reached the standing platform. This test was repeated until three repetitions were obtained without errors. The performance of the participants was filmed with the video camera and registered with the Kinect v2.

2.4. Data analysis

Since the reliable tracking range of the Kinect v2 is restricted to 4 m (from 4.5 to 0.5 m) (Dolatabadi et al., 2016; Geerse et al., 2015; Rocha et al., 2015), the analysis of the data was limited to that space. Spatiotemporal parameters were estimated from both the recorded video and the Kinect-based data. The video was visually analyzed frame by frame and the gait events (heel strike and toe-off) were determined from the height of the ankles and toes. Spatiotemporal parameters were derived from them (Perry, 1992). Outliers of the Kinect-based data were discarded by visual inspection. After this, spatiotemporal parameters were estimated: (a) as in the video analysis; (b) from the speed of the ankles and the toes (Clark et al., 2013; Mentiplay et al., 2015); (c) from the distance between the knees (Auvinet et al., 2015); (d) from the distance between the sacrum and the ankles and toes (Zeni et al., 2008); and (e) from the height of the center of mass (Baldewijns et al., 2014) (Table 1). Spatiotemporal measures included speed, stride distance and time, step distance, time, and asymmetry, and double support and swing time. For each repetition, the average of the spatiotemporal parameters estimated using the aforementioned methods and the recorded video in all the detected steps was computed. Mean absolute and relative errors were estimated, also for each repetition, between the averaged spatiotemporal parameters derived from the methods and those from the recorded video. Absolute error was computed as the absolute value of the difference between a measure obtained with one of the methods and that obtained from the recorded video. The relative error was computed as the absolute error divided by the measure obtained with

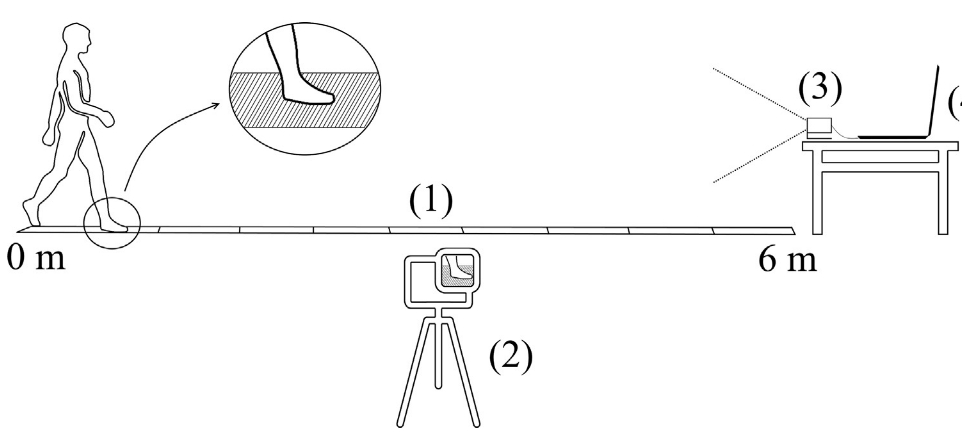

Fig. 1. Description of the setup. The setup consisted of (1) a vinyl walkaway; (2) a video camera; (3) a Kinect v2; and (4) a laptop.

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