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Short communication

Validity of time series kinematical data as measured by a markerless motion capture system on a flatland for gait assessment

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ABSTRACT

As a cost-effective, clinician-friendly gait assessment tool, the Kinect v2 sensor may be effective for assessing lower extremity joint kinematics. This study aims to examine the validity of time series kinematical data as measured by the Kinect v2 on a flatland for gait assessment. In this study, 51 healthy subjects walked on a flatland while kinematic data were extracted concurrently using the Kinect and Vicon systems. The kinematic outcomes comprised the hip and knee joint angles. Parallel translation of Kinect data obtained throughout the gait cycle was performed to minimize the differences between the Kinect and Vicon data. The ensemble curves of the hip and knee joint angles were compared to investigate whether the Kinect sensor can consistently and accurately assess lower extremity joint motion throughout the gait cycle. Relative consistency was assessed using Pearson correlation coefficients. Joint angles measured by the Kinect v2 followed the trend of the trajectories made by the Vicon data in both the hip and knee joints in the sagittal plane. The trajectories of the hip and knee joint angles in the frontal plane differed between the Kinect and Vicon data. We observed moderate to high correlation coefficients of 20%–60% of the gait cycle, and the largest difference between Kinect and Vicon data was 4.2°. Kinect v2 time series kinematical data obtained on the flatland are validated if the appropriate correction procedures are performed. Future studies are warranted to examine the reproducibility and systematic bias of the Kinect v2.

1. Introduction

Gait abnormality is the leading determinant of disability in adults with stroke (Chiou and Burnett, 1985), and gait analysis is valid for multiple applications (Eltoukhy et al., 2017b). Microsoft's Kinect version 1 (v1), released in 2011, is an inexpensive, portable, and user-friendly markerless motion capture system. Microsoft then released Kinect v2 in 2014. Both Kinect v1 and v2 have different working principles, resolutions, and frame rates. By assessing the validity of Kinect v2 data obtained during gait, Eltoukhy et al. (2017b) found that Kinect v2 is an acceptable tool for assessing sagittal plane knee and hip range of motion (ROM) and joint angles throughout the gait cycle.

However, they validated data obtained by the Kinect v2 system during gait on a treadmill. Although Eltoukhy et al. (2017a) primarily focused on validating Kinect v2 use for flatland gait analysis, the validity of Kinect v2 time series kinematic data during gait analysis has not been demonstrated. To support the practicality of Kinect v2 for gait assessment, Kinect v2 time series kinematic data obtained during gait on flatland warrants validation because gait analysis in the clinical setting is performed on such surfaces. We aim to validate time series kinematic data assessed by Kinect v2 on flatland for gait assessment.

2. Materials and methods

In total, 51 injury-free individuals [mean age: 20.9 (standard deviation (SD): 0.2) years; mean height: 166.9 (SD: 8.8) cm; mean mass: 61.1 (SD: 1.0) kg; male: 35] volunteered. The Hiroshima International University ethics committee approved this study (15–43), and all participants provided written informed consent.

We used the Microsoft Kinect v2 sensor (Microsoft Corp., Redmond, WA) and obtained a skeleton model directly from the Microsoft Kinect official Software Development Kit v2. Before data collection, we placed the Kinect v2 sensor on a tripod 0.8 m above the floor. The stick figure comprises 25 points as estimates of subjects' joint centers (JCs). We used the anatomical landmarks

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of the ankle, knee, and hip JCs to calculate the knee and hip joint angles, respectively. The Mobile Motion Visualizer AKIRA (System-friend Inc., Itsukaichi, Japan) was used to record Kinect data simultaneously with RGB video data.

Three-dimensional motion analysis system data were acquired at 120 Hz using a seven-camera Vicon MX (Vicon Motion Systems, Oxford, UK). We placed 33 reflective markers, including markers placed on the acromion process, elbow, radial styloid process, top of the iliac crest, anterior superior iliac spine, posterior superior iliac spine, superior aspect of the greater trochanter, medial and lateral femoral condyles, midpoint between the greater trochanter and the lateral femoral condyles, medial and lateral malleoli, midpoint between the lateral knee joint line and the lateral malleolus, head of the first and fifth metatarsals, and the calcaneal tuberosity. With these anatomical markers, we constructed coordinate systems for the pelvis, thigh, shank, and foot segments. JCs of the hip, knee, and ankle were approximated as described previously (Andriacchi et al., 1982; Kito et al., 2010; Koyama et al., 2015; Kurabayashi et al., 2003; Tateuchi et al., 2017). JC of the knee on the frontal plane was located by identifying the midpoint of a line linking the medial femoral condyle marker to the lateral femoral condyle marker. Furthermore, JC of the ankle was located by identifying the midpoint of a line linking the medial malleolus marker to the lateral malleolus marker. The positions of these markers were obtained using BodyBuilder software (Vicon Motion Systems) and acquiring image data.

Participants wore tight-fitting shorts and an upper body garment that allowed the placement of the reflective markers without shoes. We performed gait trials along a walkway with an embedded force platform (AMTI; Watertown, MA). With the platform, we identified ground contact and toe-off of the foot during the trials. Participants started each gait trial approximately 8 m from the Kinect. All participants performed the gait trials at their own comfortable pace. Each participated in five gait trials, and we assessed the data of one trial with the typical waveform of the floor reaction force in the stance phase.

Analog signals and lamps were used to synchronize the Vicon and Kinect data. Analog signals were recorded with Vicon data. Lamp emitted light simultaneously with the analog signal transmission, which was recorded as RGB video data simultaneously with Kinect data using Mobile Motion Visualizer AKIRA software. We aligned the time stamps of the lamp light on Kinect data and that of the analog input signal on Vicon data and synchronized the Kinect and Vicon data.

We used spline interpolation to resample Vicon data to 30 Hz before analysis. We identified the phases of the gait cycle with the gait event time points of toe-off and ground contact. We performed kinematic analysis for the full gait cycle of each participant. Coordinate data from the Kinect and Vicon systems for the ankle, knee, and hip JCs were acquired and used to calculate the projection angle of the knee and hip joints toward the sagittal and frontal planes (see Appendix). Finally, we performed parallel translation of the Kinect v2 gait data obtained throughout the gait cycle to minimize the differences between Kinect and Vicon data.

We compared ensemble curves and the hip and knee joint angles throughout the gait cycle to determine whether the Kinect could consistently and accurately measure the lower extremity joint motion. Pearson correlation coefficients confirmed the validity of the Kinect v2 gait data. Statistical analyses were performed using IBM SPSS statistics 22 (IBM SPSS, Tokyo, Japan).

3. Results

Fig. 1 shows the hip joint angle trajectories, and Table 1 shows the hip joint angles during the gait cycle. The hip joint angles measured by the Kinect followed the trend of joint trajectories evaluated by Vicon. The minimum correlation coefficient throughout the gait cycle was 0.43, and the most significant difference between the data from Kinect and Vicon was 4.2°.

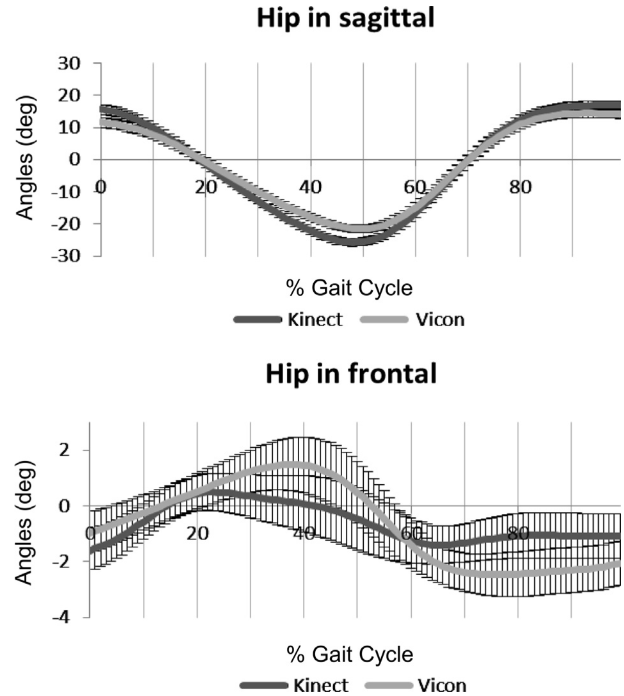

Fig. 1. Trajectories of the hip joint angles in both the sagittal and frontal planes. Average and 95% confidential interval of joint angle are demonstrated. The X axis shows the gait cycle (%) and the Y axis shows the angle (degree).

Unlike the sagittal plane, the frontal plane's curve made by Kinect data did not match the curve made by Vicon data. The correlation coefficients were >0.5 from 20% to 60% of the gait cycle, and the most significant difference was 1.4°.

Fig. 2 shows the knee joint angle trajectories, and Table 2 shows the knee joint angles during the gait cycle. Similar to the hip joint angles in the sagittal plane, the knee joint angles measured by the Kinect followed the trend of joint trajectories assessed by Vicon. Most of the correlation coefficients throughout the gait cycle were >0.5. Except for 10–20% period of the gait cycle, the maximum joint angle difference between the two systems was 3.4°.

In the frontal plane, similar to the hip joint angle, the Kinect data's curve did not match the Vicon data's curve. However, higher correlation coefficients ($r > 0.5$) were observed throughout the gait cycle, and the maximum joint angle difference between the two systems was 1.5°.

4. Discussion

During normal gait, only a single peak of hip extension and flexion occurs in each gait cycle, and peak hip extension arises before the swing phase (Perry, 1974); both of these were demonstrated by our hip joint's Vicon data in the sagittal plane. Thus, our Vicon data could be used as the reference and compared with Kinect data. Although the waveform of Kinect v2 data was similar to that of Vicon data, 95% confidence intervals (CIs) of the Kinect v2 means in each frame did not always overlap with those of the Vicon means, and the largest difference was 4.2°. Our results suggest that the pattern of sequential change in the hip angle in gait measured by Kinect v2 could be used as conclusive findings rather than that of the Kinect v1 (Pfister et al., 2014) and that the absolute degree of

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