Accuracy of the Microsoft Kinect sensor for measuring movement in people with Parkinson’s disease

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Abstract

Background: The Microsoft Kinect sensor (Kinect) is potentially a low-cost solution for clinical and home-based assessment of movement symptoms in people with Parkinson’s disease (PD). The purpose of this study was to establish the accuracy of the Kinect in measuring clinically relevant movements in people with PD.

Methods: Nine people with PD and 10 controls performed a series of movements which were measured concurrently with a Vicon three-dimensional motion analysis system (gold-standard) and the Kinect. The movements included quiet standing, multidirectional reaching and stepping and walking on the spot, and the following items from the Unified Parkinson’s Disease Rating Scale: hand clasping, finger tapping, foot, leg agility, chair rising and hand pronation. Outcomes included mean timing and range of motion across movement repetitions.

Results: The Kinect measured timing of movement repetitions very accurately (low bias, 95% limits of agreement < 10% of the group mean, ICCs > 0.9 and Pearson’s r > 0.9). However, the Kinect had varied success measuring spatial characteristics, ranging from excellent for gross movements such as sit-to-stand (ICC = 0.989) to very poor for fine movement such as hand clasping (ICC = 0.012). Despite this, results from the Kinect related strongly to those obtained with the Vicon system (Pearson’s r > 0.8) for most movements.

Conclusions: The Kinect can accurately measure timing and gross spatial characteristics of clinically relevant movements but not with the same spatial accuracy for smaller movements, such as hand clasping.

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1. Introduction

Parkinson’s disease (PD) is a multi-system neurodegenerative disorder that impairs postural control and mobility, leading to reduced community ambulation [1] and increased risk of slips, trips and falls [2]. Accurate assessment of movement allows clinicians and researchers to monitor disease progression as well as response to intervention. Conventional three-dimensional video-based motion analysis systems allow for comprehensive kinematic and kinetic analysis of movement in PD. These systems require relatively large spaces, are expensive and require considerable expertise, limiting their use in the clinic and the home. Conversely, clinical assessment tools such as the Unified Parkinson’s Disease Rating Scale (UPDRS) can be administered in daily clinical practice without any expensive equipment [3]. However, clinical assessment tools can be less comprehensive and often require subjective input. Trained professionals are needed for both conventional three-dimensional motion analysis and clinical assessment tools, requiring the patients to travel to the clinic or laboratory, or the clinician to travel to the patient’s home. The time and cost of assessment often precludes frequent testing which would be useful when measuring within day fluctuation of movement symptoms (e.g. medication fluctuations).

The Microsoft Kinect is a camera-based sensor primarily used to directly control computer games through body movement. The Kinect tracks the position of the limbs and body without the need for handheld controllers or force platforms. Use of a depth sensor for handheld controllers or force platforms. Use of a depth sensor
hypokinetic symptoms (reduced size and speed of movement). Early reports suggest the Kinect can identify pose [4–6], simple stepping movements [7] and postural control [8] in healthy adults, although some have raised concerns about the accuracy of the skeleton model estimation during unconventional body postures or when using wheelchairs or walkers [9].

There is also growing evidence for the use of exercise-based computer games (exergames) to retrain motor function in people with PD [10], although evidence of their safety and efficacy are yet to be established [11]. Exergaming as a therapeutic tool incorporates functional, purposeful and engaging exercise in a quantifiable and reliable way that also encourages high volumes of practice and potentially improved motivation and adherence [12–14]. A player’s movement can be recorded whilst playing a game using the Kinect, allowing clinicians to ensure their patients perform exercises correctly.

To date, the accuracy of the Kinect to measure movement has not been established in people with PD. The aim of this project was to assess the accuracy of the Kinect to measure functional and clinically relevant movements in people with PD. To achieve this aim, we compared movement in a group of people with PD captured concurrently with a Vicon three-dimensional motion analysis system (gold standard) and a Kinect sensor. Because the accuracy of the Kinect has not been fully established in control participants, we also tested a group of healthy adults to extend previous reports of the accuracy of the Kinect system in measuring upper and lower body kinematics.

2. Methods

Nine people with mild-to-moderately severe PD were recruited through local movement disorders clinics. Inclusion criteria for people with PD were: diagnosis of idiopathic PD (by a consultant neurologist with a specialist interest in movement disorders), absence of any other neurological problem or any severe co-morbidity likely to affect gait, absence of dementia, adequate sight and hearing (with glasses or hearing aid if required), independently mobile indoors without a walking aid and no severe dyskinesias or prolonged off periods. People with PD were tested on the peak estimate for the position of 20 anatomical landmarks at a frequency of 100 Hz. Vicon data were filtered using a 20 mm Woltering filter.

2.2. Vicon motion analysis system

The ten control participants (Mean (sd); Age: 27.5y (5.0); 5 females, 5 males) and a Vicon system. Participants stood directly facing the Kinect sensor and its skeletal tracking software, providing an estimate for the position of 20 anatomical landmarks at a frequency of 30 Hz and spatial and depth resolution of 640 × 480 pixels (Fig. 1A). We used default smoothing parameters (correction factor of 0.5, smoothing factor of 0.5, jitter radius 0.05 m, maximum deviation radius of 0.04 m and future prediction of 0 frames).

2.2. Data processing and analysis

The movements and associated outcome measures are described in Table 1. Given the differences between the Kinect skeleton and Vicon plug-in-gait models, we simplified the comparison of the two systems by using either range of motion of a single marker or two-dimensional sagittal and frontal plane kinematics where appropriate. The mean range of motion and timing of each repetition were used as outcomes except for sit-to-stand which was expressed as the total duration of the test in keeping with standard clinical reporting, and mean trunk flexion which was calculated over 10 s of standing. To avoid redundancy, we analysed the right limb only for unilateral movements. The Kinect skeletal model did not allow for measurement of forearm pronation/supination directly; therefore we measured the vertical displacement of the wrist for each repetition as a proxy measure for the timing and magnitude of forearm pronation/supination.

We assessed mean bias between the two systems (Kinect–Vicon) using a series of repeated-measure two-sided t-tests. Pearson’s r correlation was used to assess relative agreement between the two systems. Absolute accuracy was measured using intra-class correlation (ICC2,1) and 95% limits of agreement. Limits of agreement were expressed both in absolute terms and as a proportion of the group mean. Bland and Altman plots were used to inspect the error scores between the two systems in respect to the mean scores [16]. Analysis for control and PD participants was conducted separately. A p < 0.05 was used to guide interpretation.

3. Results

The ten control participants (Mean (sd); Age: 27.5y (5.0); 5 females, 5 males) and nine people with PD (Age: 68.2y (8.3); 6 females, 3 males) completed the testing session without incident. People with PD were all community-dwelling and had mild-moderate symptoms (Activities-specific Balance Confidence (ABC) Scale: 87.3
Fig. 1. Panel A illustrates the marker locations for the Kinect skeleton model and Vicon “plug-in-gait” model. Panel B shows an example trace of vertical knee displacement during the leg agility test in a person with PD. The Kinect system (black circles) tracks the Vicon system (grey line) with the same pattern but under scaled magnitude. Panel C shows an example of seated hand clapping in a person with PD, whereby the Kinect (black circles) was used to detect the timing of hand clapping but did not track the spatial scaling of the Vicon system (grey line) accurately.
The Kinect was able to accurately measure the timing of each of the movements (Table 2). Bland and Altman plots suggest that there was no relationship between the error of the Kinect sensor and the mean timing of movements (supplementary material 1). There was no significant bias between the two systems, apart from a tendency for the Kinect to underestimate the duration of the sit-to-stand by 0.5% and overestimate stride time for walking on the spot by 2.1% for controls, and overestimate elbow flexion duration by 1.3% for the PD group. Limits of agreement were under 10% of the group mean, indicating very good absolute agreement for all movements apart from hand clasping and pronation/supination for both groups and lateral trunk flexion for controls. Pearson's and intra-class correlations were under 10% of the group mean, indicating very good absolute agreement for all movements (Table 2).

### 3.1. Temporal accuracy

The Kinect was able to accurately measure the timing of each of the movements (Table 2). Bland and Altman plots suggest that there was no relationship between the error of the Kinect sensor and the mean timing of movements (supplementary material 1). There was no significant bias between the two systems, apart from a tendency for the Kinect to underestimate the duration of the sit-to-stand by 0.5% and overestimate stride time for walking on the spot by 2.1% for controls, and overestimate elbow flexion duration by 1.3% for the PD group. Limits of agreement were under 10% of the group mean, indicating very good absolute agreement for all movements apart from hand clasping and pronation/supination for both groups and lateral trunk flexion for controls. Pearson's and intra-class correlations were excellent, above 0.9 for all movements.

### 3.2. Spatial accuracy

The magnitude of error was not related to the magnitude of the movement, apart from sit-to-stand, whereby the Kinect tended to underestimate for shorter distances and overestimate for larger distance (supplementary material 2). The Kinect significantly underestimated range of motion for lateral flexion, hip kinematics during forward stepping and side stepping, vertical knee height during leg agility movements, and overestimated arm kinematics for shoulder flexion and abduction, and elbow flexion movements (Table 3). Relative 95% limits of agreement under 10% were only found for sit-to-stand and arm abduction, with particularly poor absolute agreement for hand clasping and walking on the spot. The generally poor absolute agreement was reflected in lower ICCs. Despite the poor absolute agreement, there was a strong positive linear correlation between Kinect and Vicon measurement for standing trunk flexion and hand clasping. Poor Pearson's correlations and ICCs were also noted for arm pronation for people with PD but not controls.

### 4. Discussion

To the best of our knowledge, this is the first study to establish the accuracy of the Kinect in people with PD. We found that the Kinect was able to accurately measure timing of clinically relevant movements in people with PD and, to a lesser extent, the range of motion of those movements. These results contribute to the eventual goal of developing the Kinect as a low-cost system for monitoring PD movement symptoms in the home.

Our findings concur with those of Clark et al. [8] who showed good agreement between the Kinect and Vicon for measuring trunk and lower limb kinematics during standing balance tests in 20 healthy adults. In addition, we have been able to extend what is known about the accuracy of the Kinect system for measuring upper and lower body kinematics. A case study by Fernández-Baena et al., reported the Kinect underestimated sagittal knee and hip range of motion during a forward step in one young adult by less than 10° [7]. Similarly, we found the Kinect system underestimated hip flexion by 5° during a forward step and hip abduction by 4° during a side step, in addition to reasonably small (<10°) 95% limits of agreement.

We also investigated the accuracy of upper limb kinematics with the Kinect, because PD can have a significant effect on reaching and grasping [17]. Upper limb motion may also be a viable method of controlling exergames for people with PD who are unable to stand safely for extended periods. We found the timing of repetitive shoulder and elbow kinematics was measured very accurately by the Kinect system. Although the range of motion was overestimated by the Kinect, the relative agreement was still very good. This suggests that the Kinect measures gross upper limb
movement accurately enough to control games which generally do not require the same level of accuracy demanded by clinical and research applications. The Kinect may also provide quality feedback of gross upper limb performance for clinical exergaming interventions.

The UPDRS III (motor examination) is a well recognised and validated tool to measure the severity of motor disability in people with PD [3]. One of our eventual goals is to instrument the UPDRS III using the Kinect, thus providing clinicians and researchers with remote assessment of PD symptoms. Encouragingly, we found that the accuracy of the Kinect was required before the Kinect can be used to measure movement symptoms in a home-based setting. First, the accuracy of the Kinect may be improved with a combination of better spatial resolution, more precise estimation of anatomical landmarks and using the optimal orientation of the Kinect relative to the person. The newer “Xbox One Kinect” sensor will have improved spatial and temporal resolution, potentially improving the accuracy of fine movements, such as hand clasping and toe tapping, and facilitate more precise anatomical models. Some of the inaccuracies of the Kinect can be explained by the limitations of the Kinect to estimate anatomical landmarks. There have been several recent advances in estimating the body position and movement using a single Kinect depth sensor [5,19–21]. It is likely that using these techniques in the current study, instead of the in-built 20-point skeleton model, would have produced more accurate results for spatial characteristics for finer movements such as hand clasping. In addition, only capturing the ‘front surface’ of a person, unlike conventional marker-based three-dimensional motion analysis systems also limits the accuracy of the anatomical models.

Posing at a 45 degree angle in relation to the Kinect may improve the spatial accuracy of measuring standing trunk flexion, hand clasping, finger tapping, as well as distinguishing the foot from the leg. Using more precise hand models [18] than the built in skeleton model provided with the Kinect software may result in more accurate hand movements. For example, using vertical displacement of the Kinect hand marker, in the absence of a more detailed hand model is likely to have resulted in inaccuracies detecting hand clasping and finger tapping movements in this study.

The Kinect was not able to collect the spatial characteristics with the same precision as the timing characteristics. For example, ICCs for all temporal characteristics were above 0.9 but ranged from 0.09 to 0.89 for range of motion. Despite this, the relative agreement of measurements (Pearson’s r correlation) were generally strong. First, this indicates the Kinect may be most useful for measuring slowness of movement in people with PD rather than the reduced size of movement. Second, although the measurement of the range of movement may not be as accurate as the Vicon, the Kinect may still be useful to track relative within-person change in movement over time, such as the worsening of movement symptoms with disease progression or improvement due to intervention. However, retest reliability of the Kinect to measure functional movements is yet to be established.

Further development is required before the Kinect can be used to measure movement symptoms in a home-based setting. First, the accuracy of the Kinect may be improved with a combination of better spatial resolution, more precise estimation of anatomical landmarks and using the optimal orientation of the Kinect relative to the person.

Table 2: Temporal accuracy of the Kinect system compared to the gold standard Vicon three dimensional analysis system.

<table>
<thead>
<tr>
<th>Movement</th>
<th>Mean Vicon</th>
<th>Mean Kinect</th>
<th>Bias (Kinect–Vicon)</th>
<th>ICC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controls (n = 10)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sit to stand (s)</td>
<td>8.00 (1.72)</td>
<td>7.96 (1.48)</td>
<td>0.037</td>
<td>.999</td>
</tr>
<tr>
<td>Lateral trunk flexion (s/rep)</td>
<td>3.80 (0.79)</td>
<td>3.78 (0.84)</td>
<td>0.013</td>
<td>.977</td>
</tr>
<tr>
<td>Forward stepping (s/rep)</td>
<td>2.84 (0.46)</td>
<td>2.88 (0.37)</td>
<td>0.041</td>
<td>.983</td>
</tr>
<tr>
<td>Side stepping (s/rep)</td>
<td>2.65 (1.37)</td>
<td>2.76 (1.43)</td>
<td>0.117</td>
<td>.990</td>
</tr>
<tr>
<td>Shoulder flexion (s/rep)</td>
<td>2.79 (0.54)</td>
<td>2.80 (0.53)</td>
<td>0.117</td>
<td>.999</td>
</tr>
<tr>
<td>Shoulder abduction (s/rep)</td>
<td>2.87 (0.61)</td>
<td>2.86 (0.60)</td>
<td>0.006</td>
<td>.991</td>
</tr>
<tr>
<td>Elbow flexion (s/rep)</td>
<td>2.69 (0.56)</td>
<td>2.68 (0.55)</td>
<td>0.003</td>
<td>.997</td>
</tr>
<tr>
<td>Hand clasping (s/rep)</td>
<td>0.45 (1.11)</td>
<td>0.45 (1.11)</td>
<td>0.001</td>
<td>.999</td>
</tr>
<tr>
<td>Pronation supination (s/rep)</td>
<td>0.66 (1.12)</td>
<td>0.69 (1.10)</td>
<td>0.024</td>
<td>.950</td>
</tr>
<tr>
<td>Leg agility (s/rep)</td>
<td>0.34 (0.07)</td>
<td>0.36 (0.08)</td>
<td>0.015</td>
<td>.962</td>
</tr>
<tr>
<td>Walking on the spot (s/rep)</td>
<td>1.16 (1.14)</td>
<td>1.18 (1.14)</td>
<td>0.025</td>
<td>.983</td>
</tr>
<tr>
<td>Parkinson’s disease (n=9)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sit to stand (s)</td>
<td>15.11 (5.76)</td>
<td>15.09 (5.67)</td>
<td>0.019</td>
<td>.999</td>
</tr>
<tr>
<td>Lateral trunk flexion (s/rep)</td>
<td>6.37 (2.64)</td>
<td>6.21 (2.60)</td>
<td>0.157</td>
<td>.993</td>
</tr>
<tr>
<td>Forward stepping (s/rep)</td>
<td>3.33 (0.75)</td>
<td>3.33 (0.68)</td>
<td>0.001</td>
<td>.985</td>
</tr>
<tr>
<td>Side stepping (s/rep)</td>
<td>3.08 (0.77)</td>
<td>3.06 (0.70)</td>
<td>0.016</td>
<td>.994</td>
</tr>
<tr>
<td>Shoulder flexion (s/rep)</td>
<td>3.54 (1.16)</td>
<td>3.53 (1.12)</td>
<td>0.016</td>
<td>.999</td>
</tr>
<tr>
<td>Shoulder abduction (s/rep)</td>
<td>3.74 (1.40)</td>
<td>3.77 (1.35)</td>
<td>0.033</td>
<td>.998</td>
</tr>
<tr>
<td>Elbow flexion (s/rep)</td>
<td>3.23 (1.05)</td>
<td>3.28 (1.06)</td>
<td>0.043</td>
<td>.998</td>
</tr>
<tr>
<td>Hand clasping (s/rep)</td>
<td>0.55 (0.17)</td>
<td>0.54 (0.14)</td>
<td>0.007</td>
<td>.981</td>
</tr>
<tr>
<td>Pronation supination (s/rep)</td>
<td>0.69 (0.38)</td>
<td>0.72 (0.45)</td>
<td>0.036</td>
<td>.984</td>
</tr>
<tr>
<td>Leg agility (s/rep)</td>
<td>0.68 (0.46)</td>
<td>0.69 (0.47)</td>
<td>0.012</td>
<td>.998</td>
</tr>
<tr>
<td>Walking on the spot (s/rep)</td>
<td>1.29 (2.22)</td>
<td>1.29 (2.24)</td>
<td>0.004</td>
<td>.990</td>
</tr>
</tbody>
</table>

p refers to the repeated measures t-test to assess bias between the two systems.

We were unable to extract data from 4 people with PD for hand clasping because of a noisy Kinect signal; s/rep – seconds per repetition.
Author contributions

All authors contributed to the design and implementation of the study. DJ was responsible for technical implementation of capturing movement data using the Microsoft Kinect. GB, DM and BG were responsible for data collection and processing of the data. PO and LR provided important intellectual comment on the manuscript. All the authors contributed to the revision of the manuscript and approved the final version for publication.

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Conflicts of interest statement

The authors have no conflicts of interest to report.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.gaitpost.2014.01.008.

References


