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Technical Report

Validity and reliability of Kinect skeleton for measuring shoulder joint angles: a feasibility study

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Abstract

Objective To test the reliability and validity of shoulder joint angle measurements from the Microsoft Kinect™ for virtual rehabilitation.
Design Test–retest reliability and concurrent validity, feasibility study.
Setting Motion analysis laboratory.
Participants A convenience sample of 10 healthy adults.
Methods Shoulder joint angle was assessed in four static poses, two trials for each pose, using: (1) the Kinect; (2) a three-dimensional motion analysis system; and (3) a clinical goniometer. All poses were captured with the Kinect from the frontal view. The two poses of shoulder flexion were also captured with the Kinect from the sagittal view.
Main outcome measures Absolute and relative test–retest reliability of the Kinect for the measurement of shoulder angle was determined in each pose with intraclass correlation coefficients (ICCs), standard error of the measure and minimal detectable change. The 95% limits of agreement (LOA) between the Kinect and the standard methods for measuring shoulder angle were computed to determine concurrent validity.
Results While the Kinect provided to be highly reliable (ICC 0.76–0.98) for measuring shoulder angle from the frontal view, the 95% LOA between the Kinect and the two measurement standards were greater than $\pm 5^{\circ}$ in all poses for both views.
Conclusions Before the Kinect is used to measure movements for virtual rehabilitation applications, it is imperative to understand its limitations in precision and accuracy for the measurement of specific joint motions.

Keywords: Microsoft Kinect; Motion analysis; Skeleton tracking; Virtual reality; Measurement accuracy; Shoulder rehabilitation

Introduction

The use of virtual reality technology for rehabilitation, or virtual rehabilitation (VR), provides several advantages over conventional therapy. These include the increased capacity for quantitative measurement of motor performance, delivery of real-time performance feedback, and enhanced patient motivation. By exploiting the latest commercial game technologies [1–4], VR systems are being developed at increasingly low costs, making them particularly useful for in-home therapy.

Much of the current research using in-home VR is aimed at patients with neurological disorders [1–5]. However, these systems also have the potential to improve physical therapy for patients with musculoskeletal disorders. With an in-home VR system, a clinician can ensure that the patient is performing exercises correctly and reaching targeted functional goals in specific postoperative timeframes that allow proper joint healing. Although despite these advantages, the

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use of VR for postoperative joint therapy is presently very limited.

The Kinect[TM] (Microsoft Corp., Redmond, WA, USA), one of the more popular gaming sensors, would be an ideal sensor for a VR system designed for postoperative joint rehabilitation. However, as for all gaming technology, the Kinect was not developed with the intention of clinical use. As such, the accuracy of Kinect measurements must be evaluated thoroughly for movements of interest before clinical application. It is disconcerting for a study using the Kinect for VR to claim that the validity and reliability of the sensor have been established previously, with the citation of studies that have assessed the validity and reliability of different Kinect measurements [5]. For instance, it is misleading to cite the accuracy of the depth image to assure accuracy of skeletal data from the Microsoft Kinect for Windows[TM] Software Development Kit (SDK) [6].

With the ultimate goal of developing a VR system for postoperative shoulder therapy, this study aimed to assess the reliability and validity of skeletal data from the Kinect for Windows SDK for the measurement of precise shoulder angles. Previous work has found that skeletal data from the Kinect SDK can be used for accurate measurement of shoulder range of motion (ROM) [7]; however, its accuracy for the measurement of exact shoulder angles has not been investigated. A prior study by Fernández-Baena *et al.* [8], which examined accuracy of the Kinect for the measurement of shoulder ROM, observed average errors between 8° and 14° in shoulder angle trajectories. Similarly, Chang *et al.* [9] observed large errors in tracking the shoulder position with the Kinect. However, no formal analyses of validity and reliability were conducted in these studies. Furthermore, these studies used skeletal data from OpenNI (Primesense), which differ from skeletal data from the Kinect SDK. Nonetheless, the findings of Fernández-Baena *et al.* [8] and Chang *et al.* [9] identify the need to assess the accuracy of measurement of exact shoulder angles using the Kinect skeletal data.

The present feasibility study measured various shoulder angles while participants held a series of static poses. These poses consisted of shoulder configurations commonly used in postoperative shoulder rehabilitation, including one pose where the shoulder was occluded from the view of the Kinect. The shoulder angle measurements from three data acquisition systems – the Kinect, a three-dimensional (3D) motion analysis system (gold standard; trakSTAR, Ascension Technology Corp., Shelburne, VT, USA) and a goniometer (clinical standard) – were compared.

Methods

Participants

A convenience sample of 10 asymptomatic adults with no known shoulder pathology (six males and four females, mean age 22.1 ± 0.9 years) participated in the study. All participants gave informed written consent before the study. The study protocol was approved by the Institutional Review Board of Northeastern University.

Procedure

With the Kinect in the frontal view, each participant held the following static poses, two repetitions each, in a random order: flexion to 90°, flexion to max, abduction to 90°, and external rotation to max at 0° abduction (Fig. A, see online supplementary material). Two additional repetitions of the flexion to 90° and flexion to max poses were measured with the Kinect from the sagittal view. The sagittal view poses were added as pilot work revealed that the shoulder joint was occluded from the Kinect in the frontal view during the flexion to 90° pose. Thus, the two poses of shoulder flexion were repeated from the sagittal view to determine if shoulder flexion measurements were reliable and valid from this vantage point. Half of the participants performed the shoulder motion with their dominant arm, and the other half performed the shoulder motion with their non-dominant arm; this was also randomised.

The 90° poses (flexion to 90° and abduction to 90°) were set using the goniometer. For the max poses (flexion to max and external rotation to max at 0° abduction), participants were instructed to rotate to their maximum capability. Once the pose was set, measurements were recorded simultaneously using a Kinect, a 3D motion analysis system and a blinded goniometer. The pose was reset for each repetition. It is feasible that there were differences between repetitions in the max values. However, this procedure was consistent with current practice. The likelihood of variation in ROM for each pose between trials was reduced by the recruitment of healthy, pain-free subjects.

Data capture and processing

Kinect

The skeletal data captured from the Kinect for Windows SDK for each pose consisted of the 3D positions of 20 joints. The positions of shoulder and elbow joints relative to the trunk were used to measure the angles of shoulder flexion and abduction (in degrees), while the positions of the elbow and hand relative to the trunk were used to measure the angle of external rotation. Skeletal data from the Kinect for Windows SDK were accessed and analysed using MATLAB (Mathworks, Natick, MA, USA).

Goniometer

A standard 12-in. goniometer was modified so that the examiner was blinded to the measures. Goniometric measurements of shoulder joint motions were performed using standardised methods [10]. Once the goniometer was aligned to the shoulder motion by the examiner, a second examiner read and recorded the measurement (in degrees).

Table 1
Test–retest reliability results of the Kinect for the measurement of shoulder angle.

Kinect view	Pose	ICC	Mean	SEM	MDC
Front	Abduction to 90°	0.76	90.1°	2.5°	3.5°
	External rotation to max at 0° abduction	0.98	65.8°	3.7°	5.2°
	Flexion to 90°	0.85	73.7°	12.2°	17.3°
	Flexion to max	0.95	162.2°	4.0°	5.6°
Sagittal	Flexion to 90°	0.84	86.7°	4.4°	6.2°
	Flexion to max	0.37	161.5°	24.2°	34.1°

ICC, intraclass correlation coefficient; SEM, standard error of the measure; MDC, minimal detectable change.

Goniometric measures of the shoulder have demonstrated excellent reliability [11,12].

3D motion analysis

The Trakstar electromagnetic-based motion analysis system with a sampling rate of 240 Hz was used with Motion Monitor software (Innovative Sports Training, Inc., Chicago, IL, USA) to collect 3D kinematic data of the humerus and trunk. Electromagnetic receivers were secured with tape on the thorax over the spinous process of the T3 vertebrae and the posterior aspect of the distal humerus of the arm. Local coordinate axes systems for each segment were created using digitised anatomical landmarks on each segment, in accordance with the recommendations of the International Society of Biomechanics [13]. Euler angle sequences for humeral rotations were used to describe motion of the humerus relative to the thorax. Shoulder movements in the directions of abduction and flexion were described using elevation angles and external rotation with long axis rotation. All motions in flexion, abduction and external rotation were defined as positive for direct comparison with clinical goniometry measures. Root mean square accuracy of this system has been reported to be <1° [14].

Statistical analysis

Intraclass correlation coefficient (ICC) model 3,2 [ICC(3,2)] was used to determine the relative test–retest reliability of the Kinect for the measurement of shoulder angle [15]. Six ICC(3,2) values, representing the agreement of two trials for each pose from the respective views, were computed. The ICC(3,2) values were defined as 'poor' when below 0.20, 'fair' for values between 0.21 and 0.40, 'moderate' for values between 0.41 and 0.60, 'good' for values between 0.61 and 0.80, and 'very good' for values between 0.81 and 1.0 [16]. The standard error of the measure (SEM) and the minimal detectable change (MDC) were calculated to establish absolute reliability. SEM was defined as standard deviation (SD) multiplied by the square root of ICC subtracted from 1 [17], and MDC was calculated by multiplying SEM by the square root of 2 [18].

The 95% limits of agreement (LOA) between the Kinect and the two measurement standards for the shoulder were computed for each pose to determine validity [18]. To obtain the 95% LOA in each pose, the mean of the two shoulder angle measurements from each method was calculated. Next, the mean and SD of differences between (1) the Kinect and the goniometer and (2) the Kinect and the 3D motion analysis measurements were computed. The 95% LOA were defined as the mean difference ±1.96 SD of the difference, such that 95% of differences lay within these limits. If the 95% LOA were greater than ±5°, the discrepancies between measurement systems were considered to be clinically significant [19]. All statistical analyses were conducted using IBM SPSS Statistics software (IBM Corp., Armonk, NY, USA).

Results

Test–retest reliability

Results of test–retest reliability of the Kinect for the measurement of shoulder angle with ICC, SEM, and MDC values are shown in Table 1. From the frontal view, the Kinect had good to very good relative reliability for the measurement of shoulder angle in all four poses, as indicated by the

Table 2
Bland and Altman analysis and limits of agreement, calculated as ±1.96 standard deviation of the difference, between measurements of shoulder joint angle obtained using the Kinect, a goniometer and a three-dimensional (3D) magnetic tracking system.

Kinect view	Pose	Kinect vs goniometer		Kinect vs 3D magnetic tracker	
		Mean bias	95% Limits of agreement	Mean bias	95% Limits of agreement
Front	Abduction to 90°	−1.5°	−7.0 to 4.1°	3.0°	−10.6 to 16.7°
	External rotation to max at 0° abduction	1.3°	−14.3 to 16.9°	16.0°	−36.4 to 68.4°
	Flexion to 90°	−16.6°	−52.1 to 18.9°	−6.1°	−44.6 to 32.4°
	Flexion to max	−15.9°	−36.5 to 4.7°	10.6°	−15.4 to 36.7°
Sagittal	Flexion to 90°	−6.9°	−17.7 to 3.8°	6.1°	−8.7 to 20.9°
	Flexion to max	−15.0°	−44.5 to 14.5°	10.6°	−25.0 to 46.3°

high ICC(3,2) values. Small SEM and MDC values, indicating good absolute reliability, were observed for all poses from the frontal view except flexion to 90°, where the shoulder joint was occluded from the Kinect camera. From the sagittal view, the Kinect had very good relative and absolute reliability in the flexion to 90° pose, but only fair relative reliability and poor absolute reliability in the flexion to max pose.

Concurrent validity

The 95% LOA between the Kinect and the goniometer and between the Kinect and the 3D motion analysis system are shown in Table 2. Abduction to 90° was the only pose in which the Kinect measures of shoulder angle were reasonably accurate compared with either the goniometer or the 3D motion tracking system. Like the other poses, however, the 95% LOA for the discrepancy between systems exceeded ±5°, which was defined as clinically significant.

Discussion

Using the skeletal data from the Kinect for Windows SDK, the Kinect was found to be highly reliability for the measurement of shoulder angle in most poses. Highest accuracy was achieved for the measurement of shoulder angle in the abduction to 90° pose. This is consistent with a previous finding that the Kinect was accurate for the measurement of ROM during shoulder abduction [7]. However, the measurement discrepancies between the Kinect and the two measurement standards were clinically significant in all poses.

From the frontal view, the Kinect had poor results for the measurement of shoulder angle in the transverse plane (external rotation to max at 0° abduction) and the sagittal plane (flexion to 90° and flexion to max). Bonnechère *et al.* [7] reported similarly poor results using the Kinect to measure ROM during elbow flexion and knee flexion, which are both movements in the sagittal plane. Inaccurate measurements in the sagittal plane can be explained, in part, by errors introduced from estimating the position of occluded joints; a problem typical of vision-based motion tracking systems. This was most evident from the poor absolute reliability and validity of the Kinect measurements in the flexion to 90° pose from the frontal view, where the shoulder joint was occluded by the arm.

In an attempt to circumvent this problem, the flexion to 90° and flexion to max poses were also measured from the sagittal view, but this did not prove a viable solution. In the external rotation to max at 0° abduction and flexion to max poses, joint occlusion was not an issue, but the shoulder angles measured by the Kinect were still inaccurate. This major limitation poses a problem for the measurement of simple shoulder movements, as well as complex, full-body movements.

Conclusions

While the skeletal data of Kinect for Windows SDK may be accurate for commercial gaming purposes, this study revealed significant concerns about the use of these data to measure shoulder motion when precise shoulder angle measurements are required. Only a limited number of shoulder configurations were examined in this study. However, the large discrepancies in shoulder angle measurements should not be taken lightly. In fact, these results identify the need for further assessment of the accuracy of the Kinect for measurement of a wider range of shoulder angles and in impaired movements.

VR for postoperative shoulder therapy is only one example of a case where accurate shoulder angle measurements are needed. In fact, accurate shoulder angle measurements are required for most musculoskeletal and neurological rehabilitation protocols [4,8,9,20]. Before the Kinect can be used to measure movements in VR, it is imperative to understand its limitations in precision and accuracy for the measurement of specific joint motions.

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Conflict of interest: None declared.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.physio.2015.02.002.

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