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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™ (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™ 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).