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Scientific/Clinical Article

Modifying Kinect placement to improve upper limb joint angle measurement accuracy

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A R T I C L E I N F O

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A B S T R A C T

Study Design: Repeated measures.
Introduction: The Kinect (Microsoft, Redmond, WA) is widely used for telerehabilitation applications including rehabilitation games and assessment.
Purpose of the Study: To determine effects of the Kinect location relative to a person on measurement accuracy of upper limb joint angles.
Methods: Kinect error was computed as difference in the upper limb joint range of motion (ROM) during target reaching motion, from the Kinect vs 3D Investigator Motion Capture System (NDI, Waterloo, Ontario, Canada), and compared across 9 Kinect locations.
Results: The ROM error was the least when the Kinect was elevated 45° in front of the subject, tilted toward the subject. This error was 54% less than the conventional location in front of a person without elevation and tilting. The ROM error was the largest when the Kinect was located 60° contralateral to the moving arm, at the shoulder height, facing the subject. The ROM error was the least for the shoulder elevation and largest for the wrist angle.
Discussion: Accuracy of the Kinect sensor for detecting upper limb joint ROM depends on its location relative to a person.
Conclusion: This information facilitates implementation of Kinect-based upper limb rehabilitation applications with adequate accuracy.
Level of Evidence: 3b

Introduction

The Kinect (Microsoft, Redmond, WA) is a low-cost motion detection device, originally developed for gaming purposes. The Kinect provides kinematic data that used to be accessible only through traditional research purpose motion capture systems.[1-6] Yet, the Kinect costs only a fraction of traditional motion capture systems, is portable, and is less technically demanding to use. In addition, although typical research purpose motion capture systems require a person to wear markers over the body to track the person's limb motion, the Kinect captures limb motion without the need to wear any equipment on the body. This easy-to-use aspect of the Kinect is also complemented by user-friendly interfaces for obtainment of processed data, once developed for a specific application. These practical benefits of the Kinect have fueled development of Kinect-based applications for telemedicine. These applications include Kinect-based assessment tools to objectively quantify patient movements, evaluate rehabilitation progress, and aid planning of rehabilitation.[1,7-14] In addition, Kinect-based virtual reality rehabilitation games have been developed to motivate patients to continue therapeutic movements in the comfort of their home or typical environments such as school.[15-22] These Kinect-based rehabilitation applications have been shown to be well liked by both patients and therapists.[17,18,23] With its increasing popularity, a knowledge translation resource has been developed to support clinical decision making about selection and the use of

Conflict of interest: All named authors hereby declare that they have no conflicts of interest to disclose.

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Kinect games in physical therapy.[24] Thus, the Kinect is considered a promising tool to aid rehabilitation.[25,26]

During the use of the Kinect sensor for movement assessment and/or rehabilitation games, the manufacturer recommendation is to place the Kinect horizontally in front of a person.[27] While this Kinect location may work well for detecting movements in the frontal plane, accuracy of the Kinect sensor may decrease for movements in the sagittal plane. It is because the Kinect's measurement error is the largest for the depth direction (ie, direction from the Kinect sensor to a person) compared to the horizontal and vertical directions. Specifically, the root mean square errors for the Kinect sensor is 6.5, 5.7, and 10.9 mm in the horizontal, vertical, and depth direction, respectively.[28] In other words, accuracy of the Kinect depends on its relative location to a person and movements being captured, and the Kinect accuracy may be improved by modifying the Kinect sensor location. For this reason, researchers have used different Kinect locations relative to the movement of interest. For example, Pfister et al[29] placed the Kinect 45 to the left of the person in the hope to best capture the knee and hip motions during treadmill walking. However, the optimal placement of the Kinect sensor has not been systematically investigated. The knowledge of optimal Kinect placement may contribute to increasing accuracy of joint angle measurements and utility of the Kinect. The likely reason that the optimal Kinect placement has not been established is that accuracy of the Kinect changes depending on the movements[30] due to the nonuniform measurement errors in the 3 axes, and thus, the optimal Kinect placement may vary depending on the movement of interest.

One of the movements of interest for upper limb therapy is target reaching.[22,31-42] Target reaching motion is typically used in upper limb rehabilitation settings as follows. First, people with movement disorders, such as due to stroke[22,31,32] and burn injury,[33] practice target reaching motion for therapy because it is one of the most important abilities for activities of daily living.[43] In addition, target reaching motion is used as part of outcome assessments of rehabilitation therapy programs for those with movement disorders after stroke[31,34-36] and peripheral nerve injury.[37] Likewise, target reaching motion has been used to characterize movement disorders for patients such as those with stroke[38-41] and muscular dystrophy[42] because of its ability to distinguish kinematic characteristics of patients from healthy controls or the unaffected side as well as its importance in our understanding of motor control.[44,45] Although target reaching motion is frequently used in upper limb rehabilitation settings, information regarding accuracy of the Kinect sensor in measuring all upper limb joint angles during target reaching motion is limited for varying Kinect sensor locations.[25]

Therefore, the objective of this study was to examine measurement accuracy of upper limb joint angles during target reaching movement using the Kinect and to determine the impact of adjusting the location of the Kinect sensor relative to a person on the measurement accuracy. Specifically, Kinect error in the range of motion (ROM) measurement was assessed as the difference in the upper limb joint ROM detected by the Kinect using Kinect for Windows Software Development Kit (SDK) (Microsoft, Redmond, WA) and by 3D Investigator Motion Capture System (NDI, Waterloo, Ontario, Canada). The 3D Investigator system was used as a research-grade motion capture system as it has been used for research involving upper limb[46-49] and other motion analyses.[50] A smaller difference in the measurement between the 2 systems would indicate better agreement of the Kinect to the research-grade motion capture system and thus accuracy. The error in the ROM measurement was compared across 9 Kinect sensor locations to examine the extent to which this error changed with varying Kinect sensor locations and to determine if the error in the ROM could be reduced by modifying the Kinect sensor location as compared with the standard location of being horizontally in front of a person. This study intends to contribute to improving Kinect positioning relative to a patient for better measurement accuracy and standardizing a Kinect-based measurement protocol for an upper limb rehabilitation setting, which is a necessary step for implementation in clinical practice.

Methods

Subjects

Ten right-handed healthy subjects (age range, 20-37 years; 5 males and 5 females) participated in this study. The study protocol was approved by the institutional review board, and all subjects signed the informed consent forms.

Procedure

An experiment was conducted to quantify difference in the ROMs for the upper limb joint angles determined using the Kinect as compared with a research-grade motion tracking system of 3D Investigator and to compare the difference across multiple Kinect sensor locations. Subjects were seated with the right forearm resting on a table. On computer-generated cues, subjects were asked to lift their right arm, point their index finger toward a prescribed target, and return to the initial position at a comfortable speed (Fig. 1A), similarly with previous studies.[31,32,37] Twenty-one targets labeled from 1 to 21 were presented on the wall in front of the subject to cover the upper limb workspace in front of a person at or above the shoulder level (Fig. 1A). Subjects' upper limb joint positions were recorded using the Kinect and 3D Investigator systems simultaneously. Each target for each Kinect location was prescribed at least twice. The order of testing the targets was randomized within a Kinect location. The order of testing Kinect locations was randomized across subjects. The consecutive reaching was separated by 5 seconds. Subjects were provided with rest breaks between Kinect location conditions.

Nine Kinect sensor locations were tested. The 9 locations differed by the elevation and azimuth angle of the Kinect sensor relative to the right shoulder (Figs. 1B and 1C): directly in front of the right shoulder at 45° elevation (denoted by $K_{45,0}$ in Fig. 1C), 30° elevation and directly in front of the right shoulder ($K_{30,0}$), 30° elevation and 60° to the left ($K_{30,-60}$) or 60° to the right ($K_{30,60}$), at the shoulder level directly in front of the right shoulder ($K_{0,0}$), 30° to the left ($K_{0,-30}$) or to the right ($K_{0,30}$), or 60° to the left ($K_{0,-60}$) or right ($K_{0,60}$). For all locations, the Kinect sensor was tilted such that the sensor faced the subject's right shoulder. The Kinect sensor was placed 1.5 m away from the right shoulder to ensure that the right shoulder and hand were within the capture range recommended by Kinect specifications[51] while minimizing the distance between Kinect and the subject because the depth accuracy of Kinect decreases with increasing distance.[52] Any shiny or dark objects such as a watch were removed from subjects to prevent interference with Kinect's motion detection.[28,52] The position data for the right shoulder, elbow, and wrist joints in addition to hand in 3-dimensional space were obtained using custom-developed software with Kinect for Windows SDK.

During all reaching tasks, 3D Investigator system recorded positions of the infrared light-emitting markers placed on the subject's upper limb to determine the shoulder, elbow, and wrist joint positions as well as hand position in 3-dimensional space. The markers were placed on the right upper limb: 3 markers on the dorsum of the right hand, 2 markers on the right wrist (medial and lateral), 3 markers on the right forearm, 2 markers on the right elbow (medial and lateral), 3 markers on the right upper arm, and 1

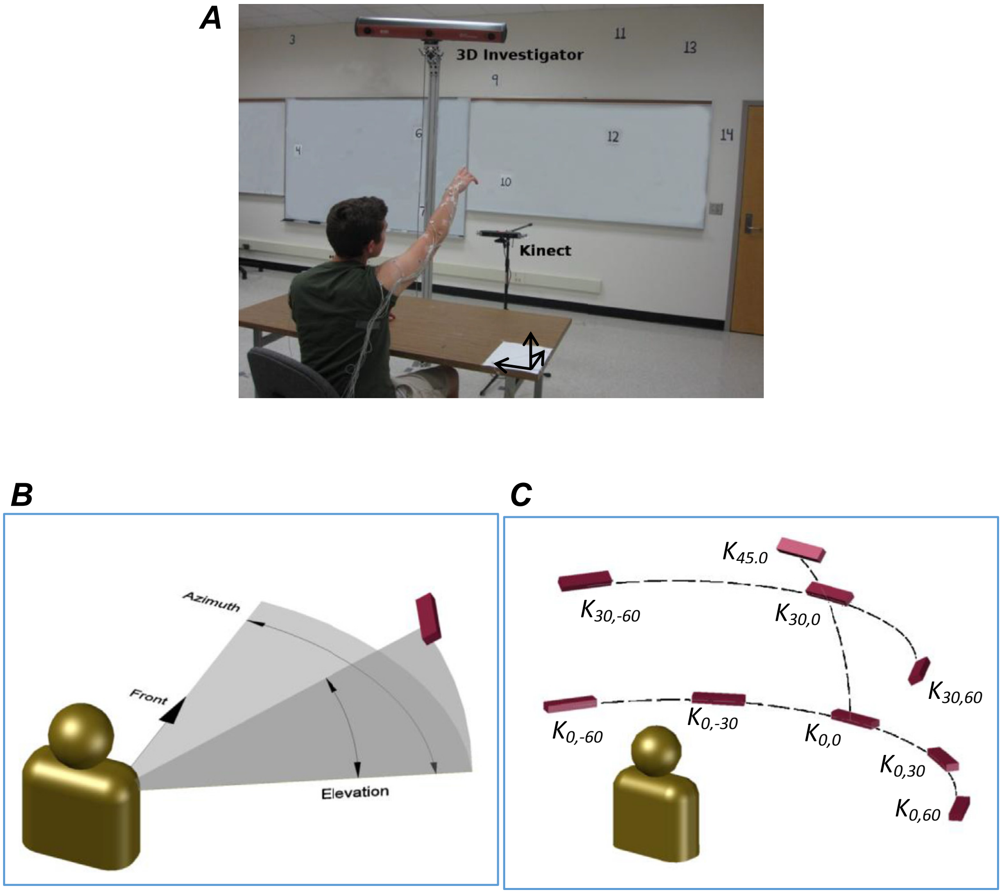

Fig. 1. (**A**) A subject performing a reaching motion toward a target. Their right upper limb motion was detected using Kinect ($K_{0,0}$ location shown in the picture) and 3D Investigator using active markers placed on the right upper limb. Numbered targets were placed on the walls in front of the subject. (**B**) Kinect location was specified by its elevation and azimuth angles relative to the subject's right shoulder. (**C**) The 9 Kinect locations tested are labeled by their elevation and azimuth angles.

marker on the right shoulder. Such marker placement of using 2 markers to estimate a joint center with additional markers to allow detection of rotational orientation is conventional in upper limb motion analysis.[42,53] In the present study, the positions of the 3 markers on the hand were averaged to find the hand position. The midpoints of the pairs of markers on the wrist and elbow joints were used as the positions of the wrist and elbow joints, respectively. The extra markers on the forearm and upper arm were used to estimate the positions of other markers if their view was obstructed during movement. In addition, 3 markers were placed on the desk on predetermined spots to enable transformation of the position data to the reference coordinate system.

Data analysis

The ROM for each of 5 upper limb joint angles during a target reaching motion was determined using data obtained from each device. The 5 joint angles were shoulder elevation, shoulder plane of elevation, shoulder axial rotation, elbow, and wrist angles. The shoulder elevation angle was the angle between the upper arm and the vertical axis, and the shoulder plane of elevation angle was the angle between the sagittal plane and the projection of the upper arm on the horizontal plane (the yaw angle represented a rotation of the arm about the vertical axis), whereas the shoulder axial rotation angle represented a rotation of the forearm about the axis of the upper arm according to the International Society of Biomechanics standard definition[54] and literature.[55] The shoulder axial rotation angle was defined to be 0 when the forearm had the largest vertical component. The elbow angle was the angle between the upper arm and the forearm. The wrist angle was the angle between the forearm and the hand.

To enable the shoulder joint angle computations relative to the horizontal and sagittal planes, all Kinect and 3D Investigator position data were transformed into the reference coordinate system. The reference coordinate system aligned with the horizontal, sagittal, and frontal planes. For the Kinect, the transformation matrix from the local coordinate system to the reference coordinate system was derived from the elevation and azimuth angles of the Kinect. The transformation matrix for the 3D Investigator was found from the 3 markers placed on the desk (horizontal plane), forming a right triangle with one side parallel to the sagittal plane and another side parallel to the frontal plane.

The start of data recording for the Kinect and 3D Investigator in 2 different computers was synchronized via an external trigger signal. Both systems recorded the sample time in addition to position information, and the sampling frequency was 16-20 Hz for the Kinect and 100 Hz for the 3D Investigator. Because the 2 data sets were sampled at different frequencies, all joint angle data for both Kinect and 3D investigator were resampled at the mean sampling frequency of the Kinect, and the resampled data were used for computing ROMs. The ROM was computed as the difference between the maximum and minimum of the joint angle observed during each target reaching motion. The error of the Kinect in the ROM measurement was determined as the difference in the ROM between the Kinect and 3D Investigator (the ROM computed using the Kinect minus the ROM computed using the 3D Investigator), for each Kinect location, each target, each joint angle, and each subject.

Statistical analysis

Repeated-measures analysis of variance was conducted to determine whether the Kinect's ROM error significantly changed with the 9 Kinect locations, 5 joint angles, 21 targets, and their second-order interactions. The significance level of .05 was used. For significant factors, Tukey post hoc analysis was used for pairwise comparisons. In addition, the bias and variability of the difference between the Kinect and 3D Investigator for the shoulder elevation and elbow ROM data were further examined using the Bland-Altman plots. Finally, the correlative relationship between the measurements from the 2 systems was further examined using intraclass correlation coefficient (ICC).

Results

The mean error in the ROMs for each Kinect location and each target is shown in Figure 2 (joint angles pooled). The analysis of variance results indicate that the error in the ROM was significantly dependent on Kinect location ($P < .001$), joint angle ($P < .001$), and the interaction between Kinect location and joint angle ($P < .001$). The target, interaction between Kinect location and target, and interaction between joint angle and target were found to be not significant ($P = .32$, .46, and .82, respectively).

The $K_{45,0}$ location resulted in the least mean error in the ROM (mean ± 95% confidence interval [CI] = 10° ± 1°) among all 9 locations (Fig. 3A; Tukey post hoc test, $P < .05$), followed by the $K_{30,0}$ location. On the other hand, the $K_{0,-60}$ location was found to result in the largest mean error in the ROM (38° ± 2°) (Fig. 3A; Tukey post hoc test, $P < .05$), followed by the $K_{0,-30}$ location. The conventional $K_{0,0}$ location was associated with the median error in the ROM among all Kinect locations (22° ± 2°).

The shoulder elevation angle was found to have the least mean error in the ROM (5° ± 1°), followed by the elbow, shoulder plane of elevation, and shoulder axial rotation angles (Fig. 3B; Tukey post hoc test, $P < .05$). The largest mean error in the ROM was found for the wrist angle (41° ± 2°, Fig. 3B; Tukey post hoc test, $P < .05$).

The mean errors in the ROMs for individual joints for each Kinect location are shown in Figure 3C. The mean error in the shoulder elevation ROM was less than 15° for all Kinect locations. For the elbow, shoulder plane of elevation, and shoulder axial rotation angles, the mean error in the ROMs varied substantially depending on the Kinect location. The mean error in the wrist ROM was greater than 20° for all Kinect locations.

The mean ± 95% CI Kinect errors in the ROMs were mostly positive (Fig. 3C), indicating that the Kinect tended to overestimate the ROM compared with the 3D Investigator. For instance, the shoulder elevation angle was overestimated for the $K_{45,0}$, $K_{0,0}$, and $K_{0,-60}$ locations by the mean ± 95% CI of 7° ± 1°, 7° ± 1°, and 12° ± 2°, respectively (statistically different from 0). The elbow angle was neither overestimated nor underestimated for the $K_{45,0}$ location (0° ± 2°, statistically indifferent from 0), whereas it was overestimated for the $K_{0,0}$ and $K_{0,-60}$ locations by 14° ± 4° and 36° ± 5°, respectively. These overestimation biases can be seen again in the Bland-

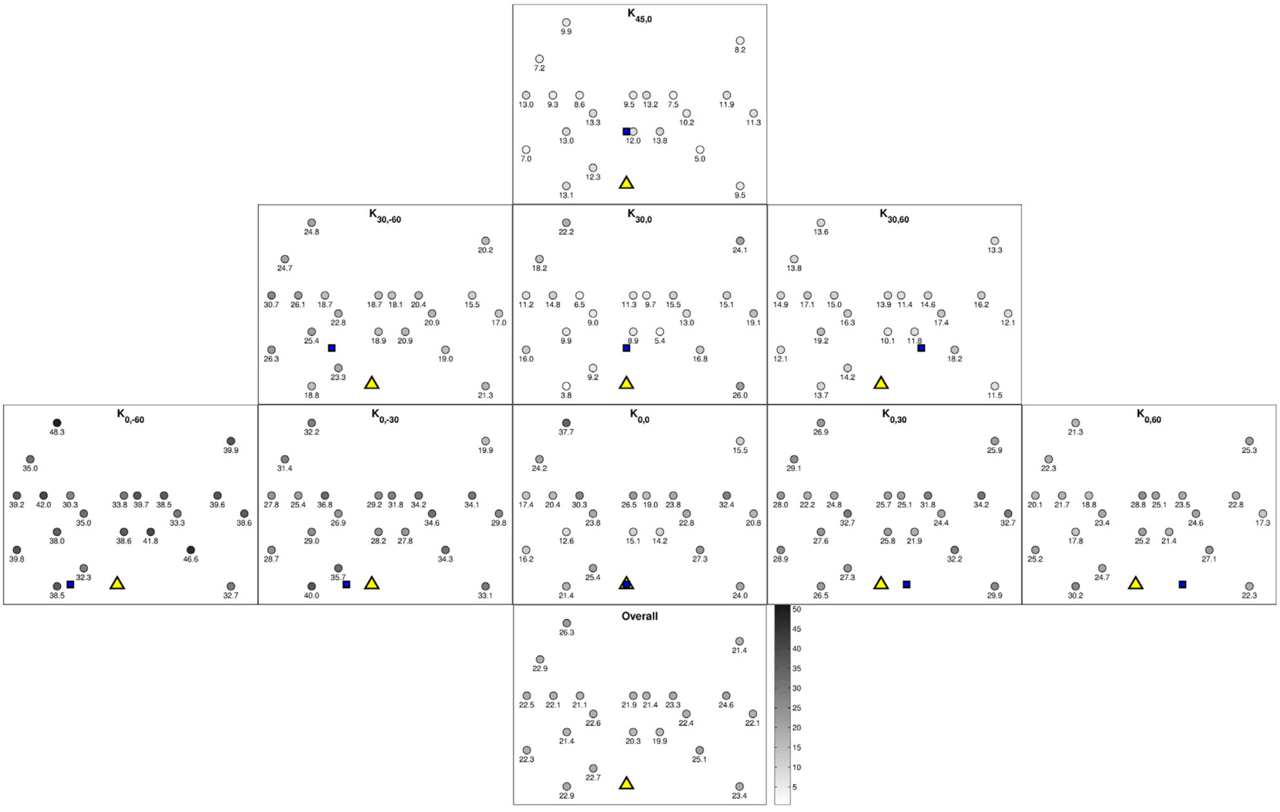

Fig. 2. Mean error in the upper limb joint ROMs (in degrees) for each target for each Kinect location (*first 3 rows*) and averaged for all Kinect locations (*bottom row*), averaged for the 5 joint angles. Within each Kinect location, the mean errors in the ROM (in degrees) are noted below each target location and with the gray scale. The triangle in the bottom center of each Kinect location denotes the right shoulder location, whereas the filled square denotes the Kinect location. The least mean error in the ROM measurement was observed for $K_{45,0}$, and the largest mean error in the ROM measurement was observed for $K_{0,-60}$. ROM = range of motion.

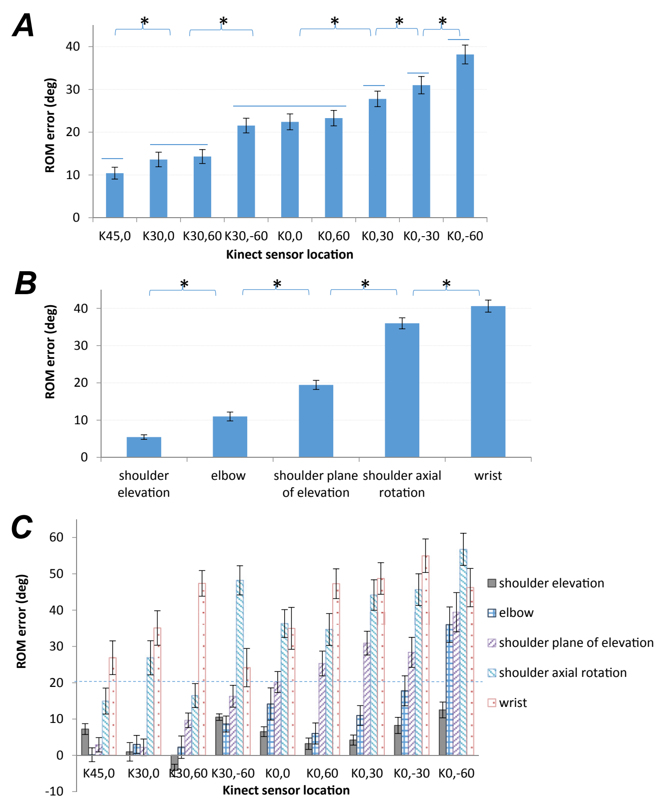

Fig. 3. (**A**) Mean error in the ROM significantly varied by Kinect locations ($P < .001$). The mean error in the ROM was the least when the Kinect was located 45° elevated in front of the subject ($K_{45,0}$) and the largest when the Kinect was located at the shoulder level and 60° to the left ($K_{0,-60}$). (**B**) Mean error in the ROM significantly varied by joint angles ($P < .001$). The mean error in the ROM was the least for shoulder elevation angle. *Stars* indicate groups with statistically significant differences. (**C**) Mean error in the ROM for each joint angle and Kinect location. All *error bars* indicate 95% confidence interval. ROM = range of motion.

Altman plots for the shoulder elevation and elbow angles (Figs. 4A and 4B). In addition to the bias, the CI of the elbow ROM difference between the 2 systems was 2.3 and 2.6 times greater for the $K_{0,0}$ and $K_{0,-60}$ locations compared with the $K_{45,0}$ location (Fig. 3C). This larger variability can be clearly seen in the Bland-Altman plots (Fig. 4B).

The agreement between the Kinect and 3D Investigator was further examined using ICC (Fig. 5). Because the wrist ROM error was greater than 20° for all Kinect locations that were deemed excessive for clinical assessment purposes (please see the detailed rationale provided in Discussion section, Clinical implication), ICC was computed using ROM data of the 3 shoulder angles and elbow angle, without the wrist data. The ICC was the highest for the $K_{45,0}$ location and the lowest for the $K_{0,-60}$ location (Fig. 5A). The correlation plots (Fig. 5B) illustrate the relationship between the ROM measurements from the 2 systems for the $K_{45,0}$ location with the highest ICC, the standard $K_{0,0}$ location, and the $K_{0,-60}$ location with the lowest ICC.

Discussion

Effects of the Kinect placement

This study demonstrated that accuracy of the Kinect sensor for detecting upper limb joint ROMs during target reaching motion depends on its location relative to a subject. Specifically, the least mean error in the ROM measurement with the highest ICC was obtained by placing the Kinect at an elevation angle of 45° in front of the subject and tilting Kinect to directly face the subject (Figs. 3A and 3C, Fig. 5A). The conventional Kinect location of right in front, facing the subject ($K_{0,0}$ with 0° azimuth angle and 0° elevation angle[27]), was outperformed by the Kinect locations of $K_{45,0}$, $K_{30,0}$, and $K_{30,60}$ (Fig. 3A, Fig. 5A). By changing the Kinect location from the conventional $K_{0,0}$ to $K_{45,0}$, the mean error in the ROM decreased approximately by half (Fig. 3A). The largest error in the ROM was obtained with the Kinect sensor placed on the left side of the subject at the elevation angle of 0°, whereas the right upper limb motion was tracked.

In the absence of these data, one may postulate that the least error might be obtained by positioning the Kinect on the side of the arm reaching movement (eg, $K_{0,-60}$ or $K_{0,60}$ locations) to capture joint angles primarily by using the Kinect's RGB camera with higher accuracy than the Kinect's depth sensor with lower accuracy.[28] However, the postulation was not supported by the data. In particular, the largest error in the ROM and the lowest ICC for the $K_{0,-60}$ location (on the left side of the subject) may have occurred as the Kinect's view of the right arm could have been obstructed by the trunk and the left arm resulting in poor detection of the right arm motion.[56] On the other hand, the least error in the ROM along with the highest ICC was achieved when the Kinect was located in the center of the targets ($K_{45,0}$; Fig. 2). As most targets were at or above the shoulder level, elevation of the Kinect sensor above the shoulder level ($K_{45,0}$ and $K_{30,–}$) resulted in less error in the ROM compared with the Kinect placed at the shoulder level ($K_{0,–}$; Fig. 3A). This Kinect location in the center of the targets may have resulted in the least error in the ROM as the upper extremity became closer to the Kinect sensor during pointing, and the shorter distance from the Kinect sensor is associated with less error in depth estimation.[28,52]

Comparison to previous studies

Consistent with previous studies, the Kinect detected movements of the shoulder and elbow joints more accurately than the wrist.[2,30,57] Specifically, the mean error in the ROM was the least for the shoulder elevation angle followed by the elbow angle, whereas the mean error in the ROM was the largest for the wrist angle followed by the shoulder axial rotation angle (Fig. 3B). The largest error in the ROM for the wrist angle may be associated with a challenge in detecting the small hand compared with the other upper limb parts and/or the small distance between the wrist and the hand with which small error in wrist or hand position estimation may result in large error in the angle. In addition, it is possible that during reaching, the hand may have reached close to the boundary of the Kinect's capture volume compared with the proximal upper limb, which could increase estimation error for the hand position and thus the wrist joint angle.[28] The second largest error in the ROM for the shoulder axial rotation angle may be related to the involvement of 3 vectors in the joint angle computation as opposed to only 2 vectors for all other joint angles because inclusion of more number of estimated data with error in calculation results in greater accumulated error.

The error in the ROM observed in this study was in similar magnitudes with previous studies. For instance, the mean error in the ROM and standard deviation of the shoulder elevation of 7° ± 10° for the $K_{0,0}$ location found in the present study was comparable with the mean error of the shoulder elevation of 10° ± 6° across previous studies.[1,3-5,58,59] The mean error in the ROM for the elbow angle of 14° ± 32° for the $K_{0,0}$ location in the present study was also comparable with the mean error in the ROM for the elbow angle of 10° ± 10° across previous studies.[1,4-6,58] In addition, the Kinect's

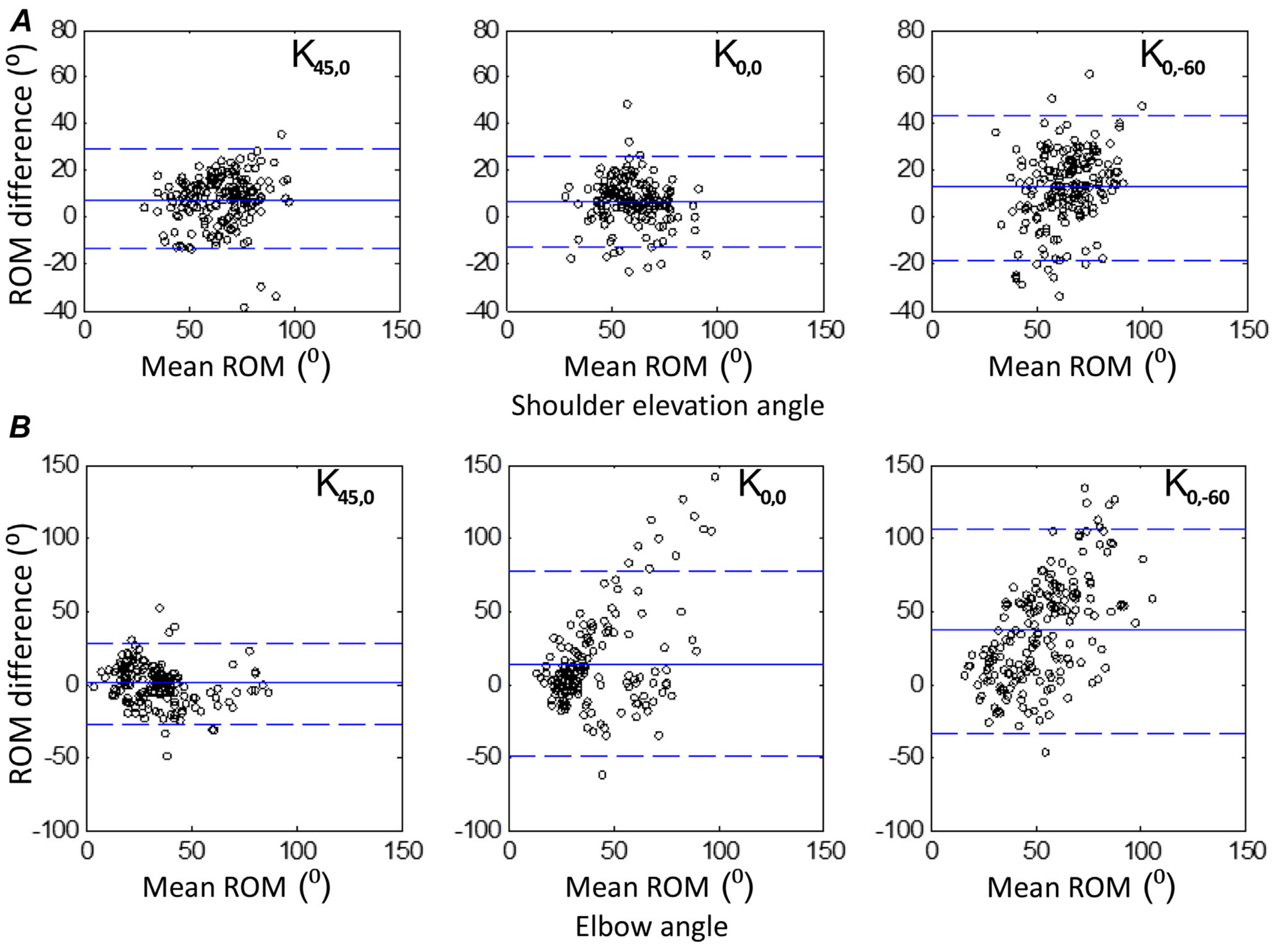

Fig. 4. Bland-Altman plots comparing the ROM from the Kinect and 3D Investigator for the (**A**) shoulder elevation angle and (**B**) the elbow angle for the 3 Kinect locations ($K_{45,0}$, $K_{0,0}$, and $K_{0,-60}$). The *solid horizontal line* indicates the mean difference, with a positive value indicating an overestimation. The *segmented horizontal lines* indicate the 95% limits of agreement. ROM = range of motion.

tendency to overestimate joint angles seen in the present study is consistent with the previous studies.[1,29]

Clinical implication

The present study provides an objective data set that can be used in designing a Kinect setup for upper limb rehabilitation applications. The need for accuracy changes depending on specific applications and goals. For example, larger Kinect error may be tolerated for applications to motivate patients to move upper limb repeatedly by engaging them in an interesting virtual reality game environment. Yet, too large Kinect error (eg, >45°) could be rather frustrating than motivating to patients as they may feel that the Kinect does not detect their motion well and the system does not work well. For assessment of rehabilitation recovery, Kinect error less than 20° may be desired as the interrater standard deviation in upper limb joint angle estimation is up to 20°[60] and additional shoulder elevation needed to reach one higher level of a standard kitchen shelf is approximately 20° based on anthropometry data.[61] For that limit, the present study suggests the following: the Kinect appears to be adequate for detecting the shoulder elevation ROM as the error in the ROM was less than 15° for all Kinect locations. However, if the target measure includes the elbow and shoulder plane of elevation angles, the Kinect sensor may be placed with elevation to minimize error in detecting the upper limb joint ROM during target reaching motion. In addition, the Kinect may not be adequate for assessing the wrist ROM as this error was greater than 20° for all Kinect locations. For example, it may be inadequate to use the Kinect as a tool to monitor if a patient becomes eligible for a constraint-induced movement therapy that requires 30° wrist extension as the 95% CI of the wrist ROM error includes or exceeds 30°. In summary, having this detailed information about joint angle estimation error helps guide use of the Kinect for upper limb reaching rehabilitation applications.

Limitations

There are ways to increase accuracy of the Kinect such as use of a Kalman filter,[40] calibrations relative to a conventional research purpose motion capture data to adjust the Kinect data,[62,63] and sensor fusion.[41,64] However, the present study used the manufacturer-provided Kinect for Windows SDK to obtain joint position data and did not use additional calibration procedures. Using the same physical sensor with another SDK with a different detection algorithm may lead to different magnitudes of error. Second, the error in the upper limb joint ROM reported in this study may be specific to upper limb reaching motion toward targets at or above the shoulder height of seated persons. Generalizability to other specific motions was not examined in the present study. Third, the present study tested healthy adults to cover wide joint

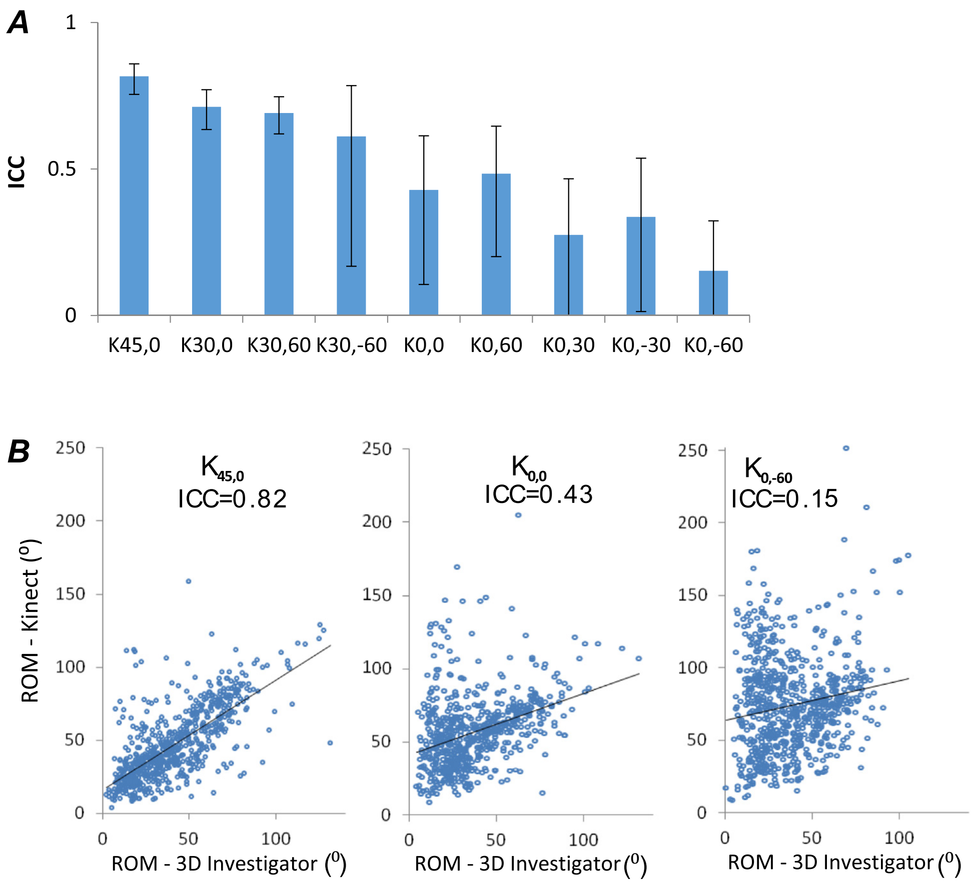

Fig. 5. (A) ICC between the Kinect and 3D Investigator in the ROM measurement for all shoulder and elbow angles is shown for each Kinect location. The *error bars* indicate 95% confidence interval. (B) Correlation plots between the Kinect and 3D Investigator for the ROM measurement of all shoulder and elbow angles are shown for 3 Kinect locations ($K_{45,0}$, $K_{0,0}$, and $K_{0,-60}$). ICC = intraclass correlation coefficient; ROM = range of motion.

ROMs observed during reaching. Patients with severe upper limb spasticity due to neurologic disorders may not have wide joint ROMs, and the Kinect may have difficulty distinguishing upper limb segments from each other or from the trunk when the limb is tight. Finally, a small sample size was used in this study, and the generalizability to the healthy population at large may be limited.

Conclusion

The location of the Kinect sensor relative to a subject can affect its accuracy in the detection of upper limb joint angle ROMs. The detailed information regarding the measurement error can be used to evaluate how much error is expected for each Kinect location and for each joint angle. This finding can be used for better placement of the Kinect sensor and understanding of its accuracy in future studies using the Kinect for upper limb motion detection. The results of this study have implications for low-cost virtual reality applications, such as rehabilitation games, assessment, and telemedicine.

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Quiz: #444

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#1. The study compared ROM measures for the
  a. traditional goniometric method vs. the Kinect system
  b. traditional goniometric method vs. the 3D InvestigatorTM Motion Capture system
  c. Kinect vs. the 3D InvestigatorTM Motion Capture system
  d. none of the above

#2. The Kinect error was the least when the apparatus was placed
  a. in 45° of elevation in front of the subject
  b. directly in front of the subject
  c. behind the subject
  d. directly above the subject

#3. The conventional placement of the Kinect is
  a. in 60° of elevation in front of the subject
  b. behind the subject
  c. directly above the subject
  d. in front of the subject with no elevation

#4. The methods presented in the study currently are most likely best suited for use in a/an ____________setting
  a. in patient rehab
  b. out patient clinical
  c. research
  d. Star Wars movie

#5. The authors characterize the accuracy of the Kinect method as adequate
  a. false
  b. true

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