Can shoulder range of movement be measured accurately using the Microsoft Kinect sensor plus Medical Interactive Recovery Assistant (MIRA) software?

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http://dx.doi.org/10.1016/j.jse.2017.06.004

CAN SHOULDER RANGE OF MOVEMENT BE MEASURED ACCURATELY USING THE MICROSOFT KINECT SENSOR + MIRA SOFTWARE?

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Abstract

Aim

To compare the accuracy of measuring shoulder range of movement (ROM) with a simple laptop and sensor combination with assessments of Trained Observers (TO's - shoulder physiotherapists and shoulder surgeons) using full Motion Capture (MoCap) laboratory equipment as the gold standard.

Methods

The Microsoft Kinect is a 3D human motion tracking sensor normally used with an Xbox video game console. Medical Interactive Recovery Assistant (MIRA) software allows this small sensor to measure shoulder movements with a normal computer.

Forty-nine healthy volunteers had infrared surface markers positioned to allow MoCap measurement of cardinal shoulder movements. Movements were simultaneously measured by TO's , MoCap and the MIRA device. Internal rotation was assessed with the shoulder abducted 90° and external rotation with the shoulder adducted.

Visual estimation and MIRA measurements were compared with gold-standard MoCap measurements for agreement using Bland-Altman methods.

Results

1670 measurements were available for analysis. MIRA measurements of all four cardinal shoulder movements were significantly more precise than TO's.

The limits of agreement were : (95% confidence interval)

Forward Flexion	MIRA +/-11° (8.7-12.6)	TO +/-16° (14.6-17.6)
Abduction	MIRA +/-11° (8.7-12.8)	TO +/-15° (13.4-16.2)
External rotation	MIRA +/-10° (8.1-11.9)	TO +/-21° (18.7-22.6)
Internal rotation	MIRA +/-9° (7.2-10.4)	TO +/-18° (16.0-19.3)

Conclusions

A lap-top combined with a Microsoft Kinect sensor and the MIRA software, can measure shoulder movements with acceptable levels of accuracy. This technology, which can be easily set-up, may also allow precise shoulder ROM measurement outside the clinic setting.

Keywords - Sensor, Kinect, MIRA, Validation, Measurement, Technology, Gamification, Exergames

Level of Evidence - Level 1 - Testing previously developed diagnostic criteria in a consecutive series of patients and a universally applied "gold standard".

Introduction

Accurate measurement of shoulder range of movement (ROM) is an extremely important element of assessing shoulder pathology. Restriction of shoulder movement limits function. Identifying impaired ROM aids diagnosis and evaluation of severity for common conditions such as frozen shoulder, rotator cuff deficiency and subacromial impingement. Repeat measurement can help to track a patient's recovery or response to treatment. [3,13]

Various methods of measurement have previously been employed including the traditional goniometer, questionnaires [13], camcorders, electromagnetic sensors [15,16] and visual estimation to help manage shoulder rehabilitation [12]. An accurate, automated process may be more efficient and objective compared to traditional assessment [12,14]. The use of remote sensor technology provides several advantages over conventional modes of measurement. They deliver increased capacity for quantification of motor performance and real-time feedback enhancing patient motivation [10].

The Kinect™ sensor (Microsoft Corp., Redmond, WA, USA) was developed as an add-on for the Xbox 360™ video game console (Microsoft Corp., Redmond, WA, USA). It allows users to interact with the gaming system by tracking body movement in 3-D. The key to the 3-D movement recognition is the sensor's depth camera which utilises an infrared (IR) laser projector, generating a speckle pattern and an IR camera which detects the reflections from objects. The Kinect is able to create a 3-D map of these objects by measuring deformations in the reference speckle pattern [7]. The Kinect sensor can be paired with a standard notebook or desktop computer and software developed to measure and track body movements; for example, as part of an in-home shoulder rehabilitation programme.

The current 'gold standard' method of measuring body movement is by using motion capture (MoCap) technology such as the Vicon™ (Vicon Motion Systems Ltd. UK) marker-tracking system. It incorporates multiple high-resolution cameras and makes use of infra-red reflective markers to achieve millimetre resolution of 3-D spacial displacements at greater than 100 frames per second [7,11].

Conversely, clinical assessment and rehabilitation of patents with shoulder pathology is routinely performed by trained observers, visually assessing shoulder movement without the aid of sensors or MoCap technology.

This study aims to assess the accuracy of the Kinect sensor paired with the software developed by Medical Interactive Recovery Assistant (MIRA™, MIRA Rehab Ltd, UK). Therefore, the level of agreement between MoCap and the Kinect + MIRA system will be compared with the level of agreement between MoCap and the visual estimation of trained observers.

Materials and Methods

The investigation was conducted in the dedicated motion capture laboratory at the Institute for Biomedical Research into Human Movement (IRM). This MoCap lab in [redacted] utilises a Vicon system consisting of ten, high resolution cameras fitted with IR optical filters and an array of IR LEDs for illumination. The cameras were calibrated before the motion capture session. The calibration accuracy achieved was 0.01 mm. Forty-nine healthy individuals consented to participate. Reflective markers were then applied to the participants in a standardised pattern, based on surface anatomical locations (plugingait model upper limbs and thorax)[see figure 1]. Using the 3D locations of these markers recorded by the system in real-time, the Vicon software calculated joint centres and composite shoulder movement relative to the thorax (Scapulo-thoracic and Gleno-humeral motions combined).

The Kinect sensor was set up within the MoCap lab to facilitate simultaneous measurements. The sensor was placed 1.5 m above the floor on a tripod, 2-3m from the participant [see figure 2]. Using a USB 2.0 port, the Kinect sensor was connected to a Lenovo™ (Beijing, China) laptop with a Windows 7™ (Microsoft Corp., Redmond, WA, USA), 64-bit Operating System, 8GB of RAM, 2.3 GHz Intel™ i7 (Santa Clara, CA, USA) processor. MIRA software was used to process the Kinect data. This was achieved using the Microsoft Kinect Software development Kit (SDK) 1.8 for Windows and the ROM (Range of Motion) measurement tool that is part of the MIRA platform software v1.3 installed on the laptop. MIRA calculated the 3D angle of composite shoulder movement and displayed the result in real time [see figure 3].

In addition to the Vicon system and the Kinect + MIRA pairing, trained observers also recorded their visual assessment of the angle of shoulder movement. These observers comprised a Consultant Orthopaedic Surgeon, two Orthopaedic Specialty Trainee Registrars, three Upper Limb Specialist Physiotherapists and a Medical student who had received specific training in shoulder ROM assessment for this project. As in a standard clinical setting, the observers were allowed to move around the subject to view them from different positions whilst estimating the shoulder movement angles.

The participants were asked to perform each of the four cardinal shoulder movements: Abduction, Forward Flexion, Internal and External Rotation. External rotations were performed with the shoulder adducted. Internal rotation was performed with the shoulder abducted at 90 degrees. This abducted position was used so that the patients trunk did not act as a block to full internal rotation. Each movement was then held in a static position to allow simultaneous measurement by the Kinect + MIRA system, the MoCap and the trained observers. To assess agreement across the full spread of possible measurements, the participants were asked to move their shoulder to the full extent of its range and then were asked to repeat the movement to a point short of full range. This second position was chosen by the participant to help generate a pseudorandom spread of different shoulder positions. The measurements were performed for both shoulders of each participant.

The trained observers were blinded to the measurements of the other observers and of the Kinect + MIRA system. The data from the MoCAP system required extensive processing. This was performed over several days following completion of the study. This analysis allowed calculation of the movement angles. This was done in isolation from the Kinect + MIRA operator and the group of trained observers. Therefore, there was no possibility of the measurements from the trained observers or the Kinect + MIRA system being biased or influenced by the measurements the MoCap system recorded.

Approval for this study was granted by the [redacted] Research Ethics Committee (NHS Health Research Authority, National Research Ethics Service) REC reference 15/NW/0807.

Statistical Analysis

Agreements between the gold standard (MoCap) and the other two methods of measurement (Kinect + MIRA and estimation by trained observers) were analysed as recommended by Bland and Altman [1,2]. This comprised calculating the difference from the MoCap measurement for every Kinect + MIRA measurement and each trained observer measurement. The spread of these differences were then tested for normality using the Shapiro-Wilk calculation. Correlations were then assessed using Pearson's test (or Spearman's if a normal distribution was not present). Scatter Plots of these correlations were then generated. Agreement between the measurement methods were then demonstrated using Bland Altman plots. The limits of agreement (LOA) were calculated and in addition the 95% Confidence Intervals (CI) of the LOA were also calculated. These analyses were performed using IBM SPSS Statistics ver.22 (IBM, Amonk, New York, USA).

Results

A total of 1670 measurements were available for analysis from the observers, MoCap and MIRA + Kinect systems. Forty-nine measurements from the MoCap system had to be excluded as interference with IR reflections prevented calculation of the angle of shoulder movement. However, only one MIRA + Kinect measurement was identified as an outlier requiring exclusion and no measurements recorded by the trained observers required exclusion.

Correlations between the MoCap measurements and the other modes of measurement are shown in table I. Scatter plots were also produced for comparison of the correlations with MoCap measurements (see figure 4). These charts demonstrate a much closer correlation with the MoCap measurements for the MIRA + Kinect system as compared with the Trained Observer measurements.

To analyse the different measurement techniques further, the agreement was assessed using Bland Altman Plots (see figure 5) and calculation of the limits of agreement [1,2]. These charts indicate the mean difference from the MoCap measurements as the solid black line, with the 95% confidence intervals (CI) of this value shown by the solid red lines above and below it. The LOA are represented by the dotted black lines above and below the mean. The 95% CI of these values were also calculated and these are shown as the dotted green lines. The LOA and their 95% CI's are presented in Table II for further clarity.

These Bland Altman Charts show that for each of the cardinal shoulder movements, the MIRA + Kinect system has a narrower spread of plots when compared to the results from the Trained Observers. The calculated LOA show that the MIRA + Kinect has closer agreement to the MoCap than trained observers. Furthermore, the 95% CI's of these values do not overlap indicating that the superior agreement that has been found is statistically significant. The values presented in table 2 show how closely each measurement method agrees with the gold standard MoCap Measurement. For example, 95% of the measurements performed by trained observers for Forward Flexion should lie within +/-16 degrees of the MoCap measurement. However, the MIRA + Kinect system agrees more closely with 95% of measurements lying within +/-11 degrees.

Discussion

The power to measure and monitor shoulder movement using a portable and inexpensive sensor-based system brings potential benefits to research and clinical applications across a wide range of patient populations [5,8]. We compared both measurement techniques to the Vicon MoCap system as this is considered the gold standard for measurement accuracy. The MIRA + Kinect system carries benefits and drawbacks when compared to other practical aspects of motion capture. Beyond the benefits of lower cost and portability, the MIRA + Kinect system does not require markers placed on the skin which avoids lengthy set-up time, potentially indelicate body exposure and problems with inaccurate marker position [5].

Vicon MoCap technology is vulnerable to interference with data collection due to reflections from extraneous objects within the field of view or loss of signal from the IR reflective markers. The Trained Observers were asked to remove jewellery which could reflect IR and to avoid standing in positions which would block the line-of-sight of the MoCap cameras. However, despite these procedures and despite conducting the study in a dedicated MoCap lab with ten high resolution cameras, 49 measurements (13%) were still lost to analysis as interference precluded calculation of the shoulder movement angles. This demonstrates that regardless of the superior accuracy of the Vicon, MoCap system, it faces limitations even when conditions are optimised and would not be a practical technology to apply within a clinical or home setting with limited space, multiple background objects and people moving around [7]. In contrast to this, we found that the MIRA + Kinect system would be more appropriate for use in a clinical or home-based rehab role as it only produced one outlying data-point necessitating exclusion (0.3%). It also utilises sensors specifically designed to work within the home environment [7].

When compared to estimation by Trained Observers, this study has demonstrated that the MIRA + Kinect system has better agreement with gold standard measurement. However, there are other aspects to consider. Additional benefits of the system over Trained Observers is the objective nature of the sensor technology. The system can provide unbiased measurement for comparison between groups or pre and post intervention for the same individuals. Furthermore, although the system does involve a laptop and a Kinect sensor, it does not require a trained professional such as a Specialist Physiotherapist or Orthopaedic Surgeon to operate. Individuals can operate the system without supervision, following on-screen directions.

The utility of the Kinect sensor has been evaluated for joint position [17] movement analysis in postural control and gait retraining, [4,5,6] use in people with Parkinsons Disease [9] authors conclude that the sensor is useful as a means of measuring gross body movements and ergonomic assessments in 'the field' [7]. Xu et al. [17] found that the Kinect did not accurately identify joint centres particularly for lower limb joints but did comment that joint angle measurement may be of greater interest for occupational tasks than pure joint location.

Previous authors have also assessed use of a Kinect sensor to specifically measure shoulder movement. Huber et al. [10] compared the Kinect sensor to goniometer measurement and to electromagnetic motion tracking sensors. They found increased levels of bias and broader limits of agreement. The MIRA software used with the Kinect sensor in our study has undergone several cycles of refinement to optimise the positioning of the participant and the movements they perform, which may account for the different conclusion. In addition, we compared the MIRA + Kinect system with the performance of Trained Observers, emulating routine clinical practice, rather than taking five degrees as an arbitrary target value.

Use of a sensor-based technology to measure shoulder movement has clear utility in providing objective data for clinical assessment and research applications but it also opens up the possibilities of using this kind of system to enhance rehabilitation protocols. Patients can be encouraged to engage with their shoulder exercise programme by harnessing the principles of gamification within tailored 'Exergames' [9].

Other novel technologies such as wearable sensors are being developed, also with the aim of accurately plotting body movements and utilising them for shoulder rehabilitation [12]. Furthermore, an updated Kinect sensor (Kinect 2) offers increased sensitivity and the potential for motion analysis of smaller joints [5,17].

We acknowledge that our study faces several limitations. The participants were all asked to wear close fitting garments facilitating IR marker positioning. This is also beneficial for the Kinect sensor. We have not compared the different measurement methods for situations where loose / baggy clothing is being worn. Clinical examination is normally performed with appropriate exposure of the limb but if the sensor is being used in a home setting, the participant may not remove baggy garments for the assessment.

The measurement of internal rotation was performed with the participant abducting their shoulder to 90 degrees. This position was used so that the forearm can move freely, without contacting the participants abdomen. This position of abduction may be difficult for some individuals with shoulder pathology to reach.

Performing Vicon and MIRA + Kinect measurements simultaneously meant that the presence of the IR markers could distort the 3D model generated by the IR Kinect sensor. However, we found the model had good agreement with the Vicon system and other authors have found this effect to be minimal [5]. The participants did not have shoulder pathology and therefore do not represent the population that would be using such a system. Although, this did allow testing across the full range of possible shoulder movements, unconstrained by pain or stiffness. Our measurements were also taken with the participants in a static pose. This was to facilitate simultaneous measurement by the MoCap, MIRA + Kinect and the Trained Observers. Therefore, our results may not be applicable to dynamic shoulder movements and further validation of this aspect may be required.

Conclusion

We conclude that MIRA software paired with a Kinect sensor measures all cardinal shoulder movements with significantly closer agreement to Vicon MoCap than Trained Observer measurements. Therefore, use of this system to measures shoulder movement during shoulder assessment and rehabilitation would be acceptable. In addition, this technology may allow precise shoulder ROM measurement, outside the clinic setting.

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Legends

Table I. Correlation coefficients with MoCap for the cardinal shoulder movements.

** Correlation significant at the 0.01 level (two tailed)

§ Spearman's test used as differences from the MoCap result did not follow a normal distribution (Shapiro-Wilk test <0.05)

¶ Pearson's test used as differences from the MoCap result followed a normal distribution (Shapiro-Wilk test >0.05) (Spearman's test also reported in parentheses for comparison)

Table II. Limits of agreement of the two measurement methods with MoCap, for the cardinal shoulder movements.

Figure 1. Positions of IR reflective markers.

Figure 2. Study set-up showing MoCap cameras, MIRA/Kinect sensor and trained observers.

Figure 3. Screen shot of MIRA software displaying measured abduction angle, using Kinect sensor.

Figure 4. Scatter plots of measurement methods against MoCap for cardinal shoulder movements.

Figure 5. Bland Altman Plots of measurement methods against MoCap for cardinal shoulder movements.