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Validity of the Microsoft Kinect for measurement of neck angle: comparison with electrogoniometry

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Introduction. Considering the importance of evaluating working postures, many techniques and tools have been developed to identify and eliminate awkward postures and prevent musculoskeletal disorders (MSDs). The introduction of the Microsoft Kinect sensor, which is a low-cost, easy to set up and markerless motion capture system, offers promising possibilities for postural studies. *Objectives*. Considering the Kinect's special ability in head-pose and facial-expression tracking and complexity of cervical spine movements, this study aimed to assess concurrent validity of the Microsoft Kinect against an electrogoniometer for neck angle measurements. *Methods*. A special software program was developed to calculate the neck angle based on Kinect skeleton tracking data. Neck angles were measured simultaneously by electrogoniometer and the developed software program in 10 volunteers. The results were recorded in degrees and the time required for each method was also measured. *Results*. The Kinect's ability to identify body joints was reliable and precise. There was moderate to excellent agreement between the Kinect-based method and the electrogoniometer (paired-sample t test, $p \geq 0.25$; intraclass correlation for test–retest reliability, ≥ 0.75). *Conclusion*. Kinect-based measurement was much faster and required less equipment, but accurate measurement with Microsoft Kinect was only possible if the participant was in its field of view.

Keywords: neck angle; Microsoft Kinect sensor; markerless motion capture; electrogoniometry

1. Introduction

Working posture is a key concept in ergonomics.[1] The background for studying body postures comes from Leonardo da Vinci, who drew sketches about postures of the human body and initiated scientific research into them. Because of the critical role of working postures in the development of musculoskeletal disorders,[2] evaluation of postures is a primary step in preventing musculoskeletal disorders. Posture evaluation studies have resulted in the development of indices and methods.[3–8] Posture evaluation methods use different concepts to assess postures. Some methods consider the force and the time sequences of a task as the key factor, some consider the frequency of repetitions and yet others consider the range of angles in the body joints. One way to evaluate postures of the human body is to measure its deviation from the neutral posture and assign a score to each position, so that the postures can be evaluated and compared with each other.[6,7,9] Previous research has shown that awkward postures result in the development of musculoskeletal disorders.[2] Among the identified musculoskeletal disorders in the upper limb and neck, the proportion of disorders related to the neck was more significant.[10] The prevalence of neck pain among the working population has been reported to range from 20 to 30%.[11,12] Regarding these facts, evaluation of neck posture becomes more important.

In order to evaluate neck posture, the neck angle must be measured. The neck position can be defined by three angles as flexion/extension, lateral flexion and rotation. Measuring these angles in each position can be carried out by a variety of tools and methods, such as visual estimation, a universal goniometer, an inclinometer and an electrogoniometer.[13] Considering the fact that all of these tools and methods have drawbacks and some of them are time consuming, developing new methods and tools with high speed and accuracy has always been appealing. The electrogoniometer was designed in 1959 by Karpovich and has developed through the years.[14] Similar to universal goniometers, electrogoniometers have two arms. Each arm should be attached to one segment of the joint which is about to be measured. There is a potentiometer between the electrogoniometer arms; changes in the joint position result in changes in the potentiometer resistance. Changes in the joint position can be measured by measuring the voltage crossing through the potentiometer, and as a result the angular motion of the joint can be calculated. The latest version of electrogoniometers can measure angles accurately in two dimensions using a single electrode. Considering the high cost of the equipment and the time-consuming process of calibration and attachment of electrodes, electrogoniometers are more commonly applied for research rather than for clinical purposes. Photographs,

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recorded videos and digital motion capture systems are examples of other tools and methods used for joint measurement that are more commonly applied for research purposes.[15]

In recent years, the Microsoft Kinect sensor (Microsoft, USA) has been used for physical rehabilitation, postural control assessment and range of motion assessment of the shoulder and elbow,[16–19] and also for many purposes in ergonomics: for assessing postures, ergonomic training of workers, ergonomic design and other concepts in ergonomics.[20–23] The introduction of the Kinect sensor provided an unprecedented perspective in 3D motion capture technology and might be considered a leap forward to allow occupational ergonomics to use the Kinect as a portable motion capture system to perform biomechanical assessment of workplaces. The Kinect sensor, which consists of a color camera and a depth sensor, is able to sense 3D environments and with the help of a randomized decision forest algorithm can identify 20 anatomical landmarks in the human body. The Kinect sensor is able to present 3D coordination of these up to 30 frames/s in a real-time manner. The Kinect was released in November 2010 by Microsoft, for the Xbox game console. Because of its great capability, low cost and ease of use, a few months after releasing the Kinect researchers from different branches of science became enthusiastic to develop new applications for the sensor's capability, aiming to perform new tasks. In February 2012, Microsoft released the Kinect software development kit (SDK) for Windows and expanded its uses.[24] Since it has not been long since implementation of the Kinect in research, most studies have focused on proving the ability and accuracy of the Kinect, in identifying human body anatomical landmarks, and comparing it with the existing motion capturing systems, like Vicon.[16,21] Few studies have focused on application of the Kinect for measuring the elbow and shoulder range of motion, and it is essential to test the Kinect application for other parts of the human body [18] Considering the high accuracy and validity of the Kinect reported by many researchers,[16,24,25] the Kinect has great potential to be used in studies on human body posture or kinesiology, and the studies conducted so far have not answered all of the questions about its use in postural studies and most of them have claimed that further studies and software developments are needed.

Although the Kinect has been used for measurements of many parts of the human body, its use for neck measurements is in many ways different from that for other human body parts: first, due to the complexity of neck measurements because the neck has three axes of movement in different planes; and second, the Kinect has special algorithms to identify head-pose and facial-expression tracking and can make a difference in cervical spine movement measurements. In addition, there is a lack of studies evaluating the three axes of neck movements.[24,26]

The aim of this study was to evaluate the capability of the Kinect sensor to identify the neck and head, calculate the neck angles in different planes, follow head movements in a time period and present data for each moment. Another aim of this study was to test the correlation between the data derived from the Kinect with a well-established assessment tool for neck angle; therefore, in this study flexible electrogoniometers were used.

2. Methods

2.1. *Participants*

Ten healthy adults (age: 25.5 ± 2.5 years, height: 182 ± 12 cm, weight 76.5 ± 18.5 kg), with no history of disability or medical condition that could affect their postural control, participated in this experiment. The study protocol was approved by the Ethics Committee of Urmia University of Medical Sciences and all of the participants signed an informed written consent form prior to their participation.

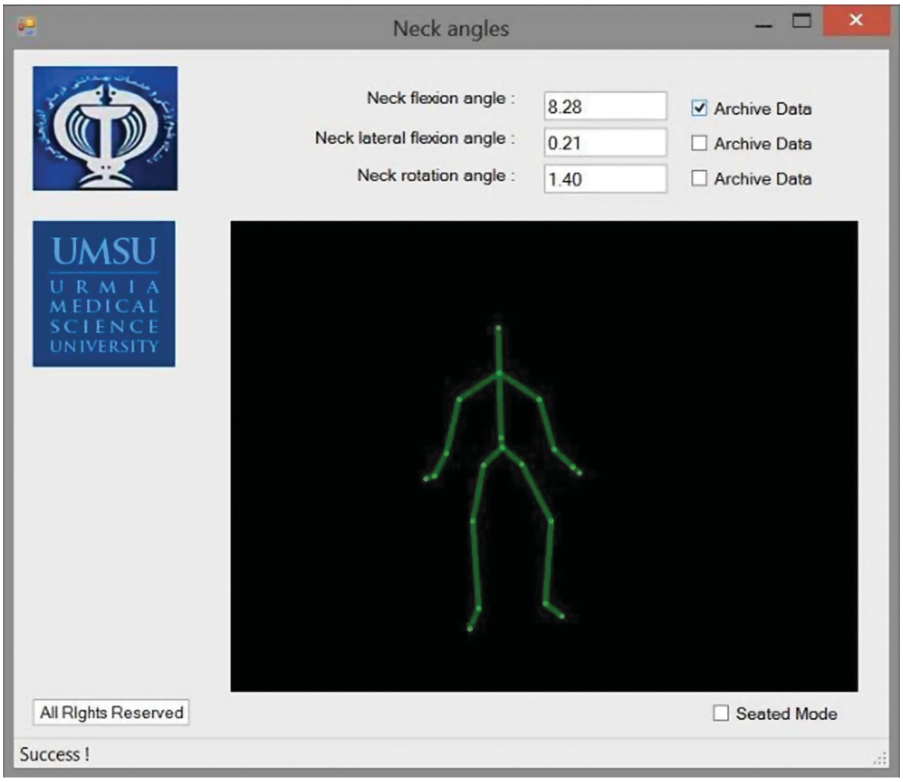
2.2. *Electrogoniometer system*

This study used the Biometrics flexible electrogoniometer system (Biometrics, UK). Two flexible electrogoniometer electrodes, SG110 and Q110, were used to provide an accurate measurement of neck angles in different planes. According to Biometrics Datasheets, the accuracy of measurement is ±2° in the range of ±90°. Each flexible electrogoniometer electrode consists of a thin, flexible strain, fixed on two plastic plates at each end. The electrodes were connected to a DataLINK DLK900 unit (Biometrics, UK), and the main unit was connected to a Windows 8 PC to acquire data; DataLink version 7.5 software was used.

2.3. *Microsoft Kinect system*

This study used Microsoft Kinect for Xbox 360 (Microsoft, USA). The Kinect sensor provides a unique combination of sensors, and works well for interacting with video games, which is the primary goal of Kinect. However, the Microsoft SDK can process raw data from the sensor and provide information such as skeleton tracking for two people and word recognition from audio data for a given language; these data can then be used for further analysis or processes.

Using C#, special software was designed to retrieve and process data provided by the Kinect sensor in order to measure neck angles. The designed software uses the Microsoft Kinect sensor to identify the head and shoulder, and then calculates the neck angle in different planes and also calculates the neck rotation angle simultaneously in real time. Calculation of the angles in the software consists of two steps. First, the software connects vectors between the desired joint and two other joints in order to create two virtual lines that intersect in the desired joint. Second,



Neck angles

Neck flexion angle : 8.28 ☑ Archive Data

Neck lateral flexion angle : 0.21 ☐ Archive Data

Neck rotation angle : 1.40 ☐ Archive Data

All Rights Reserved

☐ Seated Mode

Success !

Figure 1. Designed software during measurement.

the software calculates the angle between those two virtual lines and as a result the neck angle is provided. For developing the software, Microsoft SDK version 1.8 was implemented. In order to show which person is identified by Kinect, a skeleton map was presented by the software. The sensor mode for identifying people can be changed to seated mode by the software. In the seated mode, only the upper limbs will be identified by the Kinect. The designed software was able to record angle values through a time period, at a frame rate of 30 frames/s (Figure 1).

2.4. Procedure

For every participant the procedure of measurement was the same and included four sessions, and in each session one of the neck angles was measured (flexion/extension divided into two parts, one for flexion and one for extension). The participants were asked to sit on a chair directly facing the Kinect sensor at a distance of 2 m from the sensor, and the Kinect sensor was placed on a tripod 1 m above the floor (Figure 2). According to the Kinect sensor user manual, the best field of view for the Kinect is obtained when the sensor is located at a height of 1 m from the ground and a distance of 1.2–3.5 m from the participants.[27] In all of the sessions of the study, the Kinect sensor position and the participant's distance from the sensor were the same. Electrogoniometer sensors were then attached to the head and neck of the participants on their relevant landmarks. Two types of electrogoniometer sensors were used, one for measuring rotation angle (Q110) and another (SG110) for measuring other angles The superior end block was adjoined to the occipital bone with an elastic head band, and the inferior end block was attached to T1–T4 vertebra by double-sided tape (Figure 3). In the Kinect-based system, as soon as the human body is presented in the sensor field of view, measurement is started and there is no need for attaching any additional marker to the participant's body and also there is no need for sensor calibration. However, for the electrogoniometer system each of the sensors needed to be calibrated after attaching to the system. In order to calibrate electrogoniometer sensors in each session before starting the measurement, the participants were asked to pose their heads in a neutral position and stand still, and then electrogoniometer sensors were calibrated to their reference.

As described, two systems for measuring neck angles were organized. In each session the participants were asked to pose their heads in certain directions which included flexion/extension, lateral flexion and rotation, and in every session only one of them was measured. At the beginning, the test procedure was fully explained to the participants and a researcher elaborated the movements to ensure that they would perform the movements correctly. In each session, the measurement was initiated when the participant's head was in neutral posture and the neck angles were

Figure 2. Placement of the Kinect and the participant.

around 0°; the participant was then asked to pose his/her head in the desired direction up to the maximum range of motion and then back to the neutral posture again. When the participant's head was in the neutral posture and the neck angle was around 0° again, the measurement was terminated. As a result of measurements in each session, changes in the angle from 0° to a maximum range of motion and then to 0° again were recorded in both systems simultaneously. In relation to the speed of movements, no particular instruction was given to the participants. Three repetitions were performed for every session.

2.5. Data processing and statistical analysis

While the participants were performing these tasks, their movements were observed and their neck angles were constantly measured by the designed software program which interacted with the Kinect sensor and also by the electrogoniometer at the same time. For both systems, the sampling rate was 30 frames/s. Both systems were connected to a Windows 8 PC and the measurement data were saved and stored on its hard disk for further analysis. Outcome data for each session consisted of two text files, one for the Kinect sensor and one for the electrogoniometer. Each file consisted of values of the desired angle recorded in degrees over a period of time. Data acquired from the systems were visually time synced and, in order to examine the absolute accuracy, no normalization was performed.

Figure 3. Electrode layout.

The time needed for setting up each of the systems prior to starting the measurements was recorded for further analysis. The set-up time for the Kinect system was the time needed for allocating the sensor and attaching the cables, and for the electrogoniometer system was the time needed for attaching the electrodes to the participant's head and neck and the cables to the Data Link unit and then to the PC.

The participants were able to understand workflow and replicate the designed movements easily. The designed software was able to calculate and perform the angles without any delays. The Kinect was able to calculate and present all of the neck angles simultaneously, but the electrogoniometer was not and a separate electrode was needed for the rotation angle.

Because the Kinect system did not require any electrodes, it was faster and much easier to set up in comparison with the electrogoniometer. Attaching electrogoniometer electrodes must be done by a trained person able to identify anatomical landmarks on the human body, and also electrodes are fragile and need to be handled carefully.

The results of Kinect measurements were compared with those of the electrogoniometer (considering the electrogoniometer as the gold standard) to assess the agreement of the two measuring techniques. In order to achieve pure agreement in statistical analysis, we collected the Kinect data while the electrogoniometer presented a constant angular degree; the results in other angles were the same. Angular discrepancies were assessed using limits of agreement (LOA) analysis with Bland–Altman plots,[28] and coefficients of variation (CV), differences between the two devices (inter-device difference) and root mean square (rms) differences were calculated. Paired-sample *t* test was used to compare the results of Kinect and electrogoniometer. Intraclass correlation (ICC) was used to investigate test–retest reliability, with 0 = *no agreement*, 1.0 = *perfect agreement/reliability*. Statistical analysis was performed with SPSS version 22.0. The significance level was set at $p < 0.05$ for all tests.

3. Results

In general, there was moderate to excellent agreement between the measurements made with the Kinect system and the electrogoniometer. The results for all four movements were analyzed and presented separately. The results are summarized in Table 1. Bland–Altman plots are also presented.

For lateral flexion, an angle (averaged overall participants) of 14.80° and standard deviation of 0.70 was measured by the Kinect. The difference between the two systems in measurements was −0.12 with a standard deviation of 0.70 and $p = 0.61$ was non-significant, with LOA of [−1.52, 1.29] (Figure 4). The coefficient of variation of methods for lateral flexion was 1.63% and the root mean square error (RMSE) was 0.69.

For flexion, an angle (averaged overall participants) of 14.70° and standard deviation of 1.20 was measured by the Kinect. The difference between the two systems in measurements was −0.26 with a standard deviation of 1.20 and $p = 0.51$ was non-significant, with LOA of [−2.60, 2.10] (Figure 5). The coefficient of variation of methods for lateral flexion was 5.61% and the RMSE was 1.12.

For extension, an angle (averaged overall participants) of 15.30° and standard deviation of 0.78 was measured

Table 1. Agreement of the Kinect with an electrogoniometer; RMSE, paired-sample *t* test *p* value, LOA (Bland–Altman) and CV.

Neck direction	Kinect–electrogoniometer (°), difference (*SD*)	RMSE (°)	*p*	LOA	CV (%)
Lateral flexion	−0.12 (0.70)	0.69	0.61	[1.29, −1.52]	1.63
Flexion	−0.26 (1.20)	1.12	0.51	[2.10, −2.60]	5.61
Extension	0.30 (0.78)	0.08	0.25	[1.84, −1.23]	3.74
Rotation	0.54 (2.02)	1.99	0.41	[4.50, −3.40]	9.24

Note: CV = coefficient of variation; LOA = limits of agreement; RMSE = root mean square error.

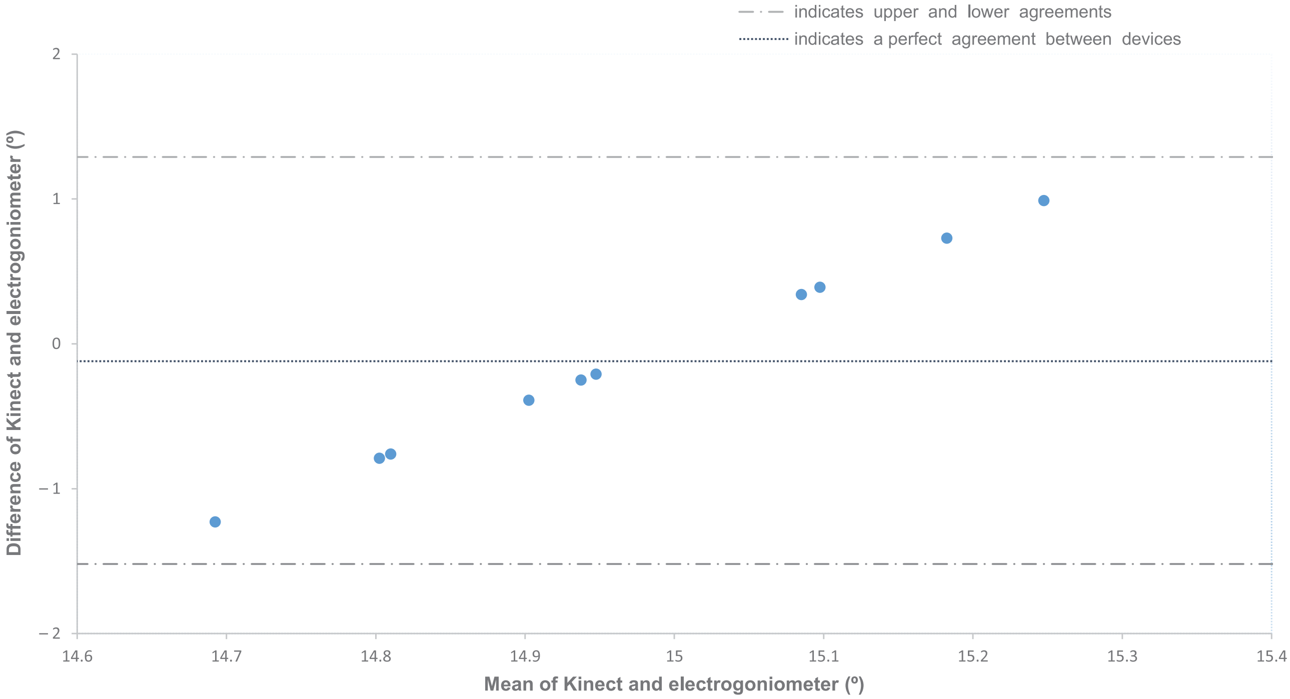


Figure 4. Bland–Altman plots for lateral flexion.

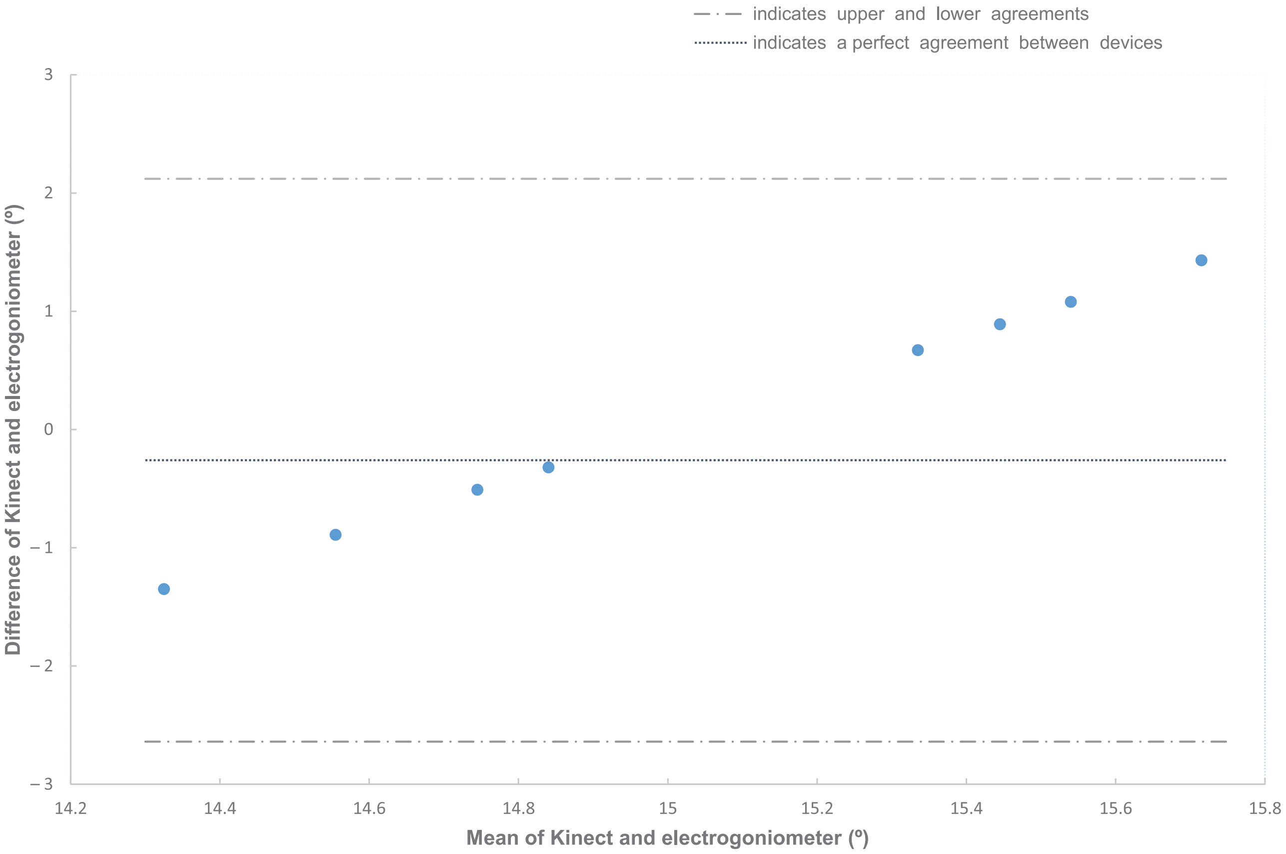


Figure 5. Bland–Altman plots for flexion.

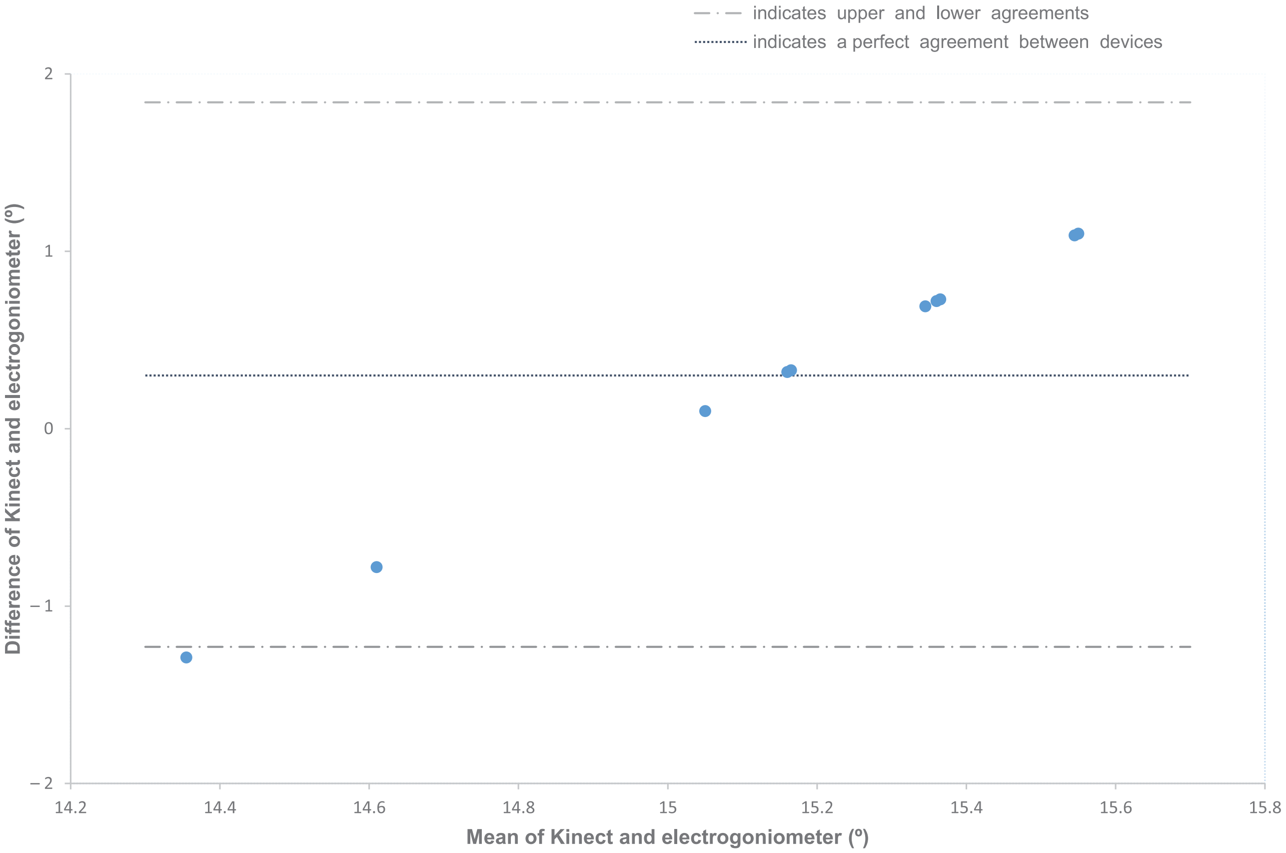


Figure 6. Bland–Altman plots for extension.

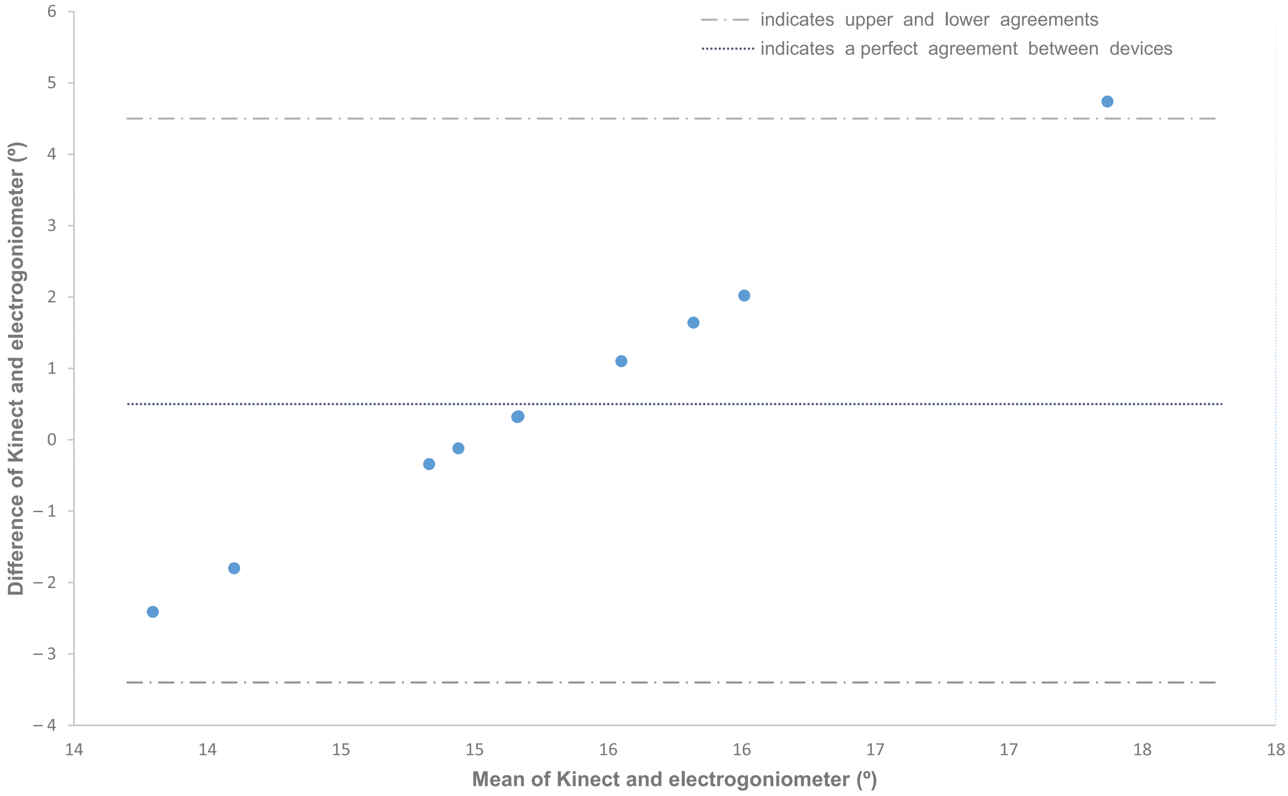


Figure 7. Bland–Altman plots for rotation.

by the Kinect. The difference between the two systems in measurements was 0.30 with a standard deviation of 0.80 and $p = 0.25$ was non-significant, with LOA of [−1.23, 1.84] (Figure 6). The coefficient of variation of methods for lateral flexion was 3.74% and the RMSE was 0.08.

For rotation, an angle (averaged overall participants) of 15.54° and standard deviation of 2.02 was measured by the Kinect. The difference between the two systems in measurements was 0.54 with a standard deviation of 2.00 and $p = 0.41$ was non-significant, with LOA of [−3.40, 4.50] (Figure 7). The coefficient of variation of methods for lateral flexion was 9.24% and the RMSE was 1.99.

The time needed for setting up the Kinect system prior to starting the measurements was 1 min (42 ± 17 s), compared with 6 min (26 ± 32 s) for the electrogoniometer system.

The results of test–retest reliability analysis for the Kinect-based technique are presented in Table 2. The ICC for each session was presented separately. The differences between the measurement sessions were computed and the means and standard deviations were also presented. All of the ICCs were >0.75.

Table 2. Test–retest reliability result for the Microsoft Kinect.

Neck direction	ICC	Mean difference (*SD*)
Lateral flexion	0.86	0.96 (0.44)
Flexion	0.80	0.36 (0.75)
Extension	0.76	0.76 (0.66)
Rotation	0.75	0.50 (1.26)

Note: ICC = intraclass correlation coefficient.

4. Discussion

The aim of this study was to evaluate the capability of the Kinect sensor to identify the neck and head, calculate the neck angles in different planes, follow the head movements in a time period and present data for each moment. Another objective of this study was to test the correlation between the data derived from the Kinect with a well-established assessment tool for neck angle, an electrogoniometer. A software program was developed to calculate the neck angle, to test the feasibility of using the Kinect sensor for measuring neck angles and to evaluate the accuracy of the developed Kinect system and also the time required to perform measurements by the Kinect in a fully automated process.

In general, the ability of the Kinect to identify human body and present the skeleton map and neck angles over the measurement time period was very good, and only in extreme cases was the Kinect not able to perform measurements. There was moderate to excellent agreement between the Kinect and the electrogoniometer system measurements. In lateral flexion, there was excellent agreement between the two measurement systems, and the Kinect was able to measure the lateral flexion angle precisely. Flexion angle agreement was very good and precise. Extension angle measurement by the Kinect was good, but the accuracy decreased when the angle increased. In order to explain this shortcoming, it might be pointed out that the Kinect lacks accuracy when the tracked participant is not facing the sensor, or when that part of the body is not visible to the camera.[21] Rotation angle measurement by the Kinect was good, but occasionally when the rotation angle was around 0 the Kinect lost its reference point due to an unknown reason; therefore, the Kinect exhibited a slight accuracy error in measurement. The results of test–retest reliability showed that the Kinect had good repeatability of measurements, all ICCs were >0.75 and agreements were good. The data collection time rapidly decreased when the Kinect system was used.

Hawi et al. [18] evaluated the accuracy and time requirements of the Kinect for range of motion measurements in comparison with manual goniometer-based measurements. They concluded that there was poor to moderate agreement between measurements made by the Kinect-based system in comparison with those of a manual goniometer ($\text{ICC} = 0.28$–0.68). They reported that the Kinect-based system was faster in measurement with excellent test–retest reliability ($\text{ICC} > 0.90$). Hawi et al. [18] concluded that some improvements must be made in positioning and the measurement protocol before using the Kinect in clinical practice. Plantard et al. compared the Kinect with a marker-based system for shoulder and elbow joint angle measurements. The RMSE was estimated at 5.2° (±1.5) for the shoulder and 8.2° (±1.3) for the elbow. Plantard et al. [29] concluded that the accuracy of the Kinect-based system is sufficient for ergonomic assessments. Dutta compared the Kinect with a Vicon motion capturing system for estimating relative 3D positions of four 0.10 m cubes. The RMSE of measurements was less than 0.011 m. It was concluded that with a small amount of further improvements the Kinect may be an alternative motion capturing system for in-field ergonomic assessments.[30] Diego-Mas and Alcaide-Marzal [21] developed a software program for Ovako working posture analysis system (OWAS) ergonomic assessment by means of Kinect sensor data. They compared the results with those provided by human observers. They concluded that using the Kinect requires overcoming lack of accuracy when the participants are not facing the sensor and that Kinect-based assessments can help ergonomists but cannot replace assessment by human experts.[21]

Implementing the Kinect for measuring body angles and joint range of motion required special software development; therefore, the SDK has been released by Microsoft, which matches the Kinect to C# and other programming languages. This means that the Kinect directly transforms its data to software like Microsoft Visual Studio. Therefore, developing a software program for postural analysis and other purposes is much easier than for the electrogoniometer.

Testing the Kinect showed that the ability of the sensor to identify the head and trace its movements was much better than that for other parts of the human body because people usually do not cover their head with clothes and the head is the top limb of the human body, and is always visible. In addition, the Kinect has special algorithms to identify the human face. Our findings concur with those of Bonnechère et al. [17], who showed that differences between the Kinect and a traditional marker-based stereophotogrammetry system were clearly smaller in the upper body compared with lower body analysis. The Kinect was able to perform measurements without any initial calibration, but electrogoniometers needed resetting of their reference 0° every time they were attached to the head. The Kinect was not sensitive to ambient conditions such as temperature, light and humidity.

Our findings show that although Microsoft Kinect has the potential ability to differentiate head postures in order to be used as an inexpensive, portable and widely available system in clinical and research programs, there are still certain aspects of implementing the Kinect in real working environments that need further research and consideration. The Kinect system only works properly when the participants are in the sensor's field of view, facing the sensor. This means that the participant must be 0.5–6.0 m away from the sensor. When the participant's head moved in a way such that the face was not in the sensor's field of view, measurement accuracy decreased. To overcome this flaw, a system with several Kinect sensors at different heights and positions must be designed to measure neck angles that combine information captured concurrently with multiple Kinect sensors to improve measurement accuracy.

Further development is possible in order to increase accuracy and ability of the Kinect system as a measurement system for neck angles. The accuracy of the Kinect system may be improved by using the latest version of the Kinect sensor. In this version, the sensor's resolution has improved and more precise estimation of landmarks and anatomical models is presented.[31] Using the image processing technique, a new joint identification algorithm can be programmed for use instead of the Kinect built-in 20-point skeleton model to improve measurement accuracy.

There were a few limitations that need to be addressed. First, in the present study the angles analyzed were limited to motions taking place along the anatomical planes. The second limitation of this study was that a specific version of Kinect (Kinect for Xbox 360) and Microsoft SDK version 1.8 were used, and the results from every new release might be different.

5. Conclusion

Using the Kinect for measuring neck angles provides both benefits and drawbacks when compared with an electrogoniometer. The major benefits are the low cost, portability, widespread availability and short set-up time of the Kinect, and the major drawback is that accurate measurements are possible only if the participants are in the Kinect's field of view. In general, the Kinect is a reliable device for ergonomic assessment of head and neck postures.

Disclosure statement

No potential conflict of interest was reported by the authors.

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