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Reliability and validity analyzes of Kinect V2 based measurement system for shoulder motions

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A B S T R A C T

Telerehabilitation systems provide some advantages against the classic rehabilitation methods. The ability of the shoulders depends on active motion range of them to do activities in daily life and to do sports. To evaluate the shoulder motions, range of motion (ROM) measurement is a basic method. Clinical goniometer and digital goniometer are the most commonly used measurement tools. However, these measurement tools have some deficiencies and difficulties. In this paper, we consider a Kinect One Sensor (Kinect V2) based measurement system for shoulder motions as an alternative method. The aim of this study is to examine the reliability and validity analyzes of the proposed shoulder measurement system. Three systems were used to evaluate validity of the Kinect V2 to measure shoulder motions: Kinect V2 based system, clinical goniometer and digital goniometer. One expert physical therapist measured shoulder abduction, flexion, external rotation, internal rotation and extension ROM values using a clinical goniometer and a digital goniometer in 40 healthy volunteers (22 males, 18 females, and 19–33 years old). All poses for each shoulder motion were captured with the Kinect V2 based system again and the ROM values were calculated. These procedures were carried out with all of the volunteer participants in three repetitions. In reliability for Kinect V2 based shoulder motion measurement system, we used the intraclass correlation coefficients (ICC), standard error of the measure (SEM), minimal detectable change (MDC). The validity test includes the 95% limits of agreement (LOA) and mean difference between the Kinect V2 based system and the both of the goniometer systems for measuring shoulder motions. The high ICC values show that the Kinect V2 based shoulder motion measurement system has very good intra-rater reliability for abduction, flexion, external rotation, internal rotation shoulder poses. For extension pose, it has good reliability result according to the ICC value. The validity analysis gives good results for all shoulder poses except internal rotation between Kinect V2 and clinical/digital goniometer. As a result, Kinect V2 based measurement system is a reliable and valid alternative telerehabilitation tool for shoulder motions.

1. Introduction

As stated in the World Health Organization (WHO) media center's report, there are over 1 billion disabled people in the world [1]. Some of these people need rehabilitation for a period of time, or some need rehabilitation at all times. These patients face many rehabilitation problems such as doing exercises incorrectly, not knowing whether they do the exercise correctly, or not finding a hospital or physiotherapist in their vicinity [2–5].

Technology helps to overcome these problems in physiotherapy as in many other areas. Telerehabilitation is a term used to describe the provision of rehabilitation services at a distance using telecommunications technology as the service delivery medium [6]. Studies show that the patients can do exercises at home like performing with physiotherapist by means of telerehabilitation [7] Moreover, making exercises with telerehabilitation are as effective as conventional rehabilitation [8–10]. Products such as Kinect, 3D motion tracking systems, are used in telerehabilitation studies. 3D motion capture systems provide excellent accuracy and reliability, but they are expensive and require a big area to be installed. In many cases, flexibility is required and the motion capture system can only be placed temporarily. Kinect sensor is relatively less expensive and is more easily portable than 3D motion capture systems [11]. There are different rehabilitation applications developed by Kinect sensor for home and rehabilitation centers [12–17].

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As Kinect is frequently used in telerehabilitation, the validity and reliability studies of Kinect based system are of vital important. In the literature, the validity and reliability tests of Kinect's human skeleton monitoring feature are performed by comparing 3D motion monitoring systems (gold standard) such as OptiTrack, Vicon or conventional measuring devices such as clinical goniometer, digital goniometer (clinical standard). Most of the validity studies of Kinect were performed for postural and balance analyzes. According to these studies, it was observed that validity reliability tests could be performed on videos or on volunteer subjects and Kinect had the competitive results. With a low cost advantage, Kinect's reliability and validity results show that it can be used instead of 3D motion systems [18–27]. In the literature, there are studies regarding the validity and reliability of Kinect on rehabilitation exercises besides postural and balance analyzes. In these studies, it is suggested that Kinect can be used for rehabilitation exercises [28–31]. Different studies have analyzed the validation and reliability of the Kinect. However, the results of the studies vary depending on the developed software, methodologies and the measures. The pathologies causing movement loss in the shoulder joint are impingement syndrome, rotator cuff tendinopathy, shoulder instability and adhesive capsulitis [34]. There are six basic motions, such as abduction, flexion, extension, adduction, internal and external rotation movements in the shoulder joint [33]. To measure the shoulder motions, we developed the Integrated Shoulder Physiotherapy Application (ISPA) in 2018 [32]. In this study, the validity and reliability analyzes of this developed Kinect based measurement system were performed for shoulder motion exercises. Since there was no 3D motion monitoring systems in the study region, Kinect was compared with the clinically and digitally approved goniometer. This study explains the characteristics of the participants, the measurement procedures, the features of the application developed for validity and reliability tests, the statistical analysis, the measurement results, reliability results and the validity results. The aim of this study is to examine the reliability and validity analyzes of Kinect V2 based measurement system.

2. Methods

2.1. Participants

A total of 40 healthy volunteers (22.08±3.11 years old, 170.85±8.78 cm, and 68.75±15.85 kg), 22 males (21.73±2.16 years old, 176.64±6.76 cm, and 75.18±14.82 kg), 18 females (22.50±4.00 years old, 163.78±4.91 cm, and 60.89±13.65 kg) participated to test the reliability and validity analyzes of Kinect V2 based measurement system.

All participants attended three of five separate testing sessions within three days. In the literature, two test sessions were observed in most samples, although in the event of loss of data and in order to enhance the reliability of the results, each participant was measured at three different times. There was only one measurement by clinical and digital goniometers for each volunteer. For Kinect V2 based measurement system, the shoulder motions of the participants were measured three times. This study was approved by Bilecik Şeyh Edebali University Ethics Committee (2017/04) and carried out in accordance with the Helsinki Declaration of the World Medical Association. This work was supported by Bilecik Şeyh Edebali University Coordinating Unit of Scientific Research Projects (2017-01.BŞEÜ.03-04).

2.2. Procedures

In this study, we used three measurement methods for shoulder motions. As the first method, the clinical goniometer (Yıldızlar, Turkey) is used as a standard 12 inch, 360° goniometer with two adjustable overlapping arms. The second method is to measure by digital goniometer (Baseline, 12-1027). Digital goniometer displays degrees with 0.1° precision. Standard measurement positioning was used by placing the stationary arm parallel to the midline of the thorax, and the moving arm aligned with the shaft of the humerus and lateral epicondyle [35]. All instructions for participants' position were the same as for the clinical and digital goniometers. Figures 1 and 2 show the photos taken for the ROM measurements by both of the goniometers.

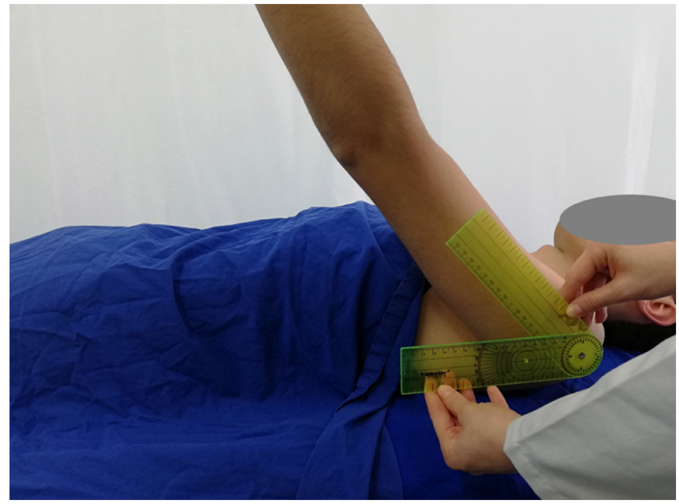

Figure 1. Active ROM measurement by clinical goniometer.

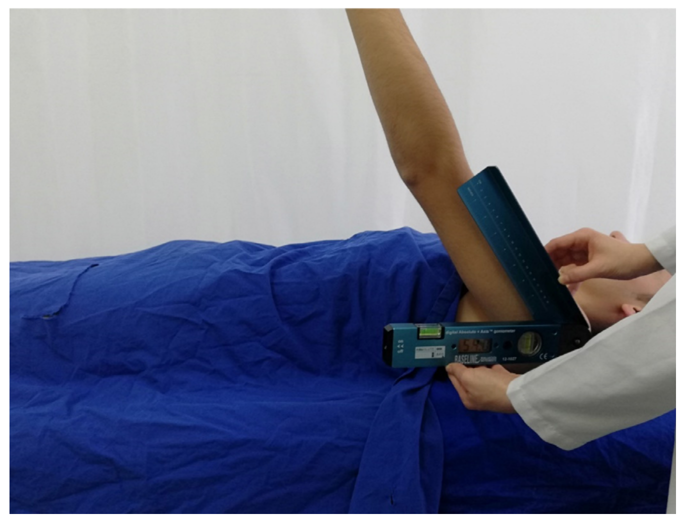

Figure 2. Active ROM measurement by digital goniometer.

In Kinect V2 based shoulder motion system, the participants are about 2 m away from the Kinect sensor. The Kinect V2 measurements were directed by the instructions of one expert physical therapist. In Figure 3, the photos of the shoulder motion measurement using Kinect V2 based system are shown.

Since the goniometer measurements were correct in the lie-down position, the goniometer measurements were made in the lie-down position. However, since the poses tested, during the exercise were suitable for standing, Kinect measurements were performed in the upright position. The highest angle of the participants as possible was saved for each of the poses. In this way, a comparable measurement method was designed since the best angle values that the participants can do in the lie-down position or upright position do not change.

Figure 3. Active ROM measurement by Kinect V2 based system.

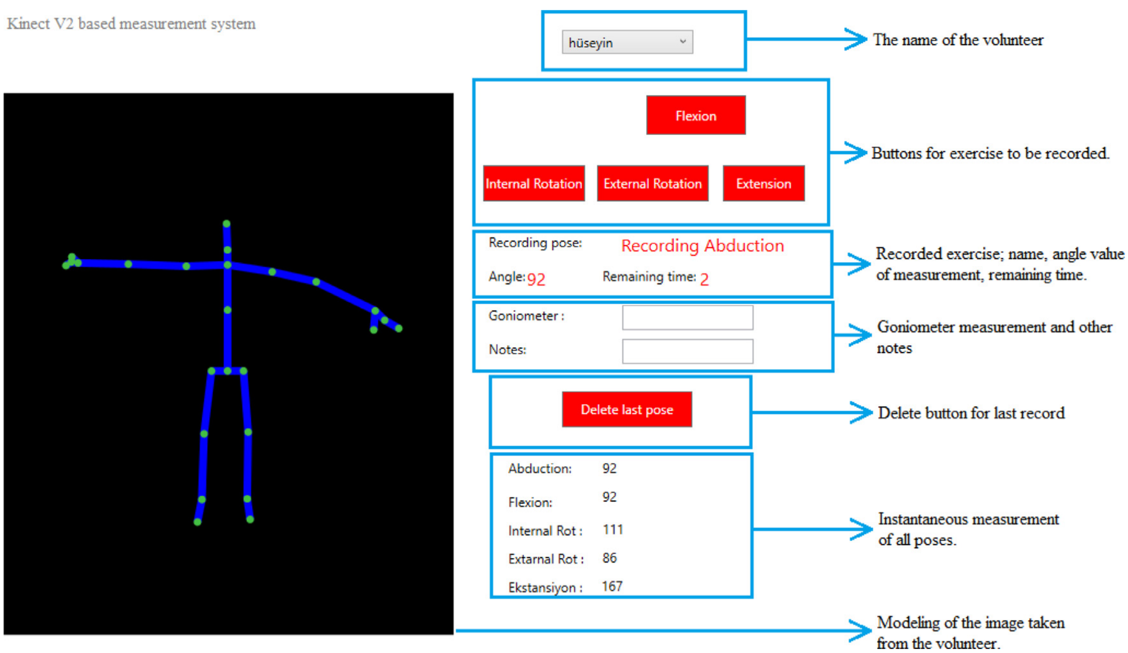

Figure 4. Developed GUI for reliability and validity tests.

2.3. Kinect V2 based measurement system for shoulder motions

In this study, Kinect V2 and Kinect SDK 2.0 were used to measure the shoulder position angles. The minimum configuration requirement to run Kinect V2 on a PC is a dual-core 3.2 GHz processor, 2 GB ram, .Net Framework 4.0, Microsoft Visual Studio 2012. Kinect V2 based shoulder motion measurement system was developed using Visual Studio environment and designed as Windows Presentation Form (WPF). The program code was written using C # programming language. We developed a GUI for reliability and validity tests as shown in Figure 4. In this GUI, the participant is firstly selected from dropdown list. Then, shoulder pose is done, the corresponding button is pressed and the recording time with 3 s starts. It saves 90 angle values in 3 s.

Kinect V2 is based on TOF (Time of Flight) principle. It comprises of color sensor, infrared depth sensor, infrared emitter and microphone array. The reflection of the signal is recorded by sending infrared lights and the delay between the emitted signal and the received signal is calculated [36]. The Kinect V2 has more advanced features than the previous Kinect version (Kinect 360 – Kinect v1). Kinect V2 consists of a depth camera with a better resolution than Kinect V1. In the skeleton tracking feature used in this study, Kinect V1 tracks 20 points while Kinect V2 tracks 25 points. The number of skeletons observed at the same time is 2 for Kinect V1, but 6 for Kinect V2.

In the proposed shoulder motions measurement system, the skeletal points of the participants are firstly taken by the skeleton tracking feature of the Kinect V2. To calculate the angle values of the shoulder poses, an assumed triangle is drawn on the image obtained from Kinect sensor as shown in Figure 5.

As can be seen from this figure, a triangle is formed with three corresponding positions A, B, C where $A = (x_1, y_1, z_1)$, $B = (x_2, y_2, z_2)$, $C = (x_3, y_3, z_3) \in R^3$. Each edge length of this triangle is calculated by using the following equations. The hip left and hip right points provided by Kinect were not useful for abduction and flexion poses. Therefore, for the left shoulder exercises, point B was formed. To form a new point; let us $A(x_1, y_1, z_1)$,$K(x_2, y_2, z_2)$,$C(x_3, y_3, z_3)$ which are provided by Kinect 2 and $B(x_4, y_4, z_4) \in R^3$ is new point which is created. The point B is reconstructed to be $B(x_4, y_4, z_4) = (x_1, y_2, z_1)$ and used for abduction and flexion exercises as shown in Figure 5.

$$a = |BC| = \sqrt{(x_2 - x_3)^2 + (y_2 - y_3)^2 + (z_2 - z_3)^2} \quad (1)$$

$$b = |AC| = \sqrt{(x_1 - x_3)^2 + (y_1 - y_3)^2 + (z_1 - z_3)^2} \quad (2)$$

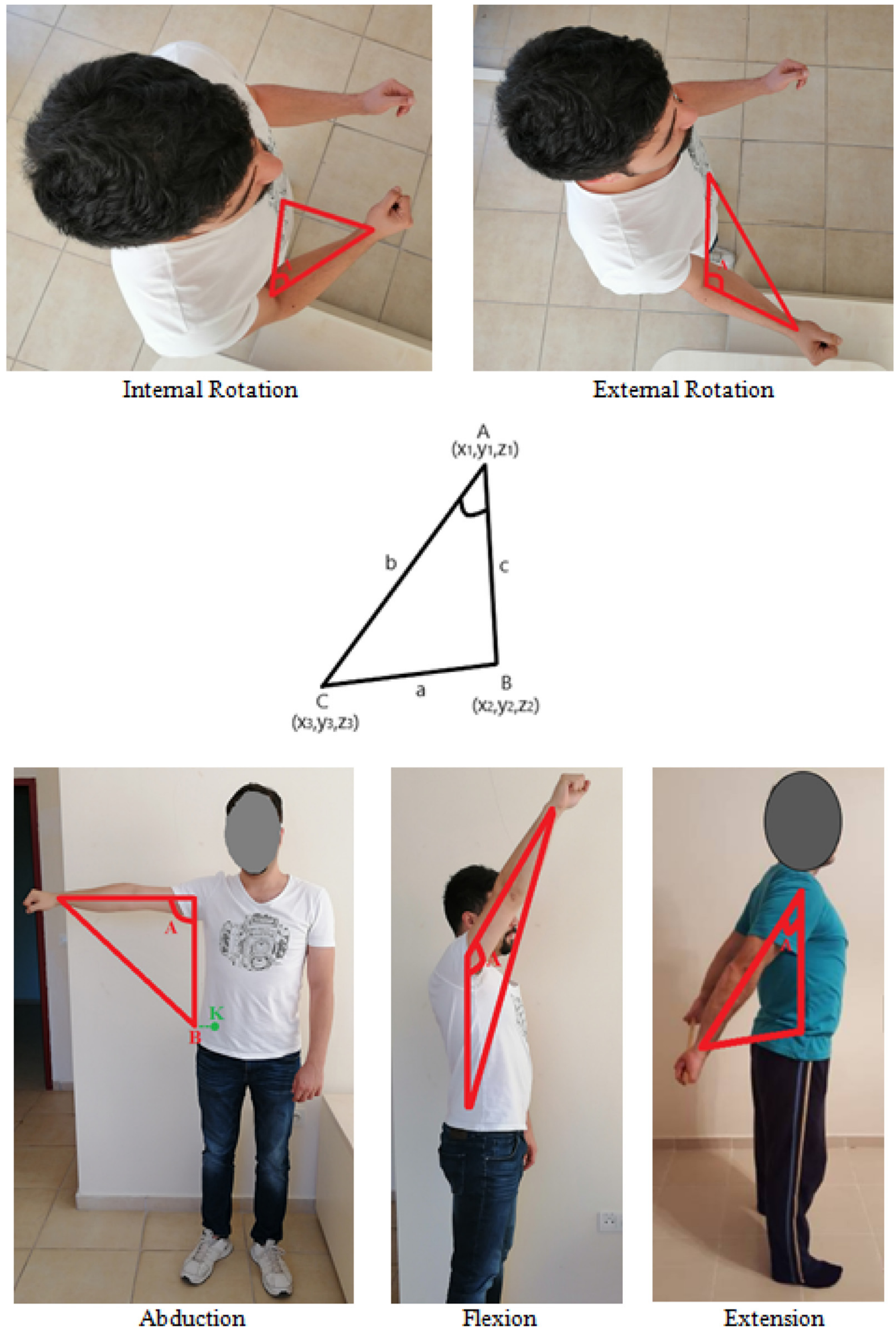

Figure 5. Calculation procedure of the angle value using Kinect V2 based measurement system.

$$c = |AB| = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2} \tag{3}$$

According to the Cosine theorem, all angles of triangle can be calculated. For example, the angle ($B\hat{A}C$) is found by Eq. (4):

$$B\hat{A}C = arccos\left(\frac{b^2 + c^2 - a^2}{2bc}\right) \tag{4}$$

BAC was used as the angle value of abduction, flexion and extension poses, $90 - B\hat{A}C$ was used for internal rotation pose and $B\hat{A}C - 90$ was used for external rotation pose.

2.4. Statistical analyzes

In this study, statistical analyzes were obtained by using SPSS version 21 and Minitab 18 (free trial version for 30 days).

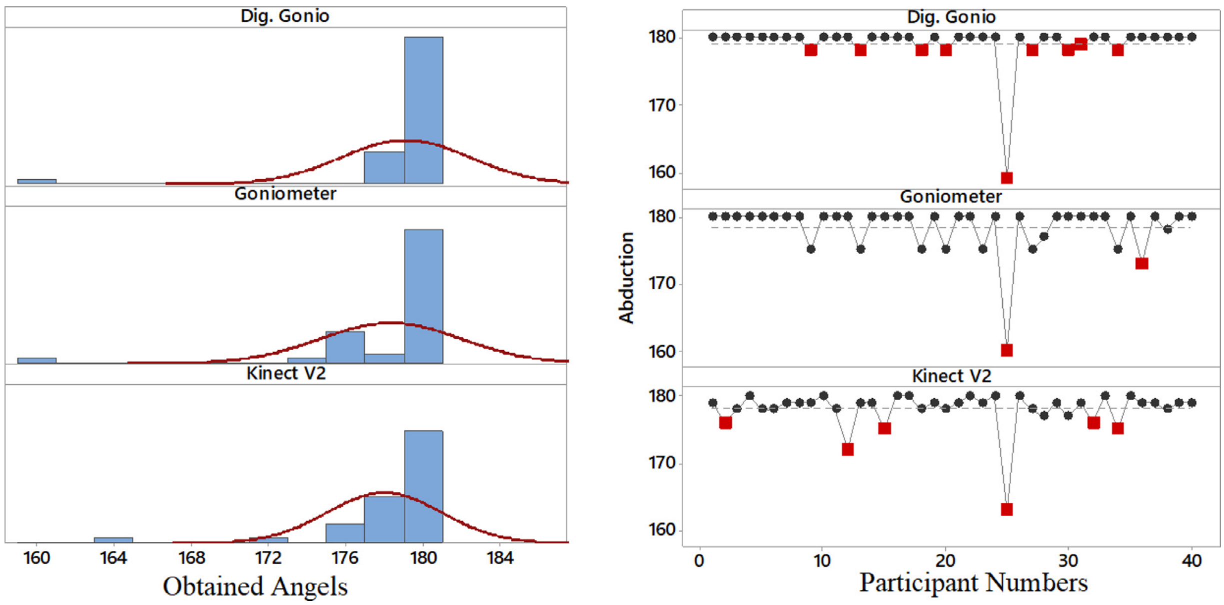

Figure 6. Abduction data obtained using clinical/digital goniometers and Kinect V2.

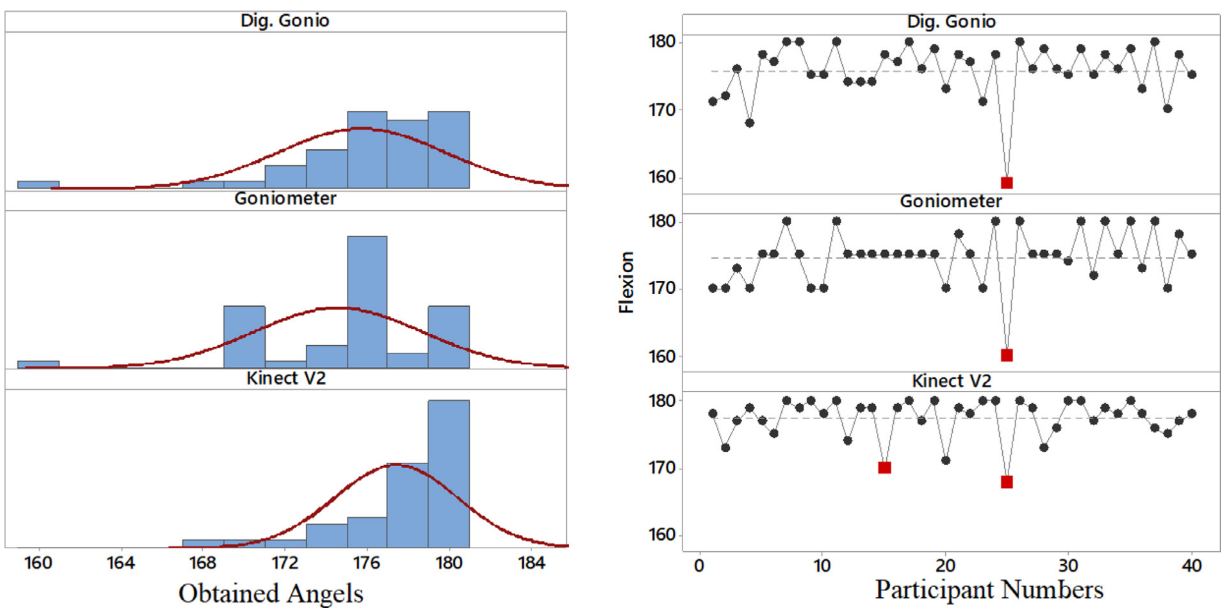

Figure 7. Flexion data obtained using clinical/digital goniometers and Kinect V2.

Firstly, Kinect sensor data were assessed for normality using the Anderson–Darling test ($p < 0.005$). According to the normality test results, the Kinect data was not normally distributed and therefore non-parametric statistics were used in this study. Intraclass correlation coefficient (ICC) model (3,k) was used because the results were compared two-way and measurements were multiple to find the result of the reliability of the Kinect V2 based measurement system for shoulder motions. Reliability is calculated by taking an average of the k raters' measurements. The ICC values are evaluated as *'poor'* when they are below 0.20, *'fair'* for values in range 0.21–0.40, *'moderate'* for values between 0.41 and 0.60, *'good'* for values in range 0.61–0.80, and *'very good'* for values between 0.81 and 1.0 [37–41]. The standard error of the measurement (SEM) and minimal detectable change (MDC) were used to show the absolute reliability. SEM and MDC values are calculated as in the following equations [42,43]:

$$SEM = StDev \times \sqrt{1 - ICC} \tag{5}$$

$$MDC = SEM \times \sqrt{2} \times \ 1.96 \tag{6}$$

where StDev denotes standard deviation. For validity test of the Kinect V2 based shoulder motion measurement system, Bland–Altman analysis is performed. To show the absolute accuracy of Kinect V2 measurements over clinical and digital goniometers, limits of agreement (LOA) and mean bias metrics are used for five shoulder poses.

3. Results and discussion

3.1. Shoulder motion data

By Kinect V2 based shoulder motion measurement system, clinical goniometer, and digital goniometer, the ROM data of shoulder abduction, flexion, external rotation, internal rotation and

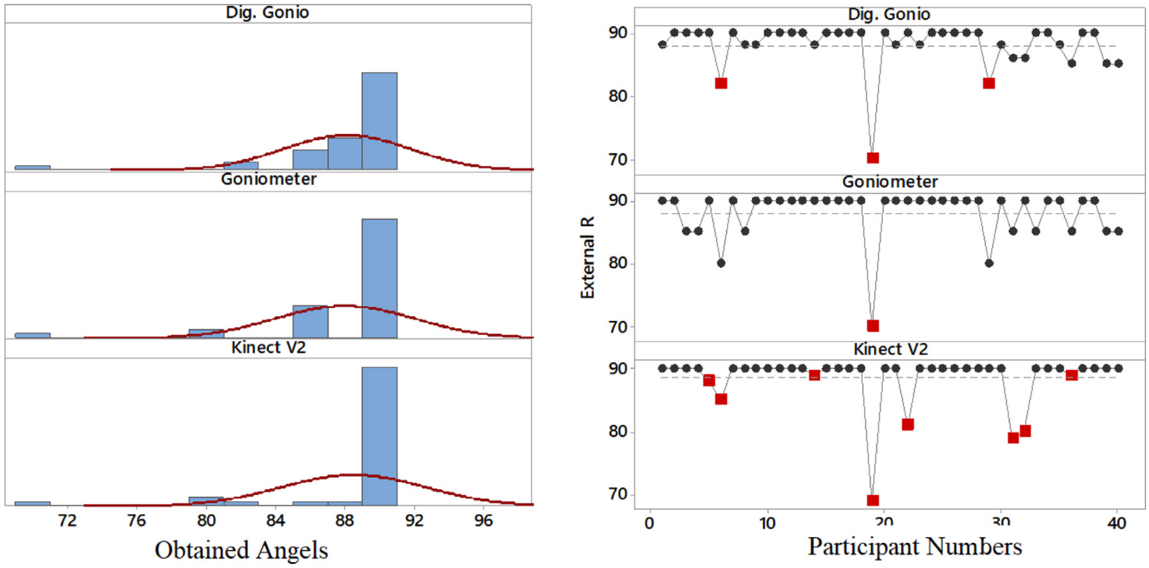

Figure 8. External rotation data obtained using clinical/digital goniometers and Kinect V2.

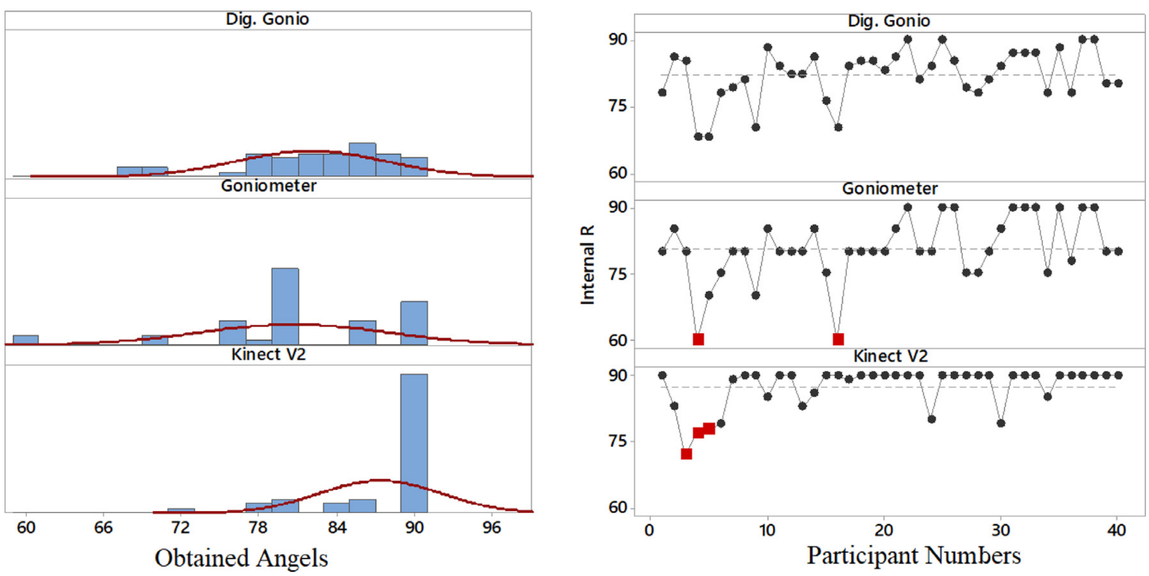

Figure 9. Internal rotation data obtained using clinical/digital goniometers and Kinect V2.

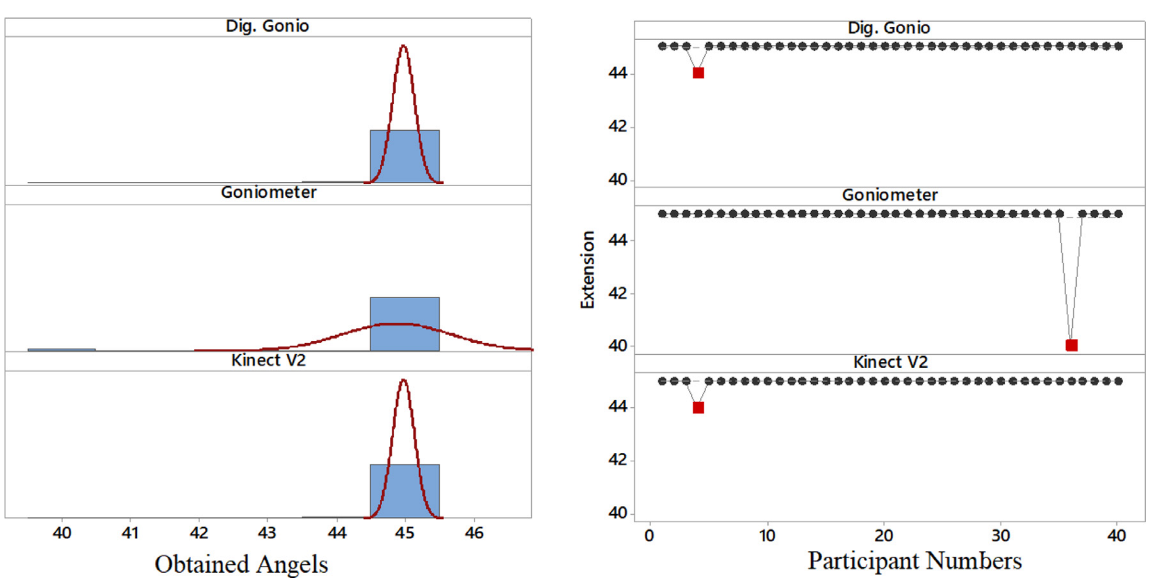

Figure 10. Extension data obtained using clinical/digital goniometers and Kinect V2.

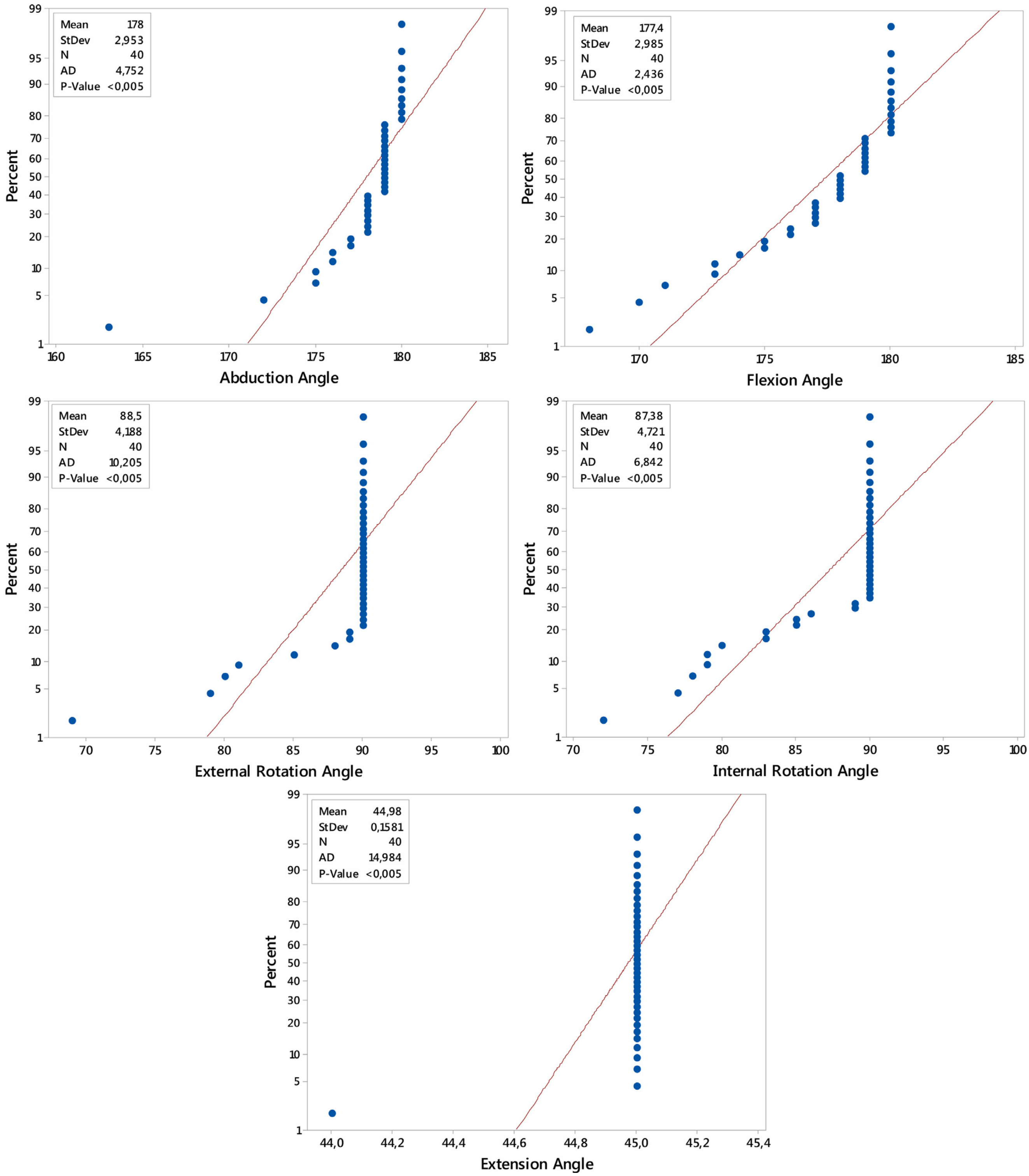

Figure 11. Normality analysis results of Kinect data using Anderson–Darling normality test.

extension are acquired from all participants. Figures 6, 7, 8, 9 and 10 show the data of five shoulder motions for three measurement methods. On the left side of these figures, there are the histogram graphics to present the distribution of data. The participants' shoulder ROM data in worksheet order are shown on the right side of these figures. Figures 6–10 has been drawn with summary report feature of Minitab software program. The red dots indicate outliers of data.

Table 1 summarizes the statistical specifications of the data obtained by the measurement methods used in this study. SE Mean stands for standard error of the mean, StDev denotes standard deviation.

Q1 represents the “middle” value in the first half of the rank-ordered data set and Q3 represents the “middle” value in the second half of the rank-ordered data set. Kinect sensor data were evaluated according to the Anderson–Darling normality test

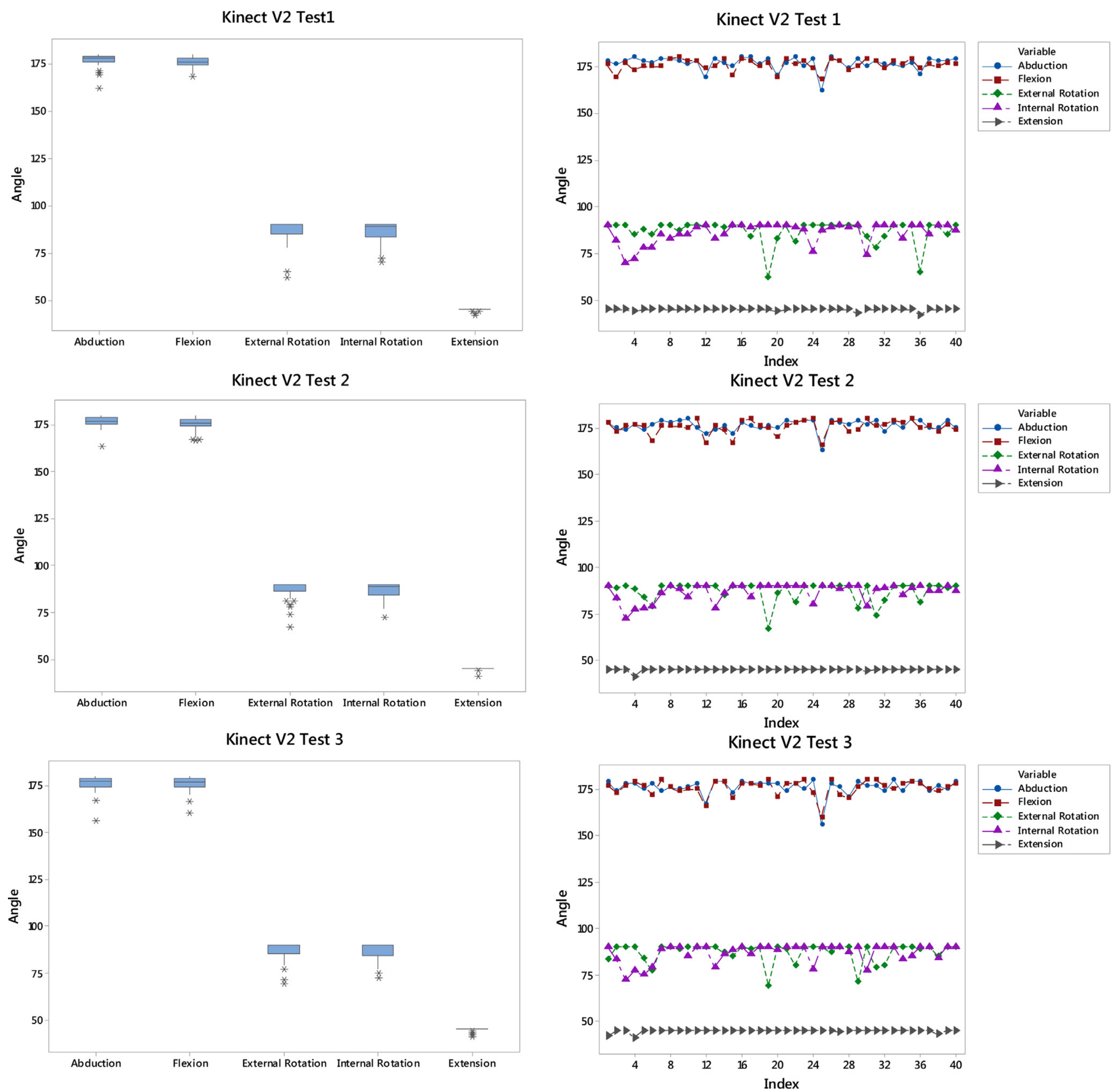

Figure 12. The shoulder angle values obtained by Kinect V2 based measurement system.

Table 1
The data obtained using clinical goniometer, digital goniometer and Kinect V2.

	Method	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Abduction	Dig. goniometer	179.10°	0.530°	3.35°	159.00°	180.00°	180.00°	180.00°	180.00°
	Goniometer	178.32°	0.580°	3.67°	160.00°	177.25°	180.00°	180.00°	180.00°
	Kinect V2	178.00°	0.467°	2.95°	163.00°	178.00°	179.00°	179.00°	180.00°
Flexion	Dig. goniometer	175.72°	0.643°	4.07°	159.00°	174.00°	176.00°	178.75°	180.00°
	Goniometer	174.57°	0.647°	4.09°	160.00°	172.25°	175.00°	177.25°	180.00°
	Kinect V2	177.40°	0.472°	2.99°	168.00°	176.25°	178.00°	180.00°	180.00°
External rotation	Dig. goniometer	88.125°	0.581°	3.674°	70.000°	88.000°	90.000°	90.000°	90.000°
	Goniometer	88.000°	0.641°	4.051°	70.000°	85.000°	90.000°	90.000°	90.000°
	Kinect V2	88.500°	0.662°	4.188°	69.000°	90.000°	90.000°	90.000°	90.000°
Internal rotation	Dig. goniometer	82.025°	0.923°	5.837°	68.000°	78.250°	83.500°	86.000°	90.000°
	Goniometer	80.700°	1.170°	7.400°	60.000°	78.500°	80.000°	85.000°	90.000°
	Kinect V2	87.375°	0.747°	4.721°	72.000°	85.250°	90.000°	90.000°	90.000°
Extension	Dig. goniometer	44.975°	0.0250°	0.158°	44.000°	45.000°	45.000°	45.000°	45.000°
	Goniometer	44.875°	0.125°	0.791°	40.000°	45.000°	45.000°	45.000°	45.000°
	Kinect V2	44.975°	0.0250°	0.158°	44.000°	45.000°	45.000°	45.000°	45.000°

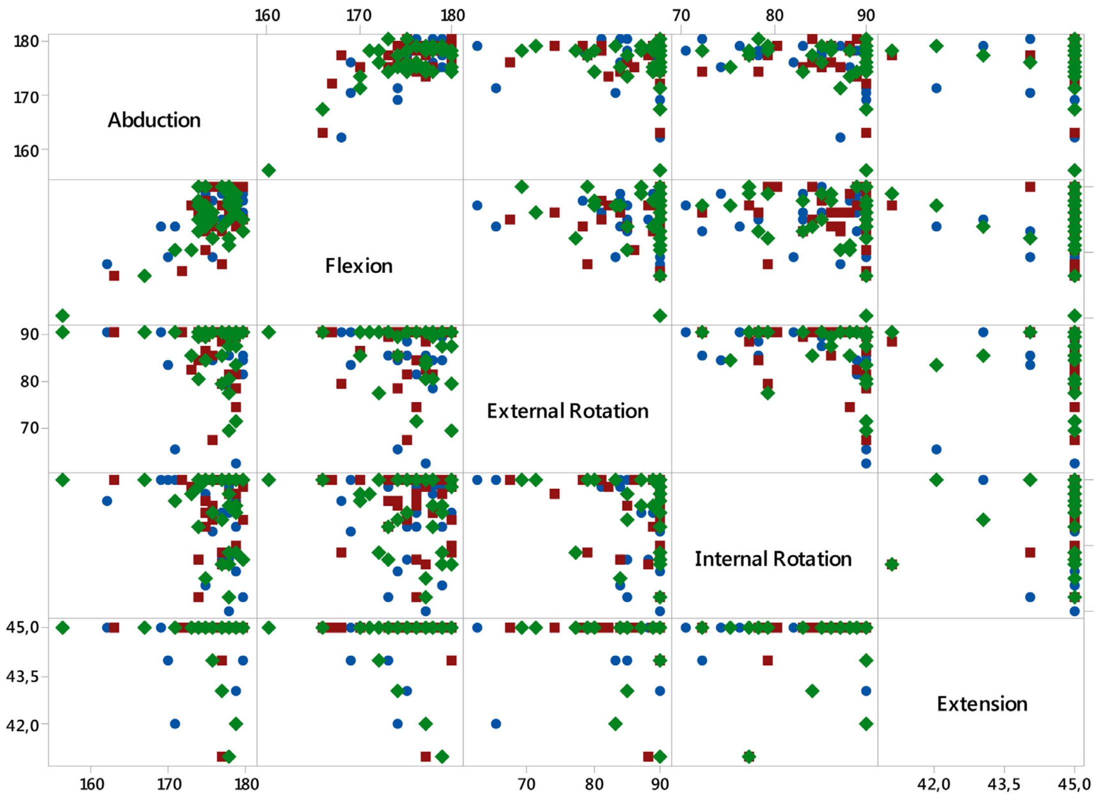

Figure 13. Reliability result: matrix plot for three repetitions of shoulder poses (blue denotes test 1, red denotes test 2 and green denotes test 3).

Table 2
Reliability results of the Kinect V2 based measurement system.

	$ICC_{(3,k)}$	Mean	StDev	SEM	MDC
Abduction	0.861	176.38°	3.620°	1.35°	3.74°
Flexion	0.851	175.72°	3.620°	1.40°	3.87°
External rotation	0.874	87.133°	5.577°	1.98°	5.49°
Internal rotation	0.965	86.833°	5.109°	0.96°	2.65°
Extension	0.620	44.817°	0.698°	0.43°	1.19°

ICC: Intraclass Correlation Coefficient, SEM: Standard Error of the Measure, MDC: Minimal Detectable Change.

($p < 0.005$). These data were not normally distributed and for that reason non-parametric statistic methods were used in this study. Figure 11 shows the Anderson–Darling normality test results of Kinect sensor data for all shoulder poses.

3.2. Reliability result

For reliability analysis, the Kinect sensor measurements were taken three times from all participants. The obtained angular values for all shoulder poses are shown in Figure 12. This figure includes the box and line plots of the shoulder angle values obtained by Kinect V2 based system three times.

The results of the reliability of the Kinect V2 based measurement system for shoulder poses are given in Table 2. This table consists of the measurement of the shoulder angle with Mean, StDev, ICC, SEM and MDC values. According to the high ICC metric values, the proposed Kinect V2 based shoulder motion measurement system has very good relative reliability for the measurement of the shoulder angles in four shoulder poses. For only extension pose, Kinect V2 based system has good relative reliability. In terms of SEM and MDC metrics, the good reliability results were obtained for all poses due to their small values. In Figure 13, the matrix plot is given to show the relationship among Kinect V2 repetition measurements. The subplot in the *i*th row and *j*th column of this figure is a scatter plot of the shoulder poses taken by the proposed Kinect V2 based measurement system for three repetitions.

3.3. Validity result

The 95% limits of agreement (LOA) between Kinect V2 based measurement system and the two goniometer systems were calculated for five shoulder poses to show the validity of the proposed system. The validity results among the Kinect V2 based measurement system, clinical goniometer and digital goniome-

Table 3
Bland–Altman analysis result of shoulder joint data obtained using clinical goniometer, digital goniometer and Kinect V2.

	Clinical goniometer vs Kinect V2		Digital goniometer vs Kinect V2	
	Mean bias	95% LOA	Mean bias	95% LOA
Abduction	0.33°	−4.86° to 5.51°	1.10°	−2.63° to 4.83°
Flexion	−2.83°	−9.88° to 4.23°	−1.63°	−9.03° to 5.68°
External rotation	−0.50°	−7.55° to 6.55°	−0.38°	−6.11° to 5.36°
Internal rotation	−6.67°	−21.42° to 8.07°	−5.35°	−18.30° to 7.60°
Extension	−0.10°	−1.69° to 1.49°	0.03°	−0.28° to 0.33°

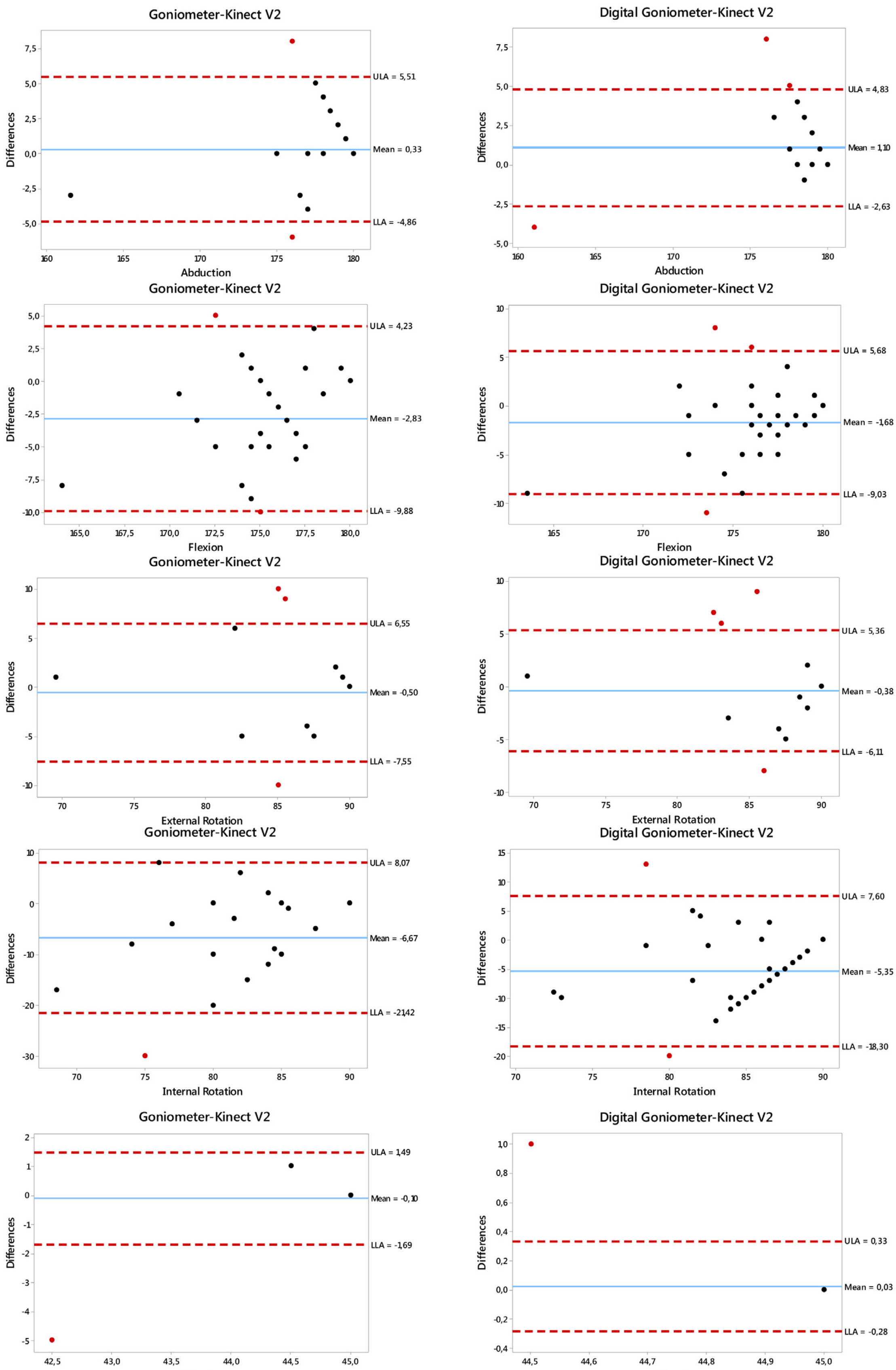

Figure 14. Bland–Altman plots of comparison between Kinect V2 and Clinical Goniometer (Left Column) and comparison between Kinect V2 and Digital Goniometer (Right Column).

ter are given in Table 3. The mean differences of the clinical goniometer from the Kinect V2 based measurement system (Clinical Goniometer-Kinect V2) were 0.33° (abduction), −2.83° (flexion), −0.50° (external rotation), −6.67° (internal rotation) and −0.10° (extension). The mean differences of the digital goniometer from the Kinect V2 based measurement system (Digital Goniometer-Kinect V2) were 1.10° (abduction), −1.63° (flexion), −0.38° (external rotation), −5.35° (internal rotation) and 0.03° (extension). According to the LOA results, the 95% LOA exceeded ±5° for the discrepancy between Kinect V2 based system and two goniometers for all shoulder poses except extension, and this was considered to be clinically significant [44–48]. Bland–Altman analysis results are shown in Figure 14 for all shoulder poses. The comparison between Kinect V2 and clinical goniometer is at the left column of this figure and the comparison between Kinect V2 and digital goniometer is at the right column of this figure. As can be seen from this figure, the differences of the shoulder pose angles obtained by two measurement systems does not distribute in a systematic way, but a random distribution for all shoulder poses except extension pose.

4. Conclusion

In this study, the validity and reliability of Kinect V2 based measurement system for the shoulder motions were presented. The proposed system consists of Kinect V2 sensor and graphical user interface. The reliability test results show that Kinect V2 based measurement system is very good for abduction, flexion, internal rotation, external rotation poses, and has good reliability for extension pose. Because of the selection of healthy individuals for the test of extension pose, it was observed that 39/40 of the volunteers has the value of ICC (3, k) = 0.62. The reason of this is that the volunteers reach full results for this shoulder pose. In the 95% LOA results of all exercises, it was observed that Kinect V2 based measurement system gives closer results to the digital goniometer than the clinical goniometer. According to the Bland–Altman analysis results, it is evident that the proposed Kinect V2 based shoulder motion measurement system is an alternative and effective method in comparison with both of the goniometers.

The obtained results are promising for the development of home-based rehabilitation systems using Kinect that is a low cost motion capture sensor. This proposed system can be used as an alternative method at the rehabilitation centers. In future works, the proposed measurement system can be applied to patients for treatment. The system can be developed by artificial intelligence methods to help patients and physiotherapists.

Ethical approval

Not required.

Acknowledgments

We gratefully acknowledge the help of all the participants who took part in the study. This study was approved by Bilecik Şeyh Edebali University Ethics Committee (2017/04) and carried out in accordance with the Helsinki Declaration of the World Medical Association. This work was supported by Bilecik Şeyh Edebali University Coordinating Unit of Scientific Research Projects (2017-01.BŞEÜ.03-04).

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