Comparison of reliabilities and validity between AR based motion capture system and physical therapist : preliminary study

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Abstract: AR based motion capture system(ABMCS) is a program that provides multiple practical type of training exercises and rehabilitation programs and with an included motion capture sensor, it is an alternative method for range of motion measurement. The present study aimed to compare the difference between the augmented reality-based measurement tool using motion capture system and the therapist's measurement using goniometer for measuring the range of motion (ROM) of the joint. Three ROM motions on the upper extremity (shoulder abduction, flexion, external rotation), two on lower extremity (knee extension, hip abduction) and trunk flexion were measured. The measurement was done simultaneously to avoid errors and the results were recorded in degrees. Excepting shoulder external rotation and trunk flexion, the result was similar and not significant difference between AR based motion capture system compared to the goniometer. A measurement tool based on augmented reality using AR based motion capture system can be expected to have a good prospect as an evaluation tool if the evaluation is conducted in the way subject and the target join is inside the focus of the sensor.

Keywords: range of motion, goniometer, augmented reality, motion capture, physical therapist

1. Introduction

Range of motion (ROM) is known as the evaluation of the movement around a joint or body part. A normal ROM plays an important role in the human activity by helping to move efficiently without a big effort. During activity of daily living such as eating, drinking, personal care, walking, running, wearing and other movements, ROM is view as an important factor of decreasing potential injury [1]. ROM is one of the primary measures for assessing joint dysfunction, diagnosing musculoskeletal deficits or impairment. The determination of ROM is an important component of a physical evaluation, as it allows the identification of joint and muscle limitations as well as the possible risk of injury. In addition, it is also used as a reference to determine the progress of recovery during a rehabilitation program. In the rehabilitation field, doctors, physical therapist, osteopaths, and other healthcare professional generally use a goniometer to measure the ROM at a joint [2].

The goniometer is defined by Gandbhir as a device that permits rotation of an object to a position or to measure an angle. For several decades, in the clinical area and rehabilitation in particular, goniometer is used as reference marker to quantify the degree of the joint limitation, to decide on appropriate therapeutic intervention program or to evaluate the effectiveness of these interventions [3]. Many preview studies emphasized on the use of the goniometric measurement as a reference standard and has been consider as the most available, valid, and objective method to measure a joint ROM [4-7]. However, goniometric measurement can be affected by several factors such as the experiment of the measurer, designing the center of rotation of the joint and ability to maintain it and the location of bony landmarks [8]. Therefore, some recent studies were questioning about the validity and accuracy of the measurement of the ROM by using the goniometer [9,10]. In order to improve the accuracy and validity of the goniometer, diverse alternative method has been applied in the clinical field. Carey, Mark A, et al. assessed the reliability, validity and usability of a digital goniometer, and Klober et al. assessed the digital inclinometer [11,12]. In another study, inertial sensory system was found to be reliable measurer tool to assess the ROM [13]. Moreover, with the recent increasement of the use of new technologies like virtual reality (VR), augmented reality (AR) computer and smartphone applications in the rehabilitation field, new methods including smartphone goniometry are become available [8]. According to a review on smartphone applications in rehabilitation conducted by Milani, Patrizia et al, there is about 40,000 available medical applications [14]. Several studies showed that iPhone goniometer and smartphone photograph are reliable with accuracy and lightly superior to the conventional manual goniometer [15,16]. Despite, the smartphone application shows a difference with standard goniometer when measuring some specific motion such as trunk movement. Otherwise, it is difficult to use clinically the smartphone application and goniometer interchangeably [17, 18]. Additionally, motion capture system has also been used to measure ROM using tracking markers. These devices usually use electromagnetic or optoelectronic devices during the measurement. nevertheless, these systems are expensive and require a complex setting and have not yet proved to be valid in measuring ROM [19]. Therefore, there is a need for a low cost, valid and easy manageable measurement tool, or application to help the healthcare professional.

Recently, AR based motion capture system(ABMCS) was developed for clinical virtual reality rehabilitation or a home training program. ABMCS was developed with multiple purpose such postural analysis, AR based upper-lower extremity strengthening program and ROM measurement system. The device includes a normal PC with common use purpose, a 3D motion analysis sensor, and ABMCS software. ABMCS uses Kinect camera's infrared and motion capture technology to detect and recognize the subject's body and motion in real time, provides an exercise guide image and able to measure joint angle. Additionally, it also provides a text explanation with easy words and normal front size, and audio instruction on the ongoing movement guide.

Our hypothesize is that the measurement of the ROM during ABMCS would be the same as the measurement during the standard ROM measurement goniometer. The inter-tester and intra-tester reliability of these two instruments would be high. Therefore, the purpose of this study was to evaluate the intra- and interobserver reliabilities and validity of upper – lower extremity and trunk ROM measurement when using ABMCS and to compare its reliability with the standard goniometer.

2.Method

2.1.Study design

This study was a case report assessing the ability and validity of the augmented reality computer software UNICARE 82-B Korea, (2016) for measuring ROM comparing to the worldwide used goniometer performed by a therapist.

2.2.Data processing

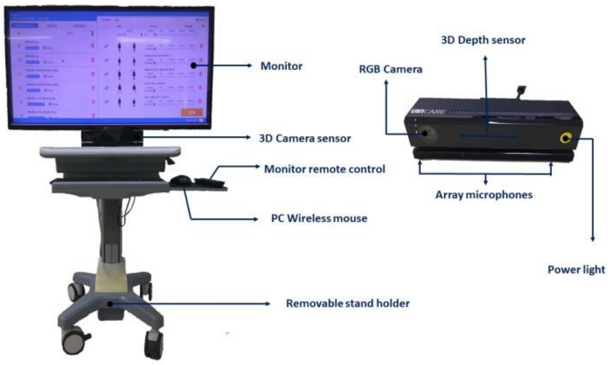
Six volunteers' healthy adults, 3 males and 3 females between the age of 22 and 30 were included in this study. In order to compare the measurement results according to height and sex, the male subjects were respectively 160cm, 170cm, and 180cm. The included female subjects were respectively 150cm, 160cm, and 170cm. The criteria for selecting subjects included those who did not have diseases such as joint contracture, and those who were able to fully exercise within the normal range motion. Exclusion criteria included those who have joint dysfunction such as joint contracture, those who are unable to fully exercise within the normal range of motion, those who can fully exercise within the normal range of motion but suffer from pain, and those who cannot perform active joint motion.

Table 1. Participants general information

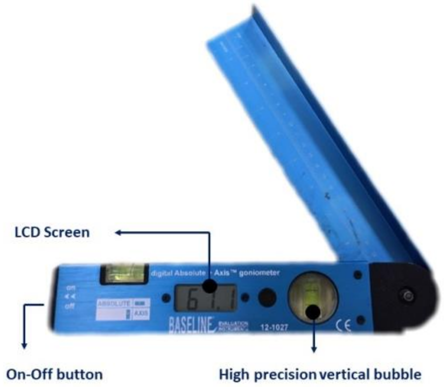
High(cm)	Age	Gender
150	23	female
160	23	female
170	24	female
160	30	male
170	26	male
180	24	male

2.3.Instruments

The goniometer used for the present study was the Baseline® Digital Absolute Axis™ Goniometer 12-1027 with an LCD screen reads 0-180°. It was selected for his simplicity of positioning and his digital screen where the result clearly appears. The ABMCS device is a real-time interactive digital healthcare system with multiple rehabilitation exercises for the lower and upper extremities. Visual and auditory instructions are applied when a programed task is properly performed or an incorrect operation is performed, which allows the subject to receive appropriate and simultaneous feedback . The device has three (3) principal components: a normal PC with a general use, a 3D motion analysis sensor, and ABMCS software. it uses Kinect camera's infrared and motion capture technology to detect and recognize body motion in real time, provides an exercise guide, records, and tracks movements in three-dimensional space. All the collected information's and data can be saved on the PC and easy manageable. In the present study, the device was running on a computer operated by Window 8 with a 3.1 GHz Intel Core i5 and 8 GB RAM and with the software ABMCS installed. The monitor used was Whestinghouse WH40BSAC manufactured with a resolution of 1920 × 1080 (Full HD). The instruments appearance and details are presented in the figure 1~ 2 below.



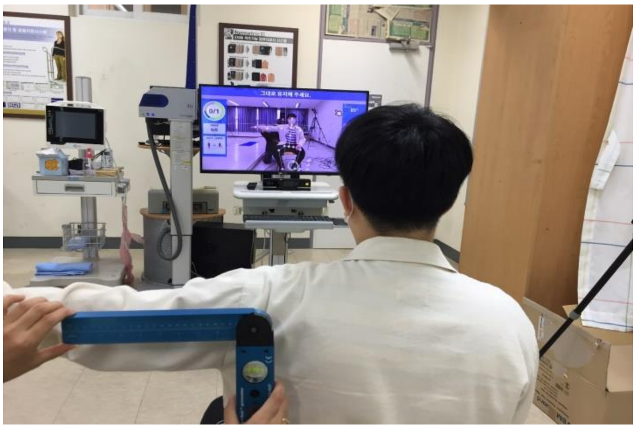
<**Figure 1**. AR based motion capture system>



<**Figure 2.** Baseline® Digital Absolute Axis™ Goniometer >

2.4.Procedure

The subject performed an active range of motion (AROM) by following the motion showed on the augmented reality (AR) monitor screen. First, the subjects received a clear verbal instruction from one of the examiners and a simple demonstration of each motion. After selecting the motion on the software, subjects receive additionally an audio explanation and visual demonstration of the motions on the screen. In order to reduce as much as possible, the bias, the therapist measured the range of motion of the subjects through digital goniometer simultaneously when the subjects executed the movement. The performed motions were composed of shoulder abduction on sitting position, shoulder flexion on sitting position, shoulder external rotation on the sitting position, trunk flexion on sitting position, hip abduction on standing position, and knee extension on sitting position (figure 4). In order to reduce the subject's postural change, the measurements were conducted in the order of shoulder abduction in sitting position from 0° to 90°, shoulder flexion in sitting position from 0° to 180°, shoulder external rotation in the sitting position with shoulder 90° abduction, 90° flexion as starting position and the knee extension on sitting position with hip and knee 90° flexion as starting position. The measurement of the trunk flexion was performed on sitting position and the subjects were instructed to bend forward as much as possible. Lastly, subjects change position form sitting to standing and the hip abduction was measured from the anatomical position of the hip joint from 0° to 50° while holding the chair with the opposite hand. All the procedure was under the supervision of two research assistants who were responsible of positioning the goniometer, reading the results (1 person) and recording the results according to the motion executed. Figure 3 shows the measurement procedure. Figure 4 shows the ABMCS interface and procedure of the measurement,



<**Figure 3**. Measurement procedure>

Motion	**Figure**	**Motion**	**Figure**
Shoulder flexion Axis: lateral acromion Stationary arm: Bisect Rib Cage Movable arm: Bisect humerus toward Lateral epicondyle		**Knee extension** Axis: Fibular head Stationary arm: lateral femur Movable arm: lateral fibular	
Shoulder abduction Axis: acromion Stationary arm: Bisect sternal notch Movable arm: Bisect humerus		**Hip abduction** Axis: Anterior superior iliac spine Stationary arm: perpendicular to floor Movable arm: Bisect femur	
Shoulder external rotation Axis: Olecranon process Stationary arm: Perpendicular to floor Movable arm: Bisect ulna		**Trunk flexion** Axis: greater trochanter Stationary arm: lateral femur Movable arm: Bisect lateral trunk	

<**Figure 4.** Measurement positions>

3.Result

There was a significant difference during shoulder external rotation in the sitting position and trunk flexion on sitting position ($p<0.05$). However, there was no significant difference in the other four movements except 6 and 13 ($p>0.05$). Table 2 shows the result including the motions, Z value and P value.

Table 2. Comparison of the results

Motion	PT	UC	Z value	P value
SA	95.40±4.88	96.46±8.59	-.105	.917
SF	162.25±17.14	155.85±14.37	-1.153	.249
SER	70.50±6.46	78.91±7.08	-2.201	.028*
KE	2.91±1.78	2.51±1.11	-.674	.500
TF	95.28±9.08	69.55±16.33	-1.992	.046*
HA	46.65±7.56	52.20±10.09	-1.572	.116

*p<0.05

PT=Physical therapist, UC=ABMCS, SA=Shoulder abduction, SF=Shoulder flexion, SER=Shoulder external rotation, KE=Knee extension, TF=Trunk flexion, HA=Hip abduction

4.Discussion

The aim of this study was to assess the validity and eligibility of ABMCS for measuring ROM and compare to the standard goniometer. Our hypothesize was that they will not be a difference between the two methods. The main finding of our study is that excepting the measurement of shoulder external rotation on sitting position and Trunk flexion on sitting position, all the other measurement results did not show a significant difference between both measurement methods. Therefore, we can affirm that our hypothesize was correct.

The external rotation of the shoulder joint was performed on a sitting position. During the goniometer measurement, the starting position of the motion was shoulder joint 90 degree abduction and the elbow joint 90 degree flexion. In this motion, the examiner used the olecranon as axis and the motor arm was set parallel to the long axis of the ulna [20]. However, ABMCS sensor recognized and measured the angle according to the hand, olecranon, and acromion position. According to previous studies, measurement of the range of motion of the shoulder joint can result in various results depending on whether the target action is controlled, whether the active range of motion is measured, or whether the range of passive joint motion is measured [21]. Therefore, when performing the motion, even if the subject's wrist extension occurs, the sensor recognizes the motion as an external rotation of the shoulder joint, indicating that a significant difference occurred in the result value.

Telerehabilitation programs with virtual reality such as ABMCS offers advantage to therapists/examiners to save time on their busy schedules and, can reach isolated areas where clinical facilities may be difficult to access and less expensive [22]. Additionally, therapists/examiners in some situations may have both hands busy and not free to correctly align the goniometer on the specific position and may influence the result [23]. However, in this kind of situations, ABMCS can benefits and helps therapists/examiners to be free and observe subject motion patterns during the task. Well known telerehabilitation programs such as RehabGesture and KinectSpace use a Kinect sensor to recognize the motions, gestures and are able to provide visual feedback to the subjects [24]. However, it is not mentioned that these software's provide a detail text explanation of the ongoing movement and an auditory cueing guiding the subject when performing the task. ABMCS provides a demonstration of the movement and a text explanation and also an audio guide to help the subjects to correctly perform the indicated movement.

Measuring the ROM requires that the therapist/examiner to know each joint structure and function, testing position, anatomic bony landmark, goniometer alignment, normal end feels and able to correctly record the results. [25]. Nevertheless, the incorporated sensor on the ABMCS automatically recognize and capture the axis and moment arm when the subject executed the motion. Therefore, there is a less risk of a potential error of measuring. Moreover, the setting parameters of the device are well structured and very easy to manipulate. It measures and records the ROM just by selecting and clicking on the desired motion and the therapist/examiner does not need a previous clinical experiences or computer skills to obtain accurate and reliable measurements.

According to previous studies, the Kinect sensor sometimes can be difficult to recognize and detect the target joint, the axis and moving joint. Moreover, the accuracy of the sensor can be influenced by the position of the sensor relative to the distance with the subject [26,27]. Seo, Na Jin, et al added that accuracy of the Kinect changes depending also on the movements and the Kinetic sensor should vary according to that [26]. Galna, Brook, et al. tried to explain the inaccuracies of the Kinect sensor by its limitation to recognize the landmarks specially on fine movements, such as hand clasping and toe tapping [27]. Additionally, in the present study, it was difficult for the sensor to detect the target joint for subject who had wide clothes and difficult to focus just on the subject when the examiner was measuring the simultaneously the ROM with goniometer. In other words, it is difficult to detect distinctly when two (2) people are in the middle of the focus of the camera. This can explain the significant difference found between ABMCS and goniometer during trunk flexion on sitting position. During trunk flexion on sitting position, the movement is done on the sagittal plan including head and trunk forward bending facing to the camera and may influence the sensor to capture distinctly the trunk motion.

There are several limitations to our research. First, since ABMCS sensor had to recognize the whole body of the person to be measured, the distance between the device and the subjects was different for each subject. Second, sensor abnormalities exited depending on the subject's clothes. For example, when wearing clothes that do not expose the joints to be measured, there have been cases where the sensor recognizes the clothes rather than the subject's joints. Third, with the visual feedback received from the screen, the subjects tried to more than they normally can, and the compensation movement patterns that can occur during active ROM was not limited. Finally, in some cases, the sensor recognized the chair that was brought for evaluation rather than the subject. Therefore, for the future studies on the telerehabilitation/augmented reality measuring the joint movement, we suggest: first, the subject's clothing should be limited to tight clothing or exposed joints to be measured, Second, consider a way to limit the compensation movement during measuring and finally, be careful not to cause sensor abnormalities or error.

5.Conclusion

The purpose of this study was to compare the difference between the augmented reality-based measurement tool using ABMCS and the therapist's measurement using goniometer for measuring the range of motion (ROM) of the joint. Looking at the statistical results and several preceding papers, it can be concluded that the measurement of the active joint motion range is not different from the augmented reality-based measurement tool and therapist. A measurement tool based on augmented reality can be expected to have a good prospect as an evaluation tool if the evaluation is conducted in consideration of the aforementioned limitations and suggestions. If augmented reality-based measurement tools are further developed and introduced into clinical practice, physical therapists will be able to reduce the time required to evaluate patients and provide better quality treatment to patients

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