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Validation Of A Smartphone Application For Measuring Shoulder Internal Rotation and External Rotation Range Of Motion With Intra-Rater Reliability

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Post-Professional Athletic Training

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Abstract

Assessing range of motion of the shoulder girdle is a critical skill needed by athletic trainers due to the complexity of the motions allowed at the joint. The process can be subjective with the majority of accepted techniques utilizing the clinician's ability to determine bony landmarks of the patient. In recent years, tools have been created to make determining range of motion of the body valid and consistent. One of the most common tools used in the clinic setting to measure shoulder range of motion is the inclinometer. With the current technical age, there have been many smartphone applications created to mimic and serve as an inclinometer. Within the clinical setting, it is common practice for one clinician to measure a patient's range of motion multiple times throughout a course of treatment. Therefore, the purpose of this study was to determine the validity of the smartphone application, "Clinometer" for measuring shoulder internal and external rotation range of motion using intra-rater reliability. An experienced Certified Athletic Trainer measured bilateral shoulder internal rotation and external rotation with a hand held goniometer and with the "Clinometer" smartphone application in 25 male participants, ages 18-23. Validation of the application and intra-rater reliability were assessed by using Pearson correlation coefficients. Smartphone validation was statistically significant for shoulder internal and external range of motion with values of 0.959 and 0.940 respectively. Intra-rater reliability was statistically significant for external rotation with the goniometer and internal and external rotations with the application (0.804, 0.800, and 0.838). The results of this study indicate that there is no difference in the hand held goniometer and the "Clinometer" smartphone application for measuring shoulder internal and external range of motion. There is also good reliability in an experienced clinician for finding and measuring end points of shoulder internal and external rotation with the application as well as external rotation with the goniometer.

Keywords: Inclinometer, range of motion, validity.

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Statement of the Problem

One similar trait of synovial joints in the body is the ability to allow for range of motion. Every joint like the ankle, knee, hip, and shoulder all have specific ranges of motion that are available for the individual joint in question. The most mobile joint of these is unarguably the shoulder.

Due to the increased mobility of the shoulder joint, there are anatomical structures that can undergo changes that over time which may limit the large range of motion. The most common pathological finding in shoulder range of motion assessment is known as glenohumeral internal rotation deficit or GIRD. This finding is demonstrated by a loss of internal rotation of more than 20 degrees when comparing dominate throwing arm to the non-dominate (Aldridge, Guffey, Whitehead, and Head, 2012). More often seen in overhead throwing athletes, specifically baseball pitchers, the loss of internal rotation is accompanied by a gain in external rotation.

The conventional baseball pitcher goes through a series of six phases of throwing; windup, early cocking, late cocking, acceleration, deceleration, and follow-through. During the late cocking phase, the increased amounts of shoulder external rotation allow for the acceleration forces to act over the longest distance, which allows for greater elastic energy to be transferred to the ball. In the acceleration phase, the internal rotation velocity has been documented to reach 7500 to 7700 degrees per second. These forces must be dissipated completely in the deceleration phase. The massive eccentric contractile requirements of the posterior shoulder musculature are likely responsible for the posterior capsular and soft tissue reaction commonly seen in throwers and for the glenohumeral internal rotation deficit seen in pitchers (Seroyer, Nho, Bach, Bush-Joseph, Nicholson, Romeo, 2010).

The change in internal range of motion at the shoulder is important to be able to assess due to the anatomical changes that can occur in the kinetic chain if GIRD is present. Multiple studies (Burkhart, Morgan, and Kibler, 2003) (Thomas, Swanik, Swanik, Kelly, 2010) (Tyler, Nicholas, Roy and Gleim, 2000) have found that having GIRD increases the potential for other shoulder pathologies such as subacromial impingement and SLAP lesions as well as potential overload stress on the ulnar collateral ligament of the elbow.

Measuring range of motion at joints in the body is vital for any physical examination. A majority of clinicians ranging from physical therapists to athletic trainers and even occupational therapists all rely on a precise measurement to determine their treatment plan and short term goals.

No matter what type of clinician or what tool is used to determine range of motion, there is always a need to have the end feel of where the range of motion in question stops. An end feel is defined by Houglum (2010) as “the nature of resistance palpated at the end of a range of motion” (page 94-95). To find a proper end feel, most assessments are done passively which means that the patient completely relaxes and the motion is carried out by another individual. There are two largely accepted, simple end feel identification scales, that of Cyriax and of Kaltenborn. Cyriax uses terms of capsular, bone-to-bone and tissue approximation for classifying normal end feels where Kaltenborn uses soft, hard and firm descriptions. Abnormal end feels are described as capsular in abnormal point of motion, bone to bone in an abnormal point of motion, springy block, spasm and empty by Cyriax. Kaltenborn simply says an abnormal end feels is any feeling that either is of an abnormal quality for a joint or occurs at an abnormal point in the joint’s range of motion (Petersen and Hayes, 2000).

Along with being able to find the correct end feel of a joint's range of motion, it is required that proper landmark placement for the range of motion is used. A landmark is a bone or anatomical structure where the range of motion device is placed. Van Ost (2010) states that the proper landmarks for goniometry of internal rotation and external rotation of the shoulder are to line the axis up with the olecranon process of the ulna, align the stationary arm perpendicular to the floor, and align the moveable arm with the shaft of the ulna siting over the styloid process of the ulna. The universal accepted range of motion for shoulder internal rotation is zero to ninety degrees in the non-overhead throwing, general population.

Overhead-throwing athletes have been shown to have an increased external rotation and decreased internal rotation of the shoulder when measured at 90 degrees of abduction (Ruotolo, Price, and Panchal, 2006). Specifically baseball pitchers have shown chronic adaptations to soft and osseous tissues in the glenohumeral joint. These changes may be simply adaptive mechanisms, some are associated with pain, decreased performance and shoulder disorders (Dwell, Tripp, Tripp, Eberman, Gorin, 2009). Specific changes that can effect the throwing shoulder include anterior capsular stretching, posterior capsular tightening and increased humeral and glenoid retroversion (Levine, Brandon, Stein, Gardner, Bigliani, Ahmad, 2006).

Due to the nature of the required precision needed in assessing range of motion, there have been many tools created to provide assistance in quantifying the movement of each joint. The goniometer and the inclinometer are a few of those tools. Goniometers are seen as the old school method with inclinometers being used more in recent times. A goniometer is often made of plastic with two "arms" and a numbered dial which provides the degree of measurement. This type of assessment allows for much more subjectivity from the clinician due to the estimation of bony landmarks such as the olecranon process of the elbow. Most bones in the human body have rounded edges that are not perfect in shape. This imperfection changes the axis of the joint from person to person and introduces an obstacle to perfect joint angle.

Inclinometers reduce subjectivity and chances of errors by using gravity to determine the change in angle. Assessing range of motion with an inclinometer is as easy as holding the instrument on the patient, zeroing out the device to determine the starting position relative to gravity then moving to through the motion with the device remaining in contact with the patient. The inclinometer then displays a reading that which is the range of motion for that joint. This protocol eliminates the need for a precise axis or perfect alignment of the moveable and stationary arms with the bony landmarks.

With the increase in reliability studies on inclinometers showing that they are more precise than goniometers (Charlton, Mentiplay, Pua, and Clark, 2014) (Kolber, Pizzini, Robinson, Yanez, and Hanney, 2013) (Kolber, Fuller, Marshall, Wrght, Hanney, 2011), there has been an increase in the types and models of inclinometers being designed. This increase in new models includes that of applications for smartphone convenience. In this day in age, the majority of the population use or have access to a smartphone and multiple applications, also referred to as "apps", which are aimed to make life easier for the user. There have been studies done which have focused on proving that these application inclinometers are reliable in measuring range of motion at the hip, lumbar and cervical spine but none comparing the hand held goniometer to a smartphone application inclinometer (Charlton et al., 2014) (Kolber et al., 2013). Therefore, there is a need for validation of smartphone application inclinometers for measuring shoulder range of motion.

Survey of Current Learning

With there being an increased need to identify the loss of shoulder internal rotation range of motion for athletes, the proper techniques in assessing shoulder range of motion are important. In an article written in *Athletic Therapy Today* (Spigelman, 2006) the author reports that any bilateral comparison that differs more than 25 degrees or has an overall total arch of motion loss of 10 percent are both indicators for the presence of GIRD. In the article different assessment techniques are outlined in both the supine and the seated position. The supine position allows for better scapula stabilization and the seated position is seen as a more functional for the upper extremity. For supine assessment, the subject lies in the position with the glenohumeral joint abducted 90 degrees and the elbow flexed at 90 degrees. Overpressure needs to be applied over the anterior humerus for internal rotation to eliminate added scapulothoraic joint motion. The subject is passively moved through internal and external rotation of their shoulder until the examiner feels an endpoint of motion and the assessment is documented. In the seated position, the subject sits in a chair with a supportive back. The shoulder is measured in 90 degrees of external rotation and 90 degrees of elbow flexion. The subject then actively rotates their shoulder and the assessments are documented.

Assessing range of motion deficits like GIRD, no matter what technique is used, require multiple assessments throughout an athletic season. Researchers (Dwelly, Tripp, Tripp, Eberman, Gorin, 2009) determined the changes in glenohumeral rotation range of motion over the course of a season with overhead-throwing athletes. The main variable in this study was the passive range of motion in collegiate baseball and softball athletes at three different time periods throughout the season as well to determine the presence of GIRD within that population. Subjects included baseball and softball players from NCAA division I and II institutions. An inclinometer was used to determine the numerical value associated with the end range of motion. The inclinometer was fixed to the distal radius with straps and loops and the subject was passively moved through each range of motion. Each motion was assessed twice and the average was documented for result purposes. The testing sessions occurred in the pre-fall, pre-spring, and the post-spring time periods of the season. The results of this study showed a dominant arm gain of 2 degrees of internal between the pre-fall and the pre-spring periods and lost 1.5 between the pre-spring and the post-spring. There was not an observed change in the number of athletes displaying GIRD from the first assessment to the third assessment.

In terms of inclinometers and goniometers, there is a deep pool of research that compares the two on the assessment of range of motion at any given joint in the body (Cools et al., 2014) (Roach, San Juan, Suprak, and Lyda, 2013) (Kolber, Fuller, Marshall, Wrght, Hanney, 2011). Most look at the inter-rater and intra-rater reliability as the result of the study. Inter-rater reliability or objectivity is defined as examining the consistency of two or more different test administrators to illustrate uniformity among data collection procedures (Matthews and Kostelis, 2011). For example, testers 1, 2 and 3 all test subject 1's range of motion. Inter-rater reliability would be when tester 1, 2 and 3 all compare their measurements and how closely they are related. Intra-rater reliability is comparing a single tester's ability to recreate the same measurement. For example, Tester 1 measures subject 1's range of motion on Monday and then again on Tuesday but then compares the measurement to see how close he was day after day. Establishing intra-rater and inter-rater reliability are both important in improving the precision of measurements.

Multiple studies have found good to excellent reliability for an inclinometer when it's compared to a standard goniometer. Cools, Wilde, Van Tongel, Ceyssens, Ryckewaert and

Cambier, (2014) determined both intra- rater and inter-rater reliability for measuring shoulder internal and external rotation. Kolber, Fuller, Marshall, Wright, and Hanney (2012) determined good intra-rater and inter-rater reliability for measuring shoulder scaption motion.

However, there have been reports of poor inter-rater reliability for shoulder range of motion for patients with shoulder pain by de Winter et al. (2004).

There have also been new advancements to the "new age" inclinometers. With the recent updates in technologies, there have been smart phone applications created to provide easy range of motion measurements at any clinician's fingertips.

Werner, Holzgrefe, Griffin, Lyons, Cosgrove, Hart, Brockmeier (2014) determined excellent inter-rater reliability for shoulder range of motion with average intra-rater reliability for a smartphone application. Han Shin, Hyun Ro, Lee, Han Oh, Kim (2012) found good inter-rater reliability for various shoulder motions with the exception of the goniometer measurement of internal rotation. These authors found excellent intra-rater reliability. Kolber, Pizzini, Robinson, Yanez, and Hanney (2013) determined good intra- and inter-rater reliability when using a smartphone app for measuring spinal motions.

With such strong reliability established for smartphone inclinometer applications, it is necessary to prove validity for those tools so they can be used in the clinical setting. Within the study performed by Kolber, Pizzini, Robinson, Yanez, and Hanney (2013), validity was established for using an iPhone 4 with the application iHandy level (iHandySoft, Inc, New York, New York) to measure spinal movements. Charlton et al. (2014), reported inferior validity in measuring hip range of motion for the smartphone application, Hip ROM Tester which was designed by a co-author of the study, when compared to an inclinometer. Werner, Holzgrefe, Griffin, Lyons, Cosgrove, Hart, Brockmeier (2014) is the only study involved in this literature search which established validity for a smartphone application to measure shoulder range of motion. The application used in this study was Clinometer (Plaincode Software Solutions). This study utilized a fellowship-trainer orthopedic surgeon, an orthopedic sports medicine fellow, an orthopedic resident physician, an orthopedic physician assistant and one medical student to create a cross section of health care providers who acted as examiners. The subjects were measured in the shoulder motions of abduction, forward flexion, external rotation with the arm at patient's side, external rotation with the arm abducted at 90 degrees, and internal rotation with the arm abducted at 90 degrees. Abduction and forward flexion were measured in the standing position with all other measurements occurring in the supine position. All examiners measured the subject with visual estimation, a standard goniometer and the Clinometer smartphone application.

This lead to the formulation of the question, is the Clinometer smartphone application valid for measuring shoulder range of motion in a more clinical based shoulder range of motion protocol with certified athletic trainers as the examiners?

Research Methodology

Participants

The participants for this study were the members of a division III baseball team, aged 18-22. To be included in the study, participants need to be considered a member of the baseball team, any position, during the non-traditional, fall season. The projected number of participants is 40. This group was selected due to baseball players having a high occurrence of upper extremity injuries that require shoulder range of motion evaluation. Tester 1 will be a certified athletic trainer and strength and conditioning specialist with over 15 years' experience. Tester 2 will be a certified athletic trainer with one year experience.

Instruments

For the testing process, two instruments will be utilized. Measurements will be taken using a standard, plastic handheld goniometer with one degree markings (figure 1, all figures can be found in appendix A~~B~~). For inclinometer measurements, a smartphone application "Clinometer" (Plaincode Software Solutions, Stephansirchen, Germany) will be used with an activity band to attach the inclinometer to the subject. (figure 2) Goniometer internal rotation, goniometer external rotation, inclinometer smartphone application internal rotation, inclinometer smartphone application external rotation results will be recorded by Tester 2 and inputted into an excel document once the end feel of the range of motion is determined by Tester 1.

Procedures for Data Collection

Participants will be asked to schedule a 10 minute appointment time, using Google Calendar, which fits into their daily class schedule. The order of the testing positions, (goniometer internal rotation, goniometer external rotation, inclinometer smartphone application internal rotation, inclinometer smartphone application external rotation) will be randomly assigned before the subjects arrive at the testing site.

Upon arrival to the testing site, all sweatshirts, long sleeve shirts, watches, bracelets will be removed from the subjects so all anatomical landmarks can be visualized. The patients' styloid processes of both the ulna and the radius will be marked as reference points (figure 3). The olecranon process will be exposed for easy alignment with the goniometer. The inclinometer smartphone application will be calibrated using the floor and the testing table leg to create a 90 degree angle. The iPhone volume will be silenced before each participant to ensure that the tester is blinded to the results of the inclinometer smartphone application.

The patients will be asked to lay supine and their shoulder placed at ninety degrees of shoulder abduction and ninety degrees of elbow flexion. A towel roll will be placed under the proximal humerus to maintain alignment of the humerus to the midline of the subject's torso during testing (figure 4).

For inclinometer measurement, the activity band and inclinometer app will be placed onto the radial aspect of the forearm out of view of the tester, just distal to the radial styloid marker (figure 5). The goniometer will be placed on the ulnar aspect of the forearm and use the olecranon process as the axis of motion, the ulnar styloid process as the point of reference for the movable arm, and perpendicular to the floor will be used as the reference point for the stationary arm (figure 6). Patients will be instructed to relax and a passive movement will be initiated by the tester. Stabilization of the scapula will be applied for both internal rotation and external rotation.

All end feels for internal rotation and external rotation will be determined by Tester 1, Tester 2, will apply stabilization of the scapula for all measurements.

The right side will be completed first for each subject. The end feel for the range of motion will be determined by the Tester 1. Tester 2 will act as the stabilizing clinician who will also document the inclinometer measurement. Tester 1 will verbalize the goniometer measurement. Tester 1 will be blinded to the inclinometer results. All together each arm will be measured twice for internal rotation and external rotation, once with the goniometer and once with the inclinometer smartphone application. After the right side is completed, the same process will be completed for the left side

Statistical Analysis

Descriptive statistics were used to determine the mean and the standard deviation for both the goniometer and the inclinometer smartphone application. When comparing the "gold standard" goniometer to the inclinometer smartphone application, a Pearson Correlation was used to determine the comparison in range of motion. An alpha level of 0.01 was used.

Limitations

Limitations to this study are the relatively small sample size of subjects and the activity band was not fitted to the iPhone in use. The activity band used in this study was constructed for a broad range of smartphone models, which created a lose fit for the iPhone. This lose fit could create a small deviation from subject to subject which could cause a small degree of difference in measurement of range of motion angles.

Ethical Consideration

The Institution Review Board at Otterbein University approved the protocol for this study. All individually identifiable factors for subjects will be removed and patients will be randomly assigned a number.

Results

After completion of the outlined methods, it was determined that allowing for two separate measurements of both internal and external range of motion, could create inaccurate results. This method created a stretch and re-stretch method which could have produced skewed data.

A second round of data collection was completed during the final weeks of the non-traditional, fall season with the same set of subjects. The same procedures were followed with the exception of measuring internal rotation and external rotation with both the smartphone application in the activity band and the goniometer at the same time (figure7). Internal rotation and external rotation order was randomized. All together for the second round of date collection, there was only one internal rotation measurement and one external rotation measurement.

There were 24 male subjects who were measured on both arms and 1 subject who was only measured on his right arm due to a left upper extremity injury. A total of 49 arms were used in this study. All subjects were members of a division III collegiate baseball team, aged 18-23.

Inclinometer Smartphone Application and goniometric measurements

Goniometer internal rotation had a mean of 62.204 ± 11.936. Goniometer external rotation had a mean of 120.837 ± 10.584. The inclinometer smartphone application internal rotation had a mean of 67.388 ± 12.563. Inclinometer smartphone application external rotation had a mean of 123.224 ± 12.687.

Internal rotation had a correlation coefficient 0.959. External rotation had a correlation coefficient of 0.940. Results can be found in Table 1 (all tables can be found in appendix B~~A~~).

Intra-rater reliability

To determine intra-rater reliability, a Pearson Correlation was used.

Goniometer Internal Rotation. The Pearson Correlation coefficient was 0.711.

Goniometer External Rotation. The Pearson Correlation coefficient was 0.804.

Inclinometer Smartphone Application Internal Rotation. The Pearson Correlation coefficient was 0.800.

Inclinometer Smartphone Application External Rotation. The Pearson Correlation coefficient was 0.838. Results can be found in Table 2.

Discussion

Due to the very strong validation relationship established with the smartphone application, Clinometer, as well as the increased reliability, the app was proven to be a more relevant clinical tool for determining internal rotation, external rotation and total arc of motion at the glenohumeral joint. The application is extremely easy to use and does not need much exposure to learn how to use. The multiple settings that the application offers, increases the clinical value to the device. With the volume on the smartphone turned on, the application is able to verbalize the end range of motion number which allows for the clinician to only focus of determining the end feel of the range of motion.

When comparing the current study to the study completed by Werner et al, in 2014, the main difference was in the testers and their training. The current study used certified athletic trainers instead of fellowship trainer orthopedic surgeons. The certified athletic trainer serves as a more applicable healthcare professional to be measuring range of motion as a preventative measure. The certified athletic trainer has more experience in measuring range of motion on a daily basis as well as in determining the appropriate end feel of a joint.

A second comparison in the studies would be the actually data collection techniques in terms of the smartphone application. In the Werner et al., study there were no clear anatomical landmarks used to place the app on the subject. In the current study, the radial styloid, the ulnar styloid and the olecranon process were used in all measurements. This allows for a more replicable method to using the application.

Overall, certified athletic trainers now have a reliable device to measure shoulder range of motion and to determine the presence of glenohumeral internal rotation deficit. Due to the effect that GIRD has on the shoulder, it is increasingly more important to determine any deficits in range of motion. All of the possible injuries that have been recorded in the literature that are linked to GIRD, have a recovery time that is between six months and a year. This puts an increased importance to determining if GIRD is present in the overhead throwing athlete.

Wilk et al. documented that a change of greater than 5 degrees in the total arc of motion, significantly increases the chances for upper extremity injury. This small difference between the throwing arm and the non-throwing arm requires increased precision in determining the internal rotation and external rotation range of motion at the glenohumeral joint. The Clinometer application provides that precision and accuracy.

The reliability that was determined in the study proves that the new age, Clinometer smartphone application to have a higher intra-rater reliability when compared to the “gold standard” goniometer. This leads to the belief that the Clinometer application is a new device that athletic trainers can put into clinical practice when measuring shoulder internal rotation, external rotation, and total arc of motion.

With the increased reliability and the established strong reliability, there needs to be future research conducted with the use of the Clinometer smartphone application and it’s ability to determine other joints range of motions.

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Appendix B~~A~~

Figures and Tables

Table 1. Pearson Correlations: Validity Relationship for the Inclinometer Smartphone Application

Range of Motion	Person Correlation Coefficient	Relationship
IR	.959	Very Strong
ER	.940	Very Strong

Table 2. Pearson Correlations: Intra-Rater Reliability Relationships for Inclinometer Smartphone Application and Goniometer for internal and external shoulder range of motion

Motion / Device	Person Correlation Coefficient	Relationship
IR / Goniometer	.711	Strong
IR / App	.800	Very Strong
ER / Goniometer	.804	Very Strong
ER / App	.838	Very Strong

Appendix A~~B~~

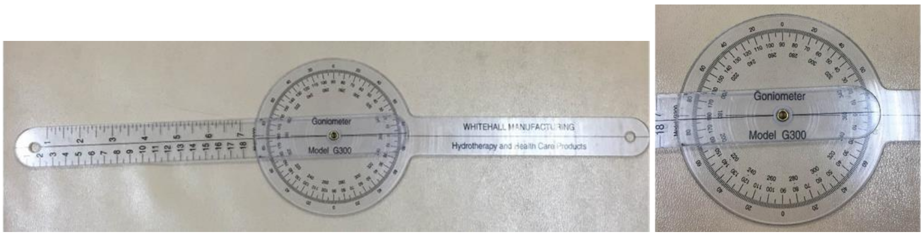

Figure 1. Standard plastic, hand-held goniometer with 1 degree markings

Figure 2. Smartphone application “Clinometer” and activity band

Figure 3. Anatomical landmarks used in measurements

Figure 4. Testing positions for internal and external shoulder rotation

Figure 5. Inclinometer app testing position

Figure 6. Goniometer testing position

Figure 7. Simultaneous measurement with inclinometer app and goniometer