Original Research

The Reliability and Validity of the ArmCare Strength and Range of Motion Sensor and Mobile Application in Baseball Players

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Background

Baseball players and coaches may not have the personnel resources to monitor the pathological declines in shoulder function throughout the season. The ArmCare Strength and Range of Motion Sensor and Mobile Application (ArmCare testing system) was designed to allow players to test and monitor their shoulder range of motion (ROM) and strength.

Purpose

To establish the reliability and concurrent validity of the ArmCare testing system for measuring ROM and strength in high school and college baseball players.

Study Design

Cross-sectional

Methods

Fifty-one baseball players self-tested their shoulder ROM and strength using the ArmCare testing system protocols and instructional video guidance. Participants repeated the testing following a 30-minute washout period and were blinded to their results. Intra-rater reliability measures were established by comparing ArmCare testing system scores between two same-day trials. Concurrent validity was assessed by comparing ArmCare testing system ROM and strength measures with standardized goniometric ROM and hand-held dynamometry measures performed by clinicians who were blinded to the results. Intraclass correlation coefficients (ICC) were used to assess the intra-rater reliability of the ArmCare self-testing system and Pearson correlation coefficients evaluated the concurrent validity among goniometric ROM and strength dynamometry.

Results

Intra-rater reliability ranged from poor to moderate (0.19 to 0.67) for AROM and moderate to good (0.73 to 0.87) for strength measures. For validity, poor overall agreement (ICC = 0.17 to 0.37) and correlation (r = 0.23 to 0.47) was found between the ArmCare testing system and all shoulder AROM measures. The ArmCare testing system

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demonstrated moderate to good agreement (ICC = 0.72 to 0.79) and correlation (r range = 0.72 to 0.81) compared to dynamometry for all strength measures.

Conclusion

The ArmCare testing system may be a reasonable self-guided examination for high school and college baseball players to measure shoulder strength. However, ROM testing using the ArmCare testing system lacks consistency and accuracy warranting further investigation.

Level of evidence

Level 3

INTRODUCTION

Baseball players are constantly striving to improve their physical capacity by optimizing their shoulder range of motion (ROM) and strength to endure the strenuous schedule of the competitive season. The stresses placed on the shoulder after throwing can result in acute decline in ROM and strength immediately after throwing, which can take several days to recover.[1] Deficits in shoulder ROM and strength have been established as important intrinsic risk factors for injury[2-4] and may present as significant barriers to performance enhancement.[5,6]

Arm care exercise programs are designed to target important functional deficits by improving ROM, strength, and reducing soreness to enhance the durability of baseball players throughout the season. However, there is a paucity of prospective studies which have evaluated the effectiveness of arm care exercise programs in improving physical function or decreasing injury risk.[7,8] To date, the most robust prospective arm care exercise program research has been conducted in youth baseball player ages 9-11 years.[6] In this study, a nearly 50% reduction in medial elbow injuries and two mile per hour improvement in pitching velocity was experienced in players who completed a comprehensive program which included strength, ROM, balance, and movement exercises.[6] Although these results are promising, group-based arm care programs may not be specific enough to effectively manage all injury risk factors and could vary among different populations.[7] A more individualized approach to arm care programming may maximize performance enhancement benefits and lead to greater injury reduction efforts through better management of physical risk factors.

The ArmCare testing system which includes a strength and ROM sensor (ActivForce2 sensor, ActivBody Inc., San Diego, California, USA) and ArmCare mobile application (www.ArmCare.com, Crossover Symmetry LLC, Florida, USA) pairs with smartphones and tablets and allows baseball players to test and monitor their own shoulder ROM and strength using self-guided instructions. The ArmCare testing system (ActivForce2 sensor and ArmCare application) includes specific testing procedures and video guidance to allow baseball players to independently monitor their shoulder function. Baseball coaches desire a greater responsibility in injury prevention and agree that the players should have a large role in managing their individual arm health, instead of relying on parents or medical profes-

sionals.[9] However, high school and college coaches may not have the personnel resources to monitor the alterations in shoulder strength and ROM which occur during the baseball season.[10,11] The ArmCare testing system could allow for frequent monitoring of ROM and strength throughout the season and better inform individualized arm care exercises to decrease these functional declines and improve performance capacity. However, the reliability and concurrent validity of the ArmCare testing system used to measure shoulder ROM and strength is unknown.

This study aimed to establish the reliability and concurrent validity of the ArmCare testing system for measuring ROM and strength in high school and college baseball players. It was hypothesized that the ArmCare testing system would demonstrate "good" intra-rater reliability with intraclass correlation coefficient (ICC) values > 0.75 when self-administered by baseball players. It was hypothesized that there would be at least "moderate" agreement and correlation exceeding ICCs and Pearson correlation values of 0.50 between shoulder ROM and strength measures using the ArmCare testing system and shoulder ROM and strength measures taken by a physical therapist using a goniometer and dynamometer, respectively.

MATERIALS AND METHODS

STUDY DESIGN

A cross-sectional design was used to establish the intra-rater reliability and concurrent validity of the ArmCare testing system to measure shoulder ROM and strength among a cohort of high school and college baseball players. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement guidelines for a cross-sectional study design were used for quality reporting.

PARTICIPANTS

A minimum sample size of 46 participants was needed to achieve a Pearson's product-moment correlation coefficient (*r*) of 0.40 with an alpha of 0.05 and 80% power for a two-tailed test. Anticipating 10% of the participants enrolled may have incomplete data, the final planned minimum target sample size was 50 participants. A convenience sample of 51 male high school and college-level baseball players between the ages of 14 and 23 were invited to enroll in the

study. Participants were excluded from study enrollment for upper extremity amputations, lack of medical clearance for participation due to a musculoskeletal injury or any other reason, recent shoulder or elbow surgery within the prior six months, or inability to read or understand English. Written informed consent and/or assent forms were obtained from all participants prior to data collection. The methodology and ethical integrity of this study was approved by the institutional review board at the University of Evansville.

PROCEDURES

Data collection occurred over an eight-week period during pre-season workouts prior to the start of the high school and college seasons. Participants completed a demographic questionnaire regarding their age, height, weight, playing position, arm dominance, medical history, and current arm health and function. To minimize the training effect, participants were randomly allocated to begin the physical testing with either the ArmCare testing system or shoulder ROM and strength measures taken by a physical therapist (PT). Prior to testing, all participants completed a standardized shoulder warm-up protocol, which included six exercises performed for one set of eight repetitions each. This warm-up was intended to elevate muscle temperature, enhance flexibility, and minimize any learning effects or muscle activation inconsistencies prior to data collection.

ARMCARE ASSESSMENT SYSTEM

The ArmCare testing system consists of the ActivForce2 dynamometer that pairs with the ArmCare.com software which is compatible with smartphones and tablets and allows players to test and monitor their arm health. Each participant applied the ArmCare strength and ROM sensor to their distal forearm using the included wrist strap. The ArmCare testing system uses video-guided instructions which allows athletes to self-test their shoulder ROM in degrees and strength in kilograms. (Figure 1)

1. Shoulder Internal Rotation (IR) ROM (Figure 1a) – The participant assumes a half kneeling position with the opposite knee up relative to the arm being tested, both feet pointed straight ahead, and the back toes pressing into the ground. The participant places his shoulder in 90° of abduction with the forearm parallel to the floor and the elbow contacting the wall so it is aligned with the shoulder. With eyes closed and palm open, the participant actively internally rotates his shoulder by bringing the palm toward the ground without excessive anterior tilting of the scapula. The participant presses anywhere on the screen interface to stop the test and record the shoulder position value in degrees.

2. Shoulder External Rotation (ER) ROM (Figure 1b) – The participant assumes a half kneeling position with the opposite knee up relative to the arm being tested, both feet pointed straight ahead, and the back toes pressing into the ground. The participant places his shoulder in 90° of abduction with the forearm parallel to the floor and the elbow contacting the wall so it is aligned with the shoulder. With eyes closed and palm open, the participant actively externally rotates his shoulder by bringing the palm toward the ceiling without arching the back. The participant presses anywhere on the screen interface to stop the test and record the shoulder position value in degrees.

3. Shoulder Flexion ROM (Figure 1c) – The participant assumes a half kneeling position with the opposite knee up relative to the arm being tested, both feet pointed straight ahead, and the back toes pressing into the ground. The participant places his shoulder in 90° of flexion with the outside of the shoulder and arm contacting the wall and the thumb up. With eyes closed and palm open, the participant actively flexes his shoulder overhead without arching the back. The participant presses anywhere on the screen interface to stop the test and record the shoulder position value in degrees.

4. Shoulder IR Strength Test (Figure 1d) – The participant lies on his back with his legs straight and the shoulder being tested slightly elevated off the ground by supporting the humerus with a small foam roll. The participant's arm is positioned in 90° shoulder abduction and 90° elbow flexion with his armpit firmly contacting a corner of a hard, immovable surface such as a wall. The participant performs a maximal isometric contraction of his internal rotators by pushing his forearm into the wall with a closed fist for five seconds. Strength values are recorded in kilograms.

5. Shoulder ER Strength Test (Figure 1e) – The participant lies on his back with his legs straight and the shoulder being tested slightly elevated off the ground by supporting the humerus with a small foam roll. The participant's arm is positioned in 90° shoulder abduction and 90° elbow flexion with his acromion and forearm contacting the wall. The participant performs a maximal isometric contraction of his external rotators by pushing his forearm into the wall with a closed fist for five seconds. Strength values are recorded in kilograms.

6. Shoulder Scaption Strength Test (Figure 1f) – The participant lies on his back with his legs straight and the shoulder being tested positioned in 45° of scapular plane elevation and elbow straight with his acromion and forearm contacting the wall. The participant performs a maximal isometric contraction of his shoulder flexors by pushing his forearm into the wall with a closed fist for five seconds. Strength values are recorded in kilograms.

RELIABILITY OF THE ARMCARE TESTING SYSTEM

Each participant had access to the ArmCare mobile application via a tablet (IPadOS, 15.6.1, 9th generation). The participants attached the ActivForce2 sensor which contains an inertial measurement unit around their wrist and performed the testing independently as directed by the video guidance on the ArmCare application. All ROM and
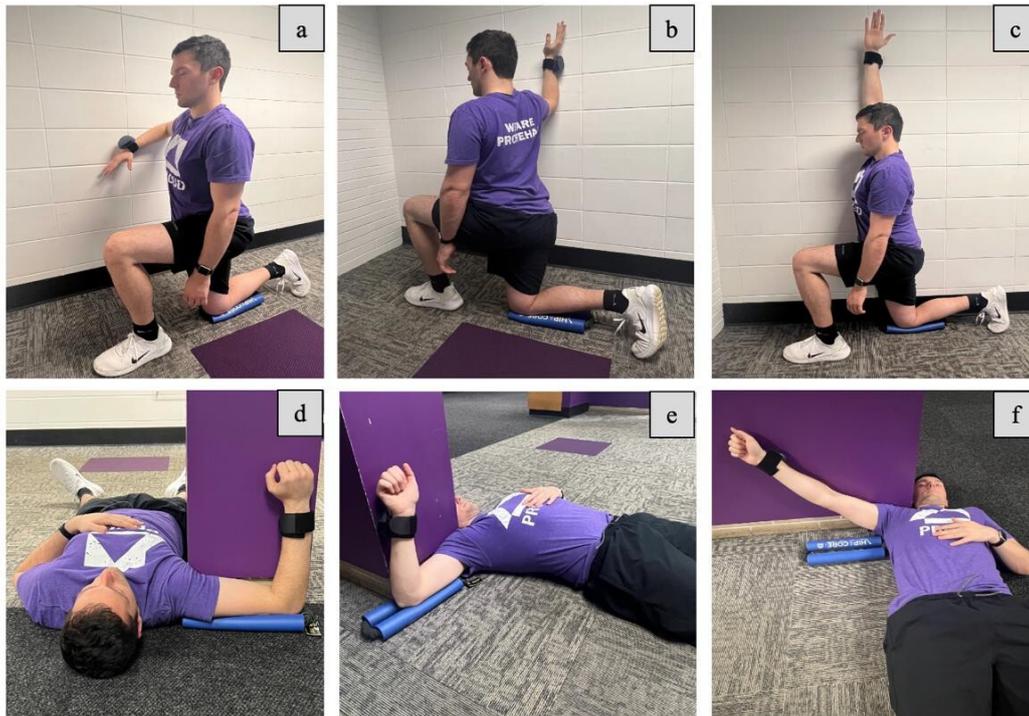
Figure 1. ArmCare testing system ROM and strength testing: (a) internal rotation ROM, (b) external rotation ROM, (c) shoulder flexion ROM, (d) internal rotation strength, (e) external rotation strength, and (f) scaption strength

strength measures were both automatically stored in the ArmCare application coach's portal and recorded on the data collection form. To establish intra-rater reliability, all participants self- tested themselves on the ArmCare testing system a second time following a 30-minute wash-out period within the same session. The participants repeated the testing as directed by the ArmCare application. All participants were blinded to their original scores. Two PTs (KM and PP), who were Certified ArmCare Specialists and had greater than 10 years of experience working in baseball, assisted with the device setup and observed the testing procedure. The observing therapists provided no coaching or testing procedure correction and were blinded to the results.

VALIDITY OF THE ARMCARE TESTING SYSTEM

To establish validity, the relationship between the ArmCare testing system ROM and strength measures protocols were compared to the criterion standard of goniometric ROM and muscle strength dynamometry measures of the same shoulder movements/strength testing. Three PTs with experience treating overhead athletes performed all ROM measures (MB and SS) and muscle strength dynamometry (JN). The test sequence was randomized to prevent order biasing, and the testers were blinded to the ArmCare testing system results. Intra-rater reliability of the evaluators performing the testing was established with ICCs for all ROM and strength measures in 10 male individuals preceding the data collection. (Appendix 1) Intra-rater reliability for active range of motion (AROM) (ICC $_{(3,*k*)}$ = 0.87-0.95) and strength (ICC $_{(3,*k*)}$ = 0.90-0.98) were "excellent" for all val-

ues based on a two-way mixed effects model using the averages of the measurements (k=3) and evaluating the consistency of rater agreement.

1. *Shoulder Active ROM:* Dominant and nondominant shoulder IR, ER, and flexion were measured on a treatment table with a standard goniometer using conventional procedures with established reliability.[12] Stabilization was provided at the scapula with the evaluator's thumb on the coracoid consistent with the protocol by Wilk et al.[13] When measuring AROM, the same PT always measured the shoulder motion with the goniometer. The average of three trials for each measurement was used for analysis.

2. *Shoulder Muscle Strength:* Dominant and nondominant shoulder IR, ER and scaption isometric strength was measured with a hand-held muscle dynamometer (Lafayette Instrument, Lafayette, IN, model# 01163).[14] Strength testing set-up and procedures between the ArmCare testing system and hand-held dynamometry were similar to improve consistency. To test the strength of the internal and external rotators, the participant was supine with legs extended with the upper extremity in 90° of shoulder abduction, 90° of elbow flexion, and forearm in contact with a wall. A folded towel was placed under the humerus to maintain the horizontal position of the shoulder. The tester placed the hand-held dynamometer against the wall positioned just proximal to the participant's wrist. The participant performed a maximal isometric contraction for five seconds in the direction of shoulder ER or IR until maximal force was obtained. Iso-

metric strength testing for scaption was performed in supine with the shoulder was positioned in 45° of abduction and the elbow extended. All strength measurements were recorded in kilograms and the average of three trials were used for analysis.

STATISTICAL ANALYSIS

Descriptive statistics were calculated including means, frequency counts and percentages, standard deviations (SD), and 95% confidence intervals for all measures. The intra-rater reliability of participants' ability to self-test their shoulder function with the ArmCare testing system was assessed with intraclass correlation coefficients ($ICC_{2*,1*}$) based on two-way mixed effects model using single rater and absolute rater agreement.[12] For concurrent validity, associations between ArmCare testing system recorded performances and shoulder goniometric ROM and muscle strength dynamometry values were evaluated parametrically using Pearson product moment correlation coefficient (r) and 95% confidence intervals. The Pearson coefficient quantifies the strength of monotonic association between strength dynamometry and goniometric ROM measures relative to the ArmCare testing system results. A coefficient of determination (R^2) was calculated to explore the proportion of variability between goniometric ROM and muscle strength dynamometry relative to the ArmCare testing system results, respectively. Additionally, intraclass correlation coefficients (ICC_{2*k*}) based on two-way mixed effects model using measure averages (k=2) and absolute agreement between the measures were examined. The incorporation of this statistical analysis is imperative as the goal of this research was not only examining the relationship but agreement since the measurements should be the same between devices, not just related. Pearson coefficients and ICCs were interpreted as: < 0.50 = poor, 0.50-0.74, = moderate, 0.75-0.90 = good, > 0.90 = excellent. All data analyses were performed with R for Mac OS 4.2.3 statistical software (RStudio for Mac, Version 2022.12.0+353). An alpha level of $p < 0.05$ was considered statistically significant for all tests.

RESULTS

Demographic information for all participants is provided in Table 1. Fifty-one high school and college level baseball players completed all testing procedures, and their data were used for analysis. The mean age ± SD of the participants in this sample was 18.9 ± 2.8 and ranged from 14 to 23 years old. All players were healthy and actively participating in pre-season training. A total of 25.5% (n=13/51) of participants reported currently experiencing arm soreness, 5.9% (n=3/51) reported current injury to their arm that did not limit their baseball participation.

ARMCARE TESTING SYSTEM INTRA-RATER RELIABILITY

Results for the intra-rater reliability (ICC, 95% CI) for both AROM and strength trials measured by the ArmCare testing system are presented in Table 2. Intra-rater reliability for

AROM ranged from "poor" to "moderate" agreement between trials. Shoulder IR AROM tests had the highest intra-rater reliability with ICC values that ranged from 0.67 (95% CI 0.48 to 0.79) to 0.65 (95% CI 0.46 to 0.78). The most inconsistent measure was dominant shoulder flexion AROM which demonstrated "poor" agreement (ICC 0.19, 95% CI -0.08 to 0.44, p = 0.08). The ICC values for strength were generally superior compared to the ROM metrics provided through the ArmCare testing system. Intra-rater ICC values ranged from "moderate" to "good" (ICC 0.73 to 0.87) agreement between both trials and were statistically significant for all strength measures. Dominant and nondominant shoulder scaption strength measures demonstrated the highest repeatability with ICC values of 0.85 (95% CI 0.68 to 0.92, p < 0.001) and 0.87 (95% CI 0.66 to 0.94, p < 0.001), respectively.

ARMCARE TESTING SYSTEM ROM VALIDITY

ArmCare testing system and goniometric shoulder AROM measurements are presented in Table 3. For shoulder AROM, a statistically significant but "poor" correlation (r range = 0.45 to 0.47) was found between the ArmCare testing system and dominant and nondominant shoulder ER. All other shoulder AROM measures were poorly correlated (r range = 0.23 to 0.37) and not statistically significant. The coefficient of determination ranged from 0.05 to 0.22. When comparing the absolute agreement, ICCs ranged from 0.11 to 0.37, indicating "poor" agreement.

ARMCARE TESTING SYSTEM STRENGTH VALIDITY

The results for concurrent validity of the ArmCare testing system to evaluate shoulder strength measures are presented in Table 4. The ArmCare testing system demonstrated "moderate" to "good" correlation coefficients compared to the Lafayette hand-held strength dynamometer which were statistically significant and ranged from 0.72 (95% CI 0.56 to 0.83) to 0.81(95% CI 0.69 to 0.89). The ICCs demonstrated "moderate" to "good" agreement and ranged from 0.72 (0.56 to 0.83) to 0.79 (0.61 to 0.88) for all strength measures. Except for dominant shoulder ER strength (R^2=0.52), all strength measures achieved a coefficient of determination greater than 0.60 suggesting that 60% of the variability in strength is explained by the ArmCare testing system.

DISCUSSION

The ArmCare testing system consists of the ActivForce2 sensor and ArmCare.com mobile application software which provides self-guided testing instructions for the athlete. The approach is designed to provide a method for baseball players to independently measure and monitor their shoulder ROM and strength without dependence on a trained rehabilitation professional or coach. Acceptable reliability is a prerequisite for adoption of the ArmCare testing system within the baseball community. The overarching aim of this study was to establish the reliability and con-

Table 1. Descriptive Characteristics of Baseball Players

Variables	High School (n=19)	College (n=32)	All (n=51)
Age, y	15.8 ± 1.1	20.7 ± 1.6	18.9 ± 2.8
Height, cm	180.5 ± 5.3	186.1 ± 5.4	184.0 ± 6.0
Weight, kg	75.8 ± 11.2	90.6 ± 9.2	85.1 ± 12.2
Dominant arm, n (%)			
Right	18 (94.7)	24 (75.0)	42 (82.4)
Left	19 (5.3)	8 (25.0)	9 (17.6)
Years of Baseball Experience	11.1 ± 1.7	15.5 ± 2.4	14.1 ± 3.2
Primary Position, n (%)			
Pitcher	4 (21.1)	18 (56.2)	22 (43.1)
Catcher	3 (15.8)	2 (6.3)	5 (9.8)
Infield Player	5 (26.3)	4 (12.5)	9 (17.7)
Outfield Player	7 (36.8)	8 (25.0)	15 (29.4)
Current Arm Injury, n (%)			
Yes	3 (15.8)	0 (0.0)	3 (5.9)
No	16 (84.2)	32 (100)	48 (94.1)
Current Arm Soreness, n (%)			
Yes	2 (10.5)	11 (34.4)	13 (25.5)
No	17 (89.5)	21 (65.6)	38 (74.5)

*y = years, KJOC = Kerlan-Jobe Orthopaedic Clinic

Table 2. Intra-Rater Reliability of the ArmCare Testing System

ArmCare Testing System Trial 1 vs. Trial 2			
Shoulder Active Range of Motion	Intraclass Correlation Coefficient (ICC)	95% Confidence Interval	p- value
Dom Shoulder IR AROM	0.67	0.48 to 0.79	< 0.001**
NonDom Shoulder IR AROM	0.65	0.46 to 0.78	< 0.001**
Dom Shoulder ER AROM	0.41	0.15 to 0.61	0.002**
NonDom Shoulder ER AROM	0.39	0.13 to 0.60	0.002**
Dom Shoulder Flexion AROM	0.19	-0.08 to 0.44	0.080
NonDom Shoulder Flexion AROM	0.63	0.43 to 0.77	< 0.001**
Shoulder Strength			
Dom Shoulder IR Strength	0.76	0.50 to 0.88	< 0.001**
NonDom Shoulder IR Strength	0.73	0.51 to 0.84	< 0.001**
Dom Shoulder ER Strength	0.78	0.61 to 0.87	< 0.001**
NonDom Shoulder ER Strength	0.79	0.62 to 0.88	< 0.001**
Dom Shoulder Scaption Strength	0.85	0.68 to 0.92	< 0.001**
NonDom Shoulder Scaption Strength	0.87	0.66 to 0.94	< 0.001**

Dom = Dominant arm, NonDom = Nondominant arm, IR = internal rotation, ER = external rotation
** Indicates a statistically significant association

current validity of the ArmCare testing system for measuring ROM and strength in high school and college baseball players. The findings from this study partially support the primary hypothesis that the ArmCare testing system can be reliably administered by baseball players to self-test shoulder ROM and strength. The AROM measures generated by the ArmCare testing system were inconsistent with ICC values ranging from 0.19 to 0.67 suggesting "poor" to "moderate" intra-reliability between trials. Conversely, all strength measures obtained by the ArmCare testing system exhibited "moderate" to "good" intra-rater reliability with ICC values ranging from 0.73 to 0.87 between both same-day testing trials. These results suggest that the ArmCare testing system demonstrates acceptable reliability for baseball players to self-test shoulder strength, but not ROM.

Shoulder ROM deficits and asymmetries have been well documented in baseball players within the literature.[3,15,16] For example, it has been found that baseball pitchers tend

Table 3. Range of Motion Concurrent Validity

Goniometric Range of Motion (degrees)	ArmCare Testing System AROM Measures (degrees)			
	ICC (95% CI)	r coefficient (95% CI)	R^2	p- value
Dom Shoulder IR AROM	0.23 (-0.03 to 0.46)	0.37 (0.01 to 0.58)	0.14	0.05
NonDom Shoulder IR AROM	0.11 (-0.08 to 0.32)	0.23 (-0.05 to 0.47)	0.05	0.15
Dom Shoulder ER AROM	0.37 (0.08 to 0.59)	0.45 (0.19 to 0.64)	0.20	0.007**
NonDom Shoulder ER AROM	0.35 (0.07 to 0.60)	0.47 (0.22 to 0.66)	0.22	0.02**
Dom Shoulder Flexion AROM	0.18 (-0.08 to 0.43)	0.34 (0.07 to 0.56)	0.11	0.10
NonDom Shoulder Flexion AROM	0.17 (-0.08 to 0.42)	0.35 (0.08 to 0.57)	0.12	0.10

Dom = Dominant arm, NonDom = Nondominant arm, IR = internal rotation, ER = external rotation, AROM = active range of motion, CI = confidence interval
** Indicates a statistically significant association

Table 4. Muscle Strength Concurrent Validity

Muscle Strength Dynamometry (kg)	ArmCare Testing System Strength Measures (kg)			
	ICC (95% CI)	r coefficient (95% CI)	(R^2)	p- value
Dom Shoulder IR	0.76 (0.62 to 0.86)	0.77 (0.63 to 0.86)	0.60	<0.001**
NonDom Shoulder IR	0.79 (0.61 to 0.88)	0.81 (0.69 to 0.89)	0.66	<0.001**
Dom Shoulder ER	0.72 (0.56 to 0.83)	0.72 (0.56 to 0.83)	0.52	<0.001**
NonDom Shoulder ER	0.76 (0.60 to 0.86)	0.78 (0.64 to 0.87)	0.61	<0.001**
Dom Shoulder Scaption	0.77 (0.63 to 0.87)	0.79 (0.65 to 0.87)	0.62	<0.001**
NonDom Shoulder Scaption	0.77 (0.63 to 0.86)	0.78 (0.64 to 0.87)	0.60	<0.001**

* Dom = Dominant arm, NonDom = Nondominant arm, IR = internal rotation, ER = external rotation, ICC = intraclass correlation coefficient, r = Pearson correlation coefficient, CI = confidence interval
** Indicates a statistically significant association

to lose shoulder ROM due to rigors of the competitive season.[1,11,17] These ROM deficits and asymmetries can be associated with an elevated risk for future musculoskeletal injury.[15,18,19] Therefore, accurate monitoring of function is needed for proper management and mitigation of injury risk.[2] Cadogan et al.[20] reported high levels of intra-rater reliability among physical therapists (ICC 0.85 to 0.99) when measuring shoulder flexion, abduction, and external rotation ROM with a novel hand-held dynamometer. These findings differ from the current findings using the ArmCare testing system which demonstrated lower levels of intra-rater reliability among baseball players using the self-guided instructions of ArmCare mobile application software. This comparison suggests that the ArmCare testing system may not be a reliable monitoring system for ROM changes for baseball players compared to other devices and/or completion by healthcare professionals. The players' limited knowledge of testing procedures, awareness of set up position, and potential compensations may have resulted in lower ICC values for ROM using the ArmCare testing system.

The identification of strength deficits is advantageous for the baseball athlete as research has shown that poor shoulder strength is associated with time loss injury.[4] Additionally, shoulder strength has been shown to decline immediately following throwing in a single throwing session[1] and throughout the season.[21,22] Previous research explor-

ing the reliability of hand-held dynamometry has reported greater ICC values ranging from 0.82 to 0.99 when testing shoulder strength in healthy overhead athletes.[23] Karagiannopoulos et al.[24] reported that novice testers demonstrated "excellent" intra-rater reliability for shoulder forward elevation, ER, and IR strength with ICC values of 0.95, 0.97, and 0.98, respectively, with the ActivForce2 hand-held dynamometer. However, in the previously referenced studies the examiner administering the strength testing was a trained healthcare provider or physical therapy student. To the authors' knowledge, this is the first study to explore the reliability of a hand-held dynamometer to measure strength following guidance that is entirely self-administered by a baseball player. The players' limited knowledge of testing procedures, awareness of set up position, and potential compensations may have resulted in lower ICC strength values (0.73 to 0.87) when using the ArmCare Assessment.

The findings from this study partially support the secondary hypothesis that the ArmCare testing system ROM and strength measures will demonstrate "moderate" concurrent validity when compared to standard goniometry and dynamometry measures collected by a physical therapist. In the current study, the correlations and agreement between shoulder goniometry and the ArmCare testing system ROM measures were small. For shoulder ROM, Pearson correlations coefficients ranged from 0.34 to 0.47 suggest-

ing a "poor" correlation for all shoulder measures. For absolute agreement, ICCs ranged from 0.17 to 0.37 indicating "poor" relationship which may indicate that the ArmCare testing system ROM measure may not relate to goniometric measurement of ROM. However, strength measurements from by the ArmCare testing system exhibited a "moderate" to "good" correlation and agreement to hand-held dynamometry measures in all shoulder positions.

Quantifying shoulder ROM and strength in a field expedient and accurate manner is relevant for baseball coaches and players. Tyler et al,[4] reported that high school baseball players with preseason shoulder weakness were at more than four times (RR, 4.58; 95% CI, 1.40-15.01; p = 0.02) greater risk for injury. Investigation of the concurrent validity of the ArmCare testing system in comparison to a criterion-standard dynamometer on shoulder muscle force production is consistent with previous research.[25] In the current study, the criterion-standard device was a hand-held dynamometer, which has been validated in a systematic review and meta-analysis as highly correlated to isokinetic strength testing of the shoulder rotator cuff muscles.[14] The results of the current study confirmed that the ArmCare testing system strongly correlates (r = 0.72 to 0.81) with measurements taken using the Lafayette dynamometer when testing shoulder ER, IR, and scaption strength. Although these results are slightly lower compared with previously reported dynamometry validation studies, these correlations are meaningful for a self-guided field expedient testing tool performed by non-healthcare professionals.

The ArmCare testing system allows baseball players to reliably monitor their own shoulder strength, which will aid in tracking shoulder function and performance throughout the season. With the ArmCare strength testing, baseball coaches can obtain regular shoulder strength updates which can inform customized arm care programming to improve strength imbalances and deficits specific to the individual player and scale workloads and pitch counts without the need for additional personnel or compromising sport specific practice obligations. Future research should explore if the accuracy of ROM measures generated by the ArmCare testing system are improved with the aid of a coach or rehab professional providing visual observation and verbal instruction to minimize compensation during the ROM procedures.

LIMITATIONS

Some limitations of this study should be noted. First, the position of the arm for AROM measurements for the ArmCare testing system was in the half kneeling position while the AROM goniometry was in the traditional supine position. These changes in postural positioning may have contributed to the differences in the two measurements, which, in turn, may have impacted the validity. The reliability findings would not be influenced since reliability was performed in the same positions. Second, the participant's effort between trials for the ArmCare testing system may have been inconsistent during repeated administration of testing. Although all participants were encouraged to provide their best efforts when performing the tests, additional verbal encouragement was not performed beyond the instruction on the ArmCare mobile application. Since the ArmCare testing system was designed for players to independently measure their own shoulder function, the absence of tester instruction and motivation was purposeful to simulate the conditions where testing would occur without the aid of healthcare professionals. Third, since the mobile application protocol requires the ActivForce2 dynamometer, the study is unable to determine if the low ROM validity was a result of the mechanical elements associated with the ActivForce2 dynamometer or the protocol itself that was created by ArmCare.com. Finally, only male high school and college baseball players were included to maximize homogeneity of the sample. Therefore, the results of this study are likely only generalizable to high school and college baseball players and not to other competition levels or athletes participating in other overhead sports.

CONCLUSION

The ArmCare testing system may be a reasonable self-guided examination for high school and college baseball players to independently measure shoulder strength. However, ROM testing using the ArmCare testing system lacks consistency and accuracy warranting further investigation before widespread implementation.

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