SHOULDER INTERNAL AND EXTERNAL ROTATION STRENGTH ASSESSMENT IN BASEBALL PITCHERS: NORMATIVE DATA AND RELIABILITY

ABSTRACT

Rotator cuff strength assessments are valuable for monitoring throwing athlete injury and performance status. Portable technology enables 'in-field' assessment and therefore increases utility. The purpose of this study was to quantify the reliability of strain gauge technology for measuring shoulder rotator strength and provide normative strength values for high school and college pitchers. Subjects (n=15) participated in three testing sessions consisting of five maximal isometric shoulder internal rotation (IR) and five external rotation (ER) trials separated by seven days. Variables of interest included peak force (Fmax), peak torque (Tmax), rate of force development (RFD) and rate of torque development (RTD). Coefficients of variation ranged from 4.3-5.8% for peak values, and 16.0-28.5% for rate measures. Intraclass correlation coefficient estimates ranged from .79-.89 for peak values, and .80-.91 for rate measures, with IR typically marginally better than ER. While practitioners need to be mindful of managing error (e.g., via familiarity), peak measures of rotator cuff strength assessed using portable strain gauge are promising for simple field-based monitoring of shoulder health for throwing athletes.

KEY WORDS: peak force; rate of force development; upper-body force output; throwing athlete; strain gauge.

INTRODUCTION

Throwing is an athletic skill used in many sports and activities such as baseball, softball, American football, javelin, among others. It is a total-body action that transmits forces generated from the ground through the legs and trunk via the arm to the implement in hand (5, 12, 26). Shoulder rotator cuff musculature funnels forces from the preceding kinetic chain, dynamically stabilizing the glenohumeral joint and subsequently decelerating the throwing arm (5, 26). Given their crucial role, means of measuring and monitoring the strength characteristics of the shoulder rotator cuff are of interest to researchers and practitioners of throwing sports performance and injury risk reduction.

In baseball, muscles responsible for shoulder internal rotation (IR) contribute to the throwing motion as the arm accelerates forward (5, 9, 23, 26). Overall rotator cuff weakness has been associated with ulnar collateral ligament repair (13). Specifically, preseason external rotation (ER) weakness has been linked to in-season throwing arm injuries (4). Given the elevated acute stress coupled with high throwing volumes, monitoring baseball pitchers' shoulder rotation strength seems important. Accurate, efficient rotator cuff strength assessments may provide valuable information on training status and fatigue. This information could be feasibly used to reduce injury frequency, maintain performance during the competitive season, and inform training during the offseason.

Maximal force production (e.g., Fmax) and the ability to produce force rapidly (e.g., rate of force development, RFD) are two core components of strength. Both are considered important qualities for injury prevention and optimizing pitching/throwing performance (17), and so measured, monitored and developed by strength and conditioning coaches. In terms of the rotator cuff, strength is usually measured with expensive laboratory equipment [i.e., isokinetic dynamometer, (6, 7, 15)] or portable hand-held dynamometry [HHD, (4, 8, 13, 22, 23, 27, 28)]; the latter is practical, given its ease of use, portability and cost. Assessments of IR and ER Fmax using HHD with pitchers have been found reliable (intraclass correlation coefficient, ICC estimate

= .89-.98) (4, 8, 13, 16, 22, 23). Coefficients of variation (CV) are also important for understanding the typical error of a measure, however, this measure seems under-reported in the literature. Reported Fmax values for pitchers from the high school (HS) to professional level range from 137-233 N for IR and 122-180 N for ER, resulting in ER:IR ratios ranging from 0.7-0.9 (8, 13, 16, 22, 23). Also, RFD is interesting to consider due to the extraordinary arm speeds observed while throwing (11). Devices such as HHD rarely provide useable measures of RFD due to low-sampling rates, and despite RFD potential interest for throwing athletes (4, 8, 13, 16, 22, 23) it remains under-measured in the field.

The length of an arm or forearm, or more generally a lever, is known to influence the torque or rotational forces that a limb produces (force multiplied by the perpendicular distance from axis of rotation). Practically, torque can influence throwing velocity as described by the work-energy relationship. Given this relationship, it may be advantageous for strength and conditioning coaches to monitor torque related measures, in favor of force. Shoulder peak torque (Tmax) and rate of torque development (RTD) can be estimated as the product of forearm length and Fmax and RFD, respectively (1, 25), and may provide better diagnostic information and insight into pitching velocity than force expression alone. This approach, utilized with youth baseball players (11.1 ± 1.2 years old), resulted in excellent reliability with HHD (ICC = .98-.99) and a positive relationship of Tmax (r^2 =.23, $p < .001$) to throwing velocity (1). Nonetheless, this approach has not been applied in more senior pitchers.

Considering the importance of shoulder IR and ER in pitching, along with the potential benefits of monitoring rotator cuff health, finding affordable, portable technologies for field use would be valuable. To adopt such an approach, it is critical to understand the variability of the measures (Fmax, Tmax, RFD and RTD) used to monitor the physiological status of the rotator cuff musculature. Previously shoulder rotator strength with this strain gauge was assessed with swimmers, and it was reported that ER force outputs were greatest in the supine position with the shoulder abducted to 90° (18). The greater ER force expression in this position was likely due to greater posterior deltoid recruitment, the likes of which is relevant for baseball pitchers during the throwing deceleration and follow through phases (5, 10).

With this in mind, the aim of this study was to establish the reliability of Fmax, Tmax, RFD and RTD using portable high sampling rate technology from a lying position with baseball pitchers (18).

METHODS

Experimental Approach to the Problem

A within-subjects repeated measures design was used to quantify inter-session reliability of maximal shoulder IR and ER kinetics. Participants completed multiple maximal isometric contractions over three testing occasions separated by seven days.

Subjects

Collegiate (n = 5) and HS (n = 10) male baseball players (age = 18.8 ± 2.0 years) participated in this study. Subjects were dressed in athletic attire and assessed at the local training facility. Anthropometrics (height = 182.7 ± 5.6 cm; body mass = 82.1 ± 8.1 kg; forearm length = 29.2 ± 1.7 cm) were measured prior to testing during the familiarization session. Forearm length was measured by tape as the distance between the olecranon process and ulnar styloid process. We performed an a priori sample size calculation for detecting an estimated ICC of .9 (i.e., for Fmax), and a lower acceptable bound of threshold of ICC = .6 (as a conservative representation of 'poor' reliability). 14 subjects were deemed sufficient, with 80% power and alpha = .05, with subsequent interpretation focusing on the interpretation of the confidence intervals (3, 29). Athletes were free of any injuries that would affect their participation. Written informed consent was collected from each participant or their caregiver before testing. Institutional review board approval was obtained from the Auckland University of Technology Ethics Committee (AUTEC 19/445).

Equipment

Force-time data were measured (1,000 Hz) using a custom designed, wireless single axis S-beam load-cell strain gauge (Hawkin TruStrength, Portland, Maine), that was zeroed between trials (see Figure 1). Earlier models of this device have been used in several studies to assess isometric force and shown to be valid compared to a gold standard (CV = 4.6-8.3%, ICC = .94-.98) (24). Trials in this study were completed via the compressive method and data were imported via Bluetooth for post-processing.

Insert Figure 1 here

Figure 1. Strain gauge capable of measuring compressive force at 1,000 Hz.

Procedures

Subjects attended three sessions, seven days apart, repeating quasi-identical protocols. The initial session familiarized participants with the assessment protocol and technology, with the latter two sessions used to determine reliability. Subjects followed a standardized, shoulder-focused warm-up preceding five 3-second maximum isometric contractions measuring throwing shoulder IR and ER strength. Thus, 10 total trials were performed and analyzed. Subjects were supine with the shoulder abducted to 90° (see Figure 2). The non-testing arm was relaxed with the hand placed on their stomach and the knees bent with feet flat on the floor. The elbow was elevated by a rolled towel placed on the floor, and the strain gauge was aligned with the subject's ulnar styloid process. The researcher initiated the trial with a 3-second countdown and verbalized "GO" and "RELAX" cues to start and complete data capture. Participants were encouraged to "rotate fast and hard" for three seconds.

Insert Figure 2

Figure 2. Dominant arm internal rotation test (top) and dominant arm external rotation test (bottom).

Raw, unfiltered force-time data were imported into MATLAB (version: 2019B, The MathWorks, Inc., MA USA), with trials screened and irregularities removed. Trial initiation was manually selected as the first point of increase from resting force pre-contraction, with Fmax and RFD identified as the instantaneous peak across the whole trial and the average force value over the 120-milliseconds following force onset, respectively (21). Tmax and RTD were calculated by multiplying the corresponding force outputs by forearm length (1, 25). These variables were identified for shoulder IR and ER and averaged for the final analysis. After exploring the noise profile of the strain gauge, we elected not to run a low pass filter so that we could observe any short duration, high frequency events throughout the testing protocol. Data were comprised of participants completing a familiarization, and two experimental sessions for intersession reliability.

Statistical Analysis

JASP (JASP Team 2023, version 0.17.1) was used for all statistical analyses. Means and standard deviations represented measures of centrality and spread of data. Differences between IR and ER were tested using a variety of paired sample t-test between the corresponding outcome variables. Test-retest reliability was quantified using percentage change in the mean (CIM), ICC estimate (3,1) and 95% confidence intervals (CI), and typical error as a CV between sessions. The CIM between sessions was also tested for statistical significance using additional paired t-tests. Typical error was considered acceptable with CV $\leq$ 10% (2), and ICCs representations of reliability as poor (<.50), moderate (.50-.74), good (.75-.89) and excellent (>.89) (20). We set the alpha level for statistical significance at $\alpha = .05$.

RESULTS

Test-retest reliability and descriptive data for IR and ER kinetics can be found in Table 1. Force and torque outputs were not different between ER and IR (p > .05). Ratios (ER:IR) were 0.93 for peak measures and 0.88 for rate measures. Peak force and torque CIMs did not differ between sessions (p > .05), with all CVs < 6.0% and ICC estimates > .75. The CI lower-bound tended to be moderate (ICC > .55), except for IR Fmax (ICC > .39). For rate dependent variables, CIMs ranged from 11.2-25.9%, CVs from 16.0-28.5% and ICC estimates > .79. The CI lower-bound indicated poor reliability for ER (ICC > .41) and moderate for IR (ICC > .71).

Insert Table 1

DISCUSSION

Rotator cuff strength assessments are useful for monitoring throwing performance and injury status, therefore assessment tools that are valid, reliable, of utility and are cost-effective, are important for implementation in practice. The main findings of this research were: 1) IR and ER Fmax/Tmax ranged between 198-218 N and 58-64 Nm respectively (ER:IR = 0.93); 2) IR and ER RFD/RTD ranged between 537-765 N/s and 157-223 Nm/s respectively (ER:IR = 0.88); 3) for peak values, typical error and ICC estimates were acceptable, and tended to be slightly better for IR versus ER; and, 4) while estimated ICCs for RFD/RTD were acceptable, typical error was unacceptable (CV > 10%).

The Fmax values reported in this study are comparable to those cited by other researchers for IR (137.4-232.5 N) and ER (122.3-179.5 N) which used similar protocols (8, 13, 16, 22, 23). It is difficult to compare the RFD/RTD as most research using portable technologies do not report these variables, most likely due to low-sampling frequencies (i.e., below the recommended 1,000 Hz (21)). Notably, regardless of variable, testing position can influence force generation (18); this coupled with varying technologies and data processing complicate definitive comparisons.

To our knowledge only one other study in youth baseball players (1) has calculated torque using a similar approach. Exact results were not reported, and given age differences, results are problematic to compare to our cohort. Since expressing IR and ER outputs as torques potentially provides additional insight into pitching velocity, the results of this study provide normative values. Given torque calculation is quite simple as illustrated in this study, it might provide an easy and practical means of adjusting strength values for variations in forearm length, and subsequently better diagnostic information for coaches and athletes.

Differences between ER and IR (9.6-43%, ER:IR = 0.68-0.91) are relatively common (8, 13, 16, 22, 23), and logical given throwing heavily relies on the shoulder IR musculature (14, 19, 23). However, differences between ER and IR were non-significant in this study (~7-12%; $p > .05$). The position used in this study resulted in higher ER force production, compared to testing at 0° of shoulder abduction, and may explain the higher ER:IR ratios (0.88-0.93). Notably, four participants in this study exhibited greater ER force production, which might suggest specific adaptations from targeted ER training with these athletes.

Fmax and Tmax did not clearly change across sessions (CIM < 3.0%, $p > .05$), with acceptable typical error (CV < 6.0%) and reliability (estimated ICC > .75) across both shoulder rotation assessments. Fmax reliability was consistent with previous findings (ICC = .93-.96) (8, 13, 16, 22, 23) albeit across different protocols and technologies. This could be a product of a relatively small and homogenous athlete sample (e.g., quite low between-subject variability), but since reporting reliability in this fashion is uncommon, it is difficult to compare this to other studies. Similarly, typical error is rarely reported by researchers; yet the low values observed render the practical utility promising.

With regards to RFD and RTD, there was a difference between sessions for ER (26%, $p < .05$), with no change for IR. The CIM may be a surprising product of the commonly reported variability associated with rate measures (21), or perhaps latent learning effects. Compared to ER, IR rate measures tended to be more reliable (estimated ICC > .80 versus .90, respectively) with lower error (CV% < 28.5 vs < 16%). Although ICC estimates were acceptable, 95% CI for IR was moderate where ER was poor (ICC < .43). Overall, the better reliability observed for IR compared to ER could be due to the different contractions and muscles associated with throwing demands. For example, shoulder ER musculature eccentrically contracts to decelerate the throwing arm (i.e. antagonist co-contraction). Conversely, IR while throwing is typically associated with concentric explosive muscle actions, which aim to maximize throwing velocity (i.e. agonist muscle activation). Typical error was deemed unacceptable (2), albeit better for IR (CV = 16.0%) versus ER (CV = 28.5%). The high variability associated with rate measures is well documented (21) and indicate the importance of considering strategies to reduce error (e.g., averaging over trials, rigorous familiarization) should the measures be used in practice. Due to mixed results, practitioners should be cautious using rate measures for monitoring shoulder rotation.

There are some limitations in this study that are worth mentioning. First, this study only included 15 participants, which were attained via an estimate of detecting reliability in maximum force measures. This small sample means our estimates for lower reliability were broad and reduces the transferability of our findings. Despite familiarization, underlying learning effects may have still been present throughout testing sessions. This could have impacted the reliability estimates, especially for participants who improved their performance over time. Finally, the assessment measured isometric strength and pitching or throwing is a dynamic action. Measuring concentric or eccentric strength could be valuable for these athletes, however, this may require more expensive and less portable equipment.

PRACTICAL APPLICATIONS

Measuring IR and ER strength can inform shoulder health (4, 13) and performance (1). Given the acceptable reliability for Fmax it would seem that this technology is a cost-effective option for practitioners to utilize in the field. Notably, the protocols were easily implemented and given the device portability. Practitioners could utilize such technology to measure shoulder rotation Fmax or Tmax, appreciating that rigorous standardization and familiarization of athletes is needed. The information can be used in a myriad of ways. For example, monitoring IR strength 48-hours post-game could inform recovery status between competitive appearances. Similarly, determining IR and ER force outputs and associated ratios could be used to guide return from injury, assist in training prescription and provide normative values to guide thresholds for training.

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CONFLICT OF INTEREST

John Cronin is an inventor and shareholder in the strain gauge technology used in this study. The results of the present study do not constitute endorsement of the product by authors or the NSCA.

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