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# Measuring Eccentric Strength of the Shoulder External Rotators Using a Handheld Dynamometer: Reliability and Validity

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***Context:*** Shoulder strength assessment plays an important role in the clinical examination of the shoulder region. Eccentric strength measurements are of special importance in guiding the clinician in injury prevention or return-to-play decisions after injury.

***Objective:*** To examine the absolute and relative reliability and validity of a standardized eccentric strength-measurement protocol for the glenohumeral external rotators.

***Design:*** Descriptive laboratory study.

***Setting:*** Testing environment at the Department of Rehabilitation Sciences and Physiotherapy of Ghent University, Belgium.

***Patients or Other Participants:*** Twenty-five healthy participants (9 men and 16 women) without any history of shoulder pain were tested by 2 independent assessors using a handheld dynamometer (HHD) and underwent an isokinetic testing procedure.

***Intervention(s):*** The clinical protocol used an HHD, a DynaPort accelerometer to measure acceleration and angular velocity of testing 30°/s over 90° of range of motion, and a Biodex dynamometer to measure isokinetic activity.

***Main Outcome Measure(s):*** Three eccentric strength measurements: (1) tester 1 with the HHD, (2) tester 2 with the HHD, and (3) Biodex isokinetic strength measurement.

***Results:*** The intratester reliability was excellent (0.879 and 0.858), whereas the intertester reliability was good, with an intraclass correlation coefficient between testers of 0.714. Pearson product moment correlation coefficients of 0.78 and 0.70 were noted between the HHD and the isokinetic data, showing good validity of this new procedure.

***Conclusions:*** Standardized eccentric rotator cuff strength can be tested and measured in the clinical setting with good-to-excellent reliability and validity using an HHD.

***Key Words:*** eccentric testing, upper extremity, injury prevention, rehabilitation

**Key Points**

- Using a handheld dynamometer, standardized eccentric rotator cuff strength can be measured in the clinical setting with good to excellent reliability and validity.
- The eccentric rotator cuff strength test provides important information that is useful for injury prevention, rehabilitation, and performance enhancement.

Shoulder injuries occur frequently in athletes performing overhead sports at different levels of competition.[1] Most shoulder injuries are believed to occur during the late phase of arm cocking, arm acceleration, and deceleration phase because large forces are produced. In particular, the external-rotator muscles are highly eccentrically loaded during the deceleration phase.[2] Extreme differences in strength between the agonist and antagonist muscle groups in the shoulder and a lack of eccentric muscle strength of the external rotators have been associated with the rate of injury in this joint.[3] Previous investigators have attempted to establish a "functional ratio"; that is, the relationship and interaction between the force produced in the shoulder external-rotator muscles eccentrically and the shoulder internal-rotator muscles concentrically.[4,5]

In specific sports, such as tennis, elite junior players without shoulder injury had shoulder-rotation muscle-strength imbalances that altered the ratios among rotator cuff muscles.[6] Although these differences did not seem to affect athletic performance, detection and prevention with exercise programs at an early age are recommended.[5] Therefore, general strength exercises are typically used for the internal and external rotators on both the nondominant and dominant sides, and functional exercises that improve eccentric rotation strength are used for the dominant throwing arm in injury-prevention programs.[7]

Because of the adaptations in rotator cuff strength (in particular, a strength imbalance between the eccentric external rotators and the concentric internal rotators), overhead athletes are possibly at risk for shoulder injury.[1] Objective measurement of rotator cuff strength in overhead athletes is important in order to take preventive action when needed but also to gain strength and improve performance.[8] Specifically, eccentric strength testing of the rotator cuff is a vital part of the clinical examination of the athlete's shoulder. The external rotators are of special importance for athletes because this muscle group works as a decelerator during the overhead throwing motion by resisting shoulder internal rotation and horizontal adduction.[9] In addition, eccentric strength testing of the rotator cuff might help the clinician when making decisions regarding return-to-play criteria after shoulder injury.[10] Therefore, the need to establish a reliable and valid protocol for eccentric testing is clear.

Numerous testing protocols have been described to examine isokinetic[6,7,11] and isometric[12] rotator cuff strength. With respect to the isometric strength measurements, handheld dynamometry has attracted more and more interest during the last few years because of its practical, cost, and user-friendly advantages over the more advanced and expensive isokinetic devices. Handheld dynamometry has demonstrated higher sensitivity and higher intraexaminer and interexaminer reliability than manual muscle testing in identifying strength deficits of the rotator cuff.[13] The handheld dynamometer (HHD) showed excellent reliability, with intraclass correlation coefficients (ICCs) ranging from 0.85 to 0.96 in both interrater and intrarater trials of shoulder-joint external and internal rotation in symptomatic participants.[14] In adolescents, the strength measurements were also valid and reliable, with ICCs ranging from 0.75 to 0.98.[12]

Testing eccentric muscle strength using an HHD has been explored in the lower extremity. Eccentric hip-adduction and -abduction strength of the dominant and nondominant legs was assessed using an eccentric break test with an HHD[15] and was reliable. However, to our knowledge no researchers have compared eccentric strength measurements between isokinetic and isometric instruments or examined the reliability of eccentric rotator cuff testing using the HHD.

Therefore, the primary aim of our study was to measure the reliability within testers and between-testers using the HHD in the clinical setting. The secondary aim was to measure the validity between the HHD and isokinetic dynamometer in an eccentric testing position for the glenohumeral external rotators.

## METHODS

### Participants

Twenty-five healthy volunteers (9 men and 16 women) gave their informed consent to participate in the study. Volunteers were excluded from the study if they had had a shoulder injury in the last 6 months, a history of neck pain, previous shoulder or neck surgery, or current symptoms related to the neck and shoulder area. Their mean age was 24.8 years (range, 19–34 years); mean height, 173.6 cm (range, 160–190 cm); and mean body weight, 64.3 kg (range, 48–84 kg). Estimated sample size was based on guidance from Walter et al,[16] who suggested that with 2 raters, a significance level of .05, and power of 80%, 19 samples were required to determine an ICC score of 0.7. All participants were physically active 1 to 2 hours per week and had no or little experience with HHD testing before the investigation. The study was approved by the Ethics Committee of Ghent University, and informed consent was obtained from all participants.

### Testers

The 2 testers were experienced and well trained in the field of shoulder assessment. In addition to their previous training, the examiners underwent specific extensive training with the HHD before the study: they performed shoulder testing isometrically and eccentrically on participants ranging from normally active people to elite overhead athletes.

### Testing Setup

The muscle testing was performed in the Department of Rehabilitation Sciences and Physiotherapy of Ghent University, Belgium. The testing setup included a portable HHD (CompuFET; Hoggan Health Industries, West Jordan, UT) with software program and a chair. Considerable research has addressed the reliability of measurements obtained with an HHD. A review article showed that 76% of evaluations had an ICC of 0.80 or above.[17] An accelerometer (DynaPort MiniMod; McRoberts BV, The Hague, the Netherlands) was used to measure acceleration and angular velocity triaxially and synchronously; for intrainstrumental and interinstrumental reproducibility, ICC = 0.99 in the x- and y-directions.[18] In another testing room, an isokinetic dynamometer (model 4; Biodex Medical Systems Inc, Shirley, NY) was used to perform isokinetic testing; high test-retest reliability, ranging from 0.82 to 0.97, was previously demonstrated for the internal- and external-rotator muscles.[19] Two assessors with clinical experience using the HHD and the isokinetic device performed all testing. The eccentric test with the HHD was performed in a seated position comparable with the testing on the isokinetic dynamometer. We chose the upright testing position for the HHD because of the applicability of this procedure for a wide variety of participants, including overhead athletes undergoing high-performance training or rehabilitation.

### Testing Procedures

The testing sequence of tester and HHD versus isokinetic dynamometer was randomized at the initial session; the sequence was maintained throughout the rest of the study. In general, the participants underwent 3 eccentric strength measurements: (1) tester 1 with the HHD, (2) tester 2 with the HHD, and (3) Biodex strength measurement. Only the dominant arm of the participants was tested. *Dominance* was determined by the hand used to throw a ball. Before the testing, the investigator measured the length of the forearm between the olecranon and the styloid process of the ulna. That measurement allowed us to calculate the peak force in Newtons (N) from the peak torque isokinetic data (N·m) for comparison with the HHD results.

For testing with the HHD, the seated participant held the elbow and shoulder in 90° of abduction and 90° of external rotation (90-90) with gentle support from the examiner's hand. The HHD was positioned 2 cm proximal to the styloid process of the ulna and placed on the dorsal side of

**Figure 1. Eccentric strength testing setup with handheld dynamometer. Participants performed a maximal external-rotation force while the investigator pushed the arm from maximal external rotation (90-90) to 90° of abduction in neutral rotation (90-0).**

the forearm. On the examiner's count, controlled by a metronome to maintain the same velocity as the isokinetic dynamometer (30°/s), the participant exerted maximal external rotation force while the examiner pushed the arm from maximal external rotation (90-90) to 90° of abduction in neutral rotation (90-0; Figure 1). The test procedure was repeated 3 times, with a 20-second pause between trials. For velocity of movement, we used a DynaPort accelerometer to validate the HHD against the Biodex. The DynaPort contains 3 orthogonally positioned acceleration sensors. The resolution was 5.5 mg, the dimensions were 87 × 45 × 14 mm, and the weight was 74 g (batteries included). Data were stored on a commercially available microsecure digital card. The sample frequency was set to 100 Hz to allow for appropriate functioning. The accelerometer was attached to the forearm using double-sided adhesive (Figure 2). Analog signals were low-pass filtered (3-dB filter, cutoff frequency = 5 Hz). Markers were manually set by 1 investigator to mark the start and end of the movement.

The isokinetic testing was performed using a Biodex System 4 isokinetic dynamometer. Participants were seated with a fixation strip over the shoulder and chest to the contralateral side, with the dominant side to the dynamometer. The dynamometer was brought to shoulder height and the shoulder-rotation attachment was installed. In the resting position, the shoulder was positioned in 90° of abduction and 0° of external rotation. The arm rested in the rotation cuff pad, with the olecranon approximating the axis of the dynamometer and the participant's hand gripping the input shaft. Gravity correction was performed and range-of-motion limits were set between 0° and 90° of external rotation. Participants performed 5 familiarization trials in a submaximal concentric mode before we collected data. Subsequently, they completed 3 maximal eccentric contractions for the external rotators at 30°/s (Figure 3). Peak force data were extracted from the CompuFET software program for the HHD measurements, and peak force data were calculated from the Biodex dynamometer measurements using the formula peak torque/length forearm. Values from the accelerometer were calculated from the x, y, and z signals (x-axis: posterior-anterior; y-axis: caudal-cranial; z-axis: medial-lateral), resulting in angular speed (°/s) and range of motion (°).


**Figure 2. DynaPort accelerometer (McRoberts BV, The Hague, the Netherlands).**

## Statistical Analyses

**Reliability.** Variability around a mean value is presented as mean ± 1 SD. The dependent variables demonstrated a normal distribution (Kolmogorov-Smirnov test), and so we applied parametric tests. Paired-samples *t* tests were used to

**Figure 3. Isokinetic testing on the dynamometer (Biodex Medical Systems Inc, Shirley, NY). Participants performed 3 maximal eccentric contractions for the external rotators at shoulder level.**

**Table. Reliability and Validity of Eccentric Rotator Cuff Strength Assessment**

| Tester(s) | Eccentric Peak Force, N | | | | Intraclass Correlation Coefficient (95% Confidence Interval) | Standard Error of Measurement | | Minimal Detectable Change | Velocity | | Pearson Correlation Coefficient[b] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Trial 1 (SD) | Trial 2 (SD) | Trial 3 (SD) | Mean ± SD | | Value | % | | Average Value, °/s (SD) | *P* Value[a] | |
| 1 | 127.74 (33.57) | 122.5 (36.01) | 111.4 (30.02) | 120.56 ± 31.92 | 0.879 (0.781, 0.940) | 11.10 | 9.2 | 30.77 | 28.67 (6.02) | .294 | 0.78 |
| 2 | 119.54 (21.09) | 112.68 (23.09) | 112.02 (21.47) | 114.76 ± 20.83 | 0.858 (0.734, 0.934) | 7.85 | 6.8 | 21.76 | 28.92 (4.99) | .336 | 0.70 |
| 1 and 2 | NA | NA | NA | NA | 0.714 (0.417, 0.873) | 14.11 | 12.0 | 39.11 | NA | NA | NA |

Abbreviation: NA, not applicable.

[a] 1-Sample *t* test.

[b] Validity of handheld dynamometer and isokinetic dynamometer mean values.

assess systematic *between-testers bias*; that is, if values obtained by 1 tester systematically differed from those of the other tester. *Relative reliability* is the degree to which individuals maintain their position in a sample with repeated measurements. To assess relative reliability, we calculated ICCs ([2,1], 2-way random model, agreement definition) with the corresponding 95% confidence intervals (95% CIs). This analysis was performed among the 3 trials for each tester (intratester reliability) and between the 2 testers (intertester reliability). *Absolute reliability* is the degree to which repeated measurements vary for individuals and was expressed as the standard error of measurements (SEM), which was calculated as SD $\times \sqrt{1 - \text{ICC}}$, where SD is the SD of all scores from the participants.[20] The SEM is also presented as SEM%, which was derived by dividing the SEM with the average of the test values. The SEM was used for calculating the minimal detectable change (MDC) and was calculated as SEM $\times 1.96 \times \sqrt{2}$ to construct a 95% CI.[20]

**Validity.** To analyze whether the speed used during the HHD testing was comparable with the speed on the isokinetic dynamometer (30°/s), we conducted a 1-sample *t* test, with a target value of 30°/s on the accelerometer data to detect any difference from that target value. Then, to evaluate the agreement between the HHD results and peak force data from the dynamometer, Pearson product moment correlation coefficients were calculated. We chose a level of $P < .05$ to indicate statistical significance.

## RESULTS

The eccentric peak force values in Newton measured by HHD and the reliability values are presented in the Table. No difference was noted between testers ($P = .671$). The intratester reliability results for each tester were ICC = 0.879 for tester 1 and ICC = 0.858 for tester 2. Between testers, the ICC = 0.714. The SEM, SEM%, and MDC are also presented in the Table. For both testers, the velocity was not significantly different from 30°/s: mean velocity was 28.67°/s (SD = 6.02) for tester 1 ($P = .294$) and 28.92°/s (SD = 4.99) for tester 2 ($P = .336$). The Pearson product moment correlation coefficients between mean HHD and isokinetic dynamometer data were 0.78 (tester 1) and 0.70 (tester 2).

## DISCUSSION

Our main finding was that standardized eccentric rotator cuff strength can be tested and measured in the clinical setting with good to excellent reliability and validity using an HHD. Reliable eccentric rotator cuff strength testing makes it possible to detect changes in eccentric strength that may occur over time. Reliable eccentric testing of rotator cuff strength can also provide a useful screening tool for overhead athletes between matches, training periods, and seasons. Preseason external-rotation weakness is known to be associated with supraspinatus strength deficits and in-season throwing-related injuries.[21] Also, muscular imbalances increase during competitive seasons in swimmers.[22] By strengthening the external rotators in prehabilitation, one could potentially reduce the risk for shoulder injuries.[23] Finally, the HHD has also been used to measure isometric strength for external and internal rotation during preseason screening in adolescent national badminton players.[24]

Eccentric testing of rotator cuff strength using the HHD has not been described previously in the literature. To our knowledge, we are the first to investigate eccentric measurement of the shoulder external rotators with an HHD. *Reliability* is defined[14] as the extent to which a measurement is repeatable and can be estimated from measurements made by a single rater or multiple raters on the same material (agreement). Two types of agreement can be distinguished according to whether 1 rater makes 2 or more measurements of the same material (intrarater agreement) or each of several raters independently measures the same material (interrater agreement). An ICC $\leq$0.40 indicates *poor reliability*, 0.40 to 0.75 indicates *fair-to-good reliability*, and $\geq$0.75 indicates *excellent reliability*.

Using an isometric testing protocol for various muscle groups, good-to-moderate reliability of the HHD was demonstrated.[25] In the shoulder, measurement of isometric shoulder strength with an HHD showed excellent reliability for interrater and intrarater trials, ranging from 0.79 to 0.96.[14] Our results also revealed excellent intratester reliability (ICC = 0.87–0.85) and good intertester reliability (ICC = 0.71). Absolute reliability was expressed as the SEM. The evidence suggests that to make valid clinical decisions, it is important to calculate the SEM.[15] The SEM estimates how repeated measures of a person on the same instrument tend to be distributed around the true score. However, the true score is always unknown because we cannot construct a measure that perfectly reflects the true score. The SEM is directly related to the reliability of a test: the larger the SEM, the lower the reliability of the test and the less precision in the measures taken and scores obtained.[26] Because all measurements contain some error, it is highly unlikely that any test will yield the same scores for a given person each time he or she is tested. Therefore, SEM is also presented as an SEM%, which is obtained by dividing the SEM by the average of the test and retest values.[15]

In our study, the SEM% score was in the range of 6.8 to 12.0 (Table). The *MDC* is defined as the minimal change that falls outside the measurement error in the score of an instrument used to measure a symptom.[27] We calculated the MDC as SEM $\times$ 1.96 $\times$ $\sqrt{2}$ to construct a 95% CI and derived values in the range of 21.76 to 39.11 (Table). The test-retest reliability (Table) of the eccentric measurements was excellent (ICC $>$0.85) for testers 1 and 2 separately and good (ICC $>$0.71) for interrater reliability. The SEM and MDC were lower, indicating better precision for testers 1 and 2 separately than for testers 1 and 2 together (interrater reliability).

*Validity* of an assessment is the degree to which it measures what it is supposed to measure. Determining concurrent validity enabled us to see how well measurements using the HHD correlated with those on the isokinetic device at the same time. Using a conservative estimate of the strength of our ICC values (the lower limit of the 95% CI), the concurrent validity of our HHD protocol with a criterion standard, the Biodex, was good to excellent, varying from 0.70 to 0.78, and showed a large correlation according to a definition of validity.[28]

Isometric muscle strength in youth as assessed by HHD showed good concurrent validity between the HHD and Cybex, with results ranging from 0.52 to 0.91 for the shoulder abductors and 0.79 to 0.96 for the shoulder lateral rotators.[12] To perform the eccentric testing, the tester must be stronger than the participant. In our experience, this could be a limitation if the examiner is not able to overcome the participant's strength: for instance, when testing senior male elite overhead athletes. In this case, the examiner may either not be able to perform the test in a standardized fashion or actually measure his or her own strength instead of the participant's. Tester strength above 120 N appeared to be a major determinant of the magnitude and reliability of the forces measured with an HHD in terms of keeping the reliability good.[29] In some strength measurements with the HHD, a stabilization device has been used. Another group[30] evaluated the influence of intertester bias when testers were of different sexes and strengths; the authors concluded that if the tester was not strong enough, the HHD would need external fixation to produce quality tests. In summary, it seems favorable for the tester to in fact be stronger than the participants; if not, an external-fixation device should be considered. It can be argued that the test protocol should be as user friendly as possible so that the test can be conducted in a field environment. Our experience from the testing procedure, with only gentle support from the examiner's hand under the participant's elbow in the 90-90 position, is that no further stabilization devices are necessary, and therefore our method seems to be acceptable. We chose the seated position because it is considered more functional than the prone or supine position.[31]

Assessing eccentric rotator cuff strength in the field environment is of great importance because many elite athletes travel around the world; therefore, an easy-to-use and reliable tool to detect changes in the shoulder area is crucial. Historically, the isokinetic device has been the criterion standard for these measurements.[6,22] However, with the HHD, these measurements can be obtained more easily and at a lower cost. Future studies in the overhead athlete population should be undertaken to establish normative data and also to determine whether the imbalances occur with pain or injury in the rotator cuff. Furthermore, the HHD can be used to measure the functional ratio, which involves eccentric testing of the shoulder external-rotator muscles and concentric testing of the internal-rotator muscles. The functional ratio[4] is used by most researchers, but in contrast, others[21] used HHD to assess isometric rotator cuff strength in overhead athletes.

A concentric ratio of 66% to 75% has been recommended for the strength of the external rotators in relation to the internal rotators for muscular balance in the rotator cuff.[11] Smaller ratios could be a risk factor for sustaining rotator cuff injuries.[3,5]

## Limitations

We note some limitations in the present study. First, the 2 testers are experienced clinicians in the field of shoulder measurement with and without HHDs. Therefore, our results cannot be extrapolated to all testers. Also, for the participants, the familiarization time could be a bias because the eccentric movement is an unusual maneuver to perform. Finally, we studied healthy nonathletes; to assess strong, healthy athletes, one must be careful when interpreting the intertester reliability.

Tennis has become one of the toughest sports worldwide; early specialization is more common, and so, too, are overuse injuries, especially in the upper extremity.[32] The HHD is used more frequently than in the past, and a recent study[33] of an at-home resistance-tubing strength-training program used the HHD as an evaluating tool.

At present, normative eccentric-strength values for the shoulder external rotators in overhead athletes are not available. In addition, data are lacking on eccentric muscle strength in injured athletes. Determining normative data and obtaining measurements on injured athletes is suggested for future research. Eccentric testing is an exhausting test procedure to perform. We suggest using the test as an objective tool during preseason and in season to detect changes that might occur. In rehabilitation, the eccentric test procedure can be performed at the end stage of rehabilitation and possibly serve as 1 criterion for return to play.[10]

## CONCLUSIONS

Standardized eccentric rotator cuff strength can be tested and measured in the clinical setting with good-to-excellent reliability and validity using an HHD. We believe this eccentric rotator cuff strength test can provide vital information for injury prevention, rehabilitation, and performance enhancement.

## REFERENCES


1. Wilk KE, Obma P, Simpson CD, Cain EL, Dugas JR, Andrews JR. Shoulder injuries in the overhead athlete. *J Orthop Sports Phys Ther*. 2009;39(2):38–54.
2. Escamilla RF, Andrews JR. Shoulder muscle recruitment patterns and related biomechanics during upper extremity sports. *Sports Med*. 2009;39(7):569–590.
3. Niederbracht Y, Shim AL. Concentric internal and eccentric external fatigue resistance of the shoulder rotator muscles in female tennis players. *N Am J Sports Phys Ther*. 2008;3(2):89–94.
4. Scoville CR, Arciero RA, Taylor DC, Stoneman PD. End range eccentric antagonist/concentric agonist strength ratios: a new perspective in shoulder strength assessment. *J Orthop Sports Phys Ther*. 1997;25(3):203–207.
5. Saccol MF, Gracitelli GC, da Silva RT, et al. Shoulder functional ratio in elite junior tennis players. *Phys Ther Sport*. 2010;11(1):8–11.
6. Ellenbecker T, Roetert EP. Age specific isokinetic glenohumeral internal and external rotation strength in elite junior tennis players. *J Sci Med Sport*. 2003;6(1):63–70.
7. Andrade Mdos S, Fleury AM, de Lira CA, Dubas JP, da Silva AC. Profile of isokinetic eccentric-to-concentric strength ratios of shoulder rotator muscles in elite female team handball players. *J Sports Sci*. 2010;28(7):743–749.
8. Trakis JE, McHugh MP, Caracciolo PA, Busciacco L, Mullaney M, Nicholas SJ. Muscle strength and range of motion in adolescent pitchers with throwing-related pain: implications for injury prevention. *Am J Sports Med*. 2008;36(11):2173–2178.
9. Laudner KG, Stanek JM, Meister K. Assessing posterior shoulder contracture: the reliability and validity of measuring glenohumeral joint horizontal adduction. *J Athl Train*. 2006;41(4):375–380.
10. Kovacic J, Bergfeld J. Return to play issues in upper extremity injuries. *Clin J Sport Med*. 2005;15(6):448–452.
11. Ellenbecker TS, Davies GJ. The application of isokinetics in testing and rehabilitation of the shoulder complex. *J Athl Train*. 2000;35(3):338–350.
12. Hebert LJ, Maltais DB, Lepage C, Saulnier J, Crete M, Perron M. Isometric muscle strength in youth assessed by hand-held dynamometry: a feasibility, reliability, and validity study. *Pediatr Phys Ther*. 2011;23(3):289–299.
13. Cadogan A, Laslett M, Hing W, McNair P, Williams M. Reliability of a new hand-held dynamometer in measuring shoulder range of motion and strength. *Man Ther*. 2011;16(1):97–101.
14. Hayes K, Walton JR, Szomor ZL, Murrell GA. Reliability of 3 methods for assessing shoulder strength. *J Shoulder Elbow Surg*. 2002;11(1):33–39.
15. Thorborg K, Petersen J, Magnusson SP, Holmich P. Clinical assessment of hip strength using a hand-held dynamometer is reliable. *Scand J Med Sci Sports*. 2010;20(3):493–501.
16. Walter SD, Eliasziw M, Donner A. Sample size and optimal designs for reliability studies. *Stat Med*. 1998;17(1):101–110.
17. Bohannon RW. Hand-held dynamometry: a practicable alternative for obtaining objective measures of muscle strength. *Isokinet Exerc Sci*. 2012;20(4):301–315.
18. Van Hees VT, Slootmaker SM, De Groot G, Van Mechelen W, Van Lummel RC. Reproducibility of a triaxial seismic accelerometer (DynaPort). *Med Sci Sports Exerc*. 2009;41(4):810–817.
19. Plotnikoff NA, MacIntyre DL. Test-retest reliability of glenohumeral internal and external rotator strength. *Clin J Sport Med*. 2002;12(6):367–372.
20. Weir JP. Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. *J Strength Cond Res*. 2005;19(1):231–240.
21. Byram IR, Bushnell BD, Dugger K, Charron K, Harrell FE, Noonan TJ. Preseason shoulder strength measurements in professional baseball pitchers: identifying players at risk for injury. *Am J Sports Med*. 2010;38(7):1375–1382.
22. Batalha NM, Raimundo AM, Tomas-Carus P, Barbosa TM, Silva AJ. Shoulder rotator cuff balance, strength, and endurance in young swimmers during a competitive season. *J Strength Cond Res*. 2013;27(9):2562–2568.
23. Niederbracht Y, Shim AL, Sloniger MA, Paternostro-Bayles M, Short TH. Effects of a shoulder injury prevention strength training program on eccentric external rotator muscle strength and glenohumeral joint imbalance in female overhead activity athletes. *J Strength Cond Res*. 2008;22(1):140–145.
24. Couppe C, Thorborg K, Hansen M, et al. Shoulder rotational profiles in young healthy elite female and male badminton players. *Scand J Med Sci Sports*. 2014;24(1):122–128.
25. Stratford PW, Balsor BE. A comparison of make and break tests using a hand-held dynamometer and the Kin-Com. *J Orthop Sports Phys Ther*. 1994;19(1):28–32.
26. Tighe J, McManus IC, Dewhurst NG, Chis L, Mucklow J. The standard error of measurement is a more appropriate measure of quality for postgraduate medical assessments than is reliability: an analysis of MRCP(UK) examinations. *BMC Med Educ*. 2010;10:40.
27. Kovacs FM, Abraira V, Royuela A, et al. Minimum detectable and minimal clinically important changes for pain in patients with nonspecific neck pain. *BMC Musculoskelet Disord*. 2008;9:43.
28. Stark T, Walker B, Phillips JK, Fejer R, Beck R. Hand-held dynamometry correlation with the gold standard isokinetic dynamometry: a systematic review. *PM R*. 2011;3(5):472–479.
29. Wikholm JB, Bohannon RW. Hand-held dynamometer measurements: tester strength makes a difference. *J Orthop Sports Phys Ther*. 1991;13(4):191–198.
30. Thorborg K, Bandholm T, Schick M, Jensen J, Holmich P. Hip strength assessment using handheld dynamometry is subject to

intertester bias when testers are of different sex and strength. *Scand J Med Sci Sports*. 2013;23(4):487–493.

31. Hurd WJ, Kaplan KM, El Attrache NS, Jobe FW, Morrey BF, Kaufman KR. A profile of glenohumeral internal and external rotation motion in the uninjured high school baseball pitcher, part II: strength. *J Athl Train*. 2011;46(3):289–295.
32. Pluim BM, Staal JB, Windler GE, Jayanthi N. Tennis injuries: occurrence, aetiology, and prevention. *Br J Sports Med*. 2006;40(5): 415–423.
33. Magnus CR, Boychuk K, Kim SY, Farthing JP. At-home resistance tubing strength training increases shoulder strength in the trained and untrained limb. *Scand J Med Sci Sports*. 2014;24(3):586–593.

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