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# Hand-held dynamometry strength measures for internal and external rotation demonstrate superior reliability, lower minimal detectable change and higher correlation to isokinetic dynamometry than externally-fixed dynamometry of the shoulder

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A R T I C L E I N F O

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A B S T R A C T

*Objectives:* To investigate inter and intra-rater reliability of hand held (HHD) and externally fixed (EFD) dynamometry for shoulder internal (IR) and external rotation (ER) strength and their correlation to isokinetic testing.
*Design:* Within participant, inter and intra-rater reliability study.
*Participants:* Twenty active, healthy male and female participants underwent testing by two examiners.
*Outcome measures:* Intra-class coefficients (ICC), percentage standard error of measurement (%SEM), and percentage minimal detectable change (%MDC) were calculated for inter-rater, intra-day and intra-rater, inter-week reliability. Maximum and average of three repetitions were compared to the isokinetic results at three speeds (60°/sec, 180°/sec, 240°/sec) for both concentric and eccentric contractions.
*Results:* Inter and intra-tester values demonstrated good to high agreement (HHD, ICC range = 0.89–0.97, %SEM = 4.80–8.60%, %MDC = 13.29–23.70%; EFD, ICC = 0.88–0.96, %SEM = 6.60–11.00%, %MDC = 18.40–30.04%). HHD and EFD showed moderate to very strong correlations to the isokinetic testing (HHD, r = 0.45–0.86; EFD, r = 0.49–0.83).
*Conclusions:* The results of this study indicate that both EFD and HHD are suitable for clinical practice and research. Hand-held dynamometry is preferred due to its higher intra- and inter-rater reliability and smaller MDC and lower SEM.



## 1. Introduction

The rate of shoulder injury is high in sports that require repetitive overhead movements such as swimming, volleyball, tennis and baseball (Agel, Palmieri-Smith, Dick, Wojtys, & Marshall, 2007; McFarland & Wasik, 1998; Sell, Hainline, Yorio, & Kovacs, 2014; Walker, Gabbe, Wajswelner, Blanch, & Bennell, 2012). Shoulder rotation strength imbalances have been reported as a risk factor for the development of shoulder pain or injury in these sports (Bak, 2010; Gandhi, ElAttrache, Kaufman, & Hurd, 2012; Rupp, Berninger, & Hopf, 1995). Strength has most commonly been reported as the absolute strength of internal or external rotation and also as the ratio between these two variables (Ellenbecker & Roetert, 2003; Wilk, Andrews, Arrigo, Keirns, & Erber, 1993). Preseason, a decrease in external rotation (ER) strength is associated with in-season injury in baseball pitchers (Byram et al., 2010) and a subsequent decrease in pitch velocity (Gandhi et al., 2012; Mullaney, McHugh, Donofrio, & Nicholas, 2005). Similarly, in swimming, weakness in either ER (Beach, Whitney, & Dickoff-Hoffmanor, 1992; McMaster, Long & Caiozzo, 1992; Rupp, Berninger, & Hopf, 1995) or internal rotation (IR) strength (Bak, 2010; Tate et al., 2012) have been reported in symptomatic shoulders. The measurement and monitoring of shoulder rotation strength or

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ratios in these overhead sports could therefore be useful in injury prevention. It is hypothesised that these measures can be used to quantify any strength deficits and assist in return to sport decisions following injury or surgery to the shoulder.

In the literature there are a number of methods for measuring shoulder strength including hand-held (HHD) (Bohannon, 1986; Dollings, Sandford, O'Conaire, & Lewis, 2012; Hayes, Walton, Szomor, & Murrell, 2002), externally-fixed (EFD) (Beshay, Lam, & Murrell, 2011; Kolber, Beekhuizen, Cheng, & Fiebert, 2007) and isokinetic dynamometry (Ellenbecker & Roetert, 2003; Leggin, Neuman, Iannotti, Williams, & Thompson, 1996; Noffal, 2003). Isokinetic testing is considered a reliable and valid mode of shoulder strength testing (Leggin et al., 1996; Plotnikoff & MacIntyre, 2002), however is not without limitations. These include significant financial, time and portability restraints. Hand-held and externally-fixed dynamometry has been investigated as an option to overcome the constraints of isokinetic testing in both clinical and research settings (Beshay et al., 2011; Dollings et al., 2012; Kolber et al., 2007). For these to be clinically useful they need to be inexpensive, portable, time efficient and demonstrate acceptable absolute and relative reliability (Stark, Walker, Phillips, Fejer, & Beck, 2011; Wollin, Purdam, & Drew, 2016).

Hand-held dynamometry of the hip has been shown to be affected by examiner gender and upper body strength (Thorborg, Bandholm, Schick, Jensen, & Hölmich, 2013a), with increased reliability in experienced clinicians with greater than ten years of experience (Kemp, Schache, Makdissi, Sims, & Crossley, 2013). In the shoulder, some studies suggest that a similar strength bias exists (Schrama, Stenneberg, Lucas, & van Trijffel, 2014; Wadsworth, Nielsen, Corcoran, Phillips, & Sannes, 1992; Wikholm & Bohannon, 1991). Recent studies have demonstrated HHD reliability in symptomatic (Hayes et al., 2002) and non-symptomatic shoulders (Beshay et al., 2011; Dollings et al., 2012). In these studies it should be noted that a range of protocols have been undertaken. One study (ICC > 0.90) used examiners (no reference to gender) with over 10 year's experience (Dollings et al., 2012). While another study (ICC > 0.80) in comparison, utilised both male and female examiners, however, they still had >10 years of experience (Beshay et al., 2011). Nevertheless, shoulder HHD is demonstrated to be reliable despite gender differences.

Two forms of HHD exist, being the 'make test', whereby the examiner holds the dynamometer still while the participant exerts a maximal isometric force against the dynamometer and the 'break test', where examiner matches the maximal isometric force then continues to exert force until the maximal effort is overcome and the joint gives way (Bohannon, 1988; Stratford & Balsor, 1994). The majority of studies have utilised the 'make test' (Beshay et al., 2011; Dollings et al., 2012) and while both methods have been proven to be reliable (Bohannon, 1988), a 'break test' yields a higher force result (Bohannon, 1988; Stratford & Balsor, 1994) so could be argued to be a more relevant measure to represent an athletes true strength.

Externally-fixed dynamometry has shown promise in overcoming some of the limitations of HDD. In addition to not requiring a skilled examiner to perform the test at the hip, EFD has been shown to be reliable in students with 1 h of training (Thorborg, Bandholm & Hölmich, 2013b), and at the shoulder, both intra and inter-related reliability have been demonstrated with ICCs > 0.8 (Beshay, Lam & Murrell, 2011) and ICC > 0.9 respectively (Kolber et al., 2007).

It is important to note that there is little published on the minimal detectable change (MDC) and standard error of measurement (SEM) for shoulder rotation strength measures. To date, no previous study has compared intra- and inter-rater absolute and relative reliability of HHD and EFD against isokinetic measurement within the one study. Prior to implementing dynamometry when monitoring therapy programs, the intra- and inter-rater reliability as well as the SEM and MDC need to be established to allow clinicians to make an informed decision on the best method for use in the clinic, injury prevention programs and in research (Hopkins, 2000). The aims of this study were to: (i) determine and compare inter and intra-rater reliability of HHD and EFD; (ii) compare HHD and EFD to an isokinetic shoulder strength measurement test.

## 2. Methods

A convenience sample of twenty healthy, active individuals employed at a sports institute gave written informed consent to participate in the study. Participants' comprised of ten male (mean ± 1 standard deviation (SD), age = 31.2 ± 9.0, height = 176 ± 6.1 cm, weight = 78.4 ± 9.7 kg, BMI = 25.2 ± 2.0) and 10 female (age = 30.1 ± 8.0, height = 167 ± 6.5 cm, weight = 64.2 ± 9.6 kg, BMI = 23.0 ± 3.2). Participants were injury free at the time of testing and participated in regular physical activity totalling at least 2.5 h a week. All participants had no previous experience of dynamometry or isokinetic testing. To ensure heterogeneity two sports physiotherapists conducted the strength testing; with the male examiner (weight = 85 kg, height = 185 cm) having 5 years' experience and the female examiner (weight = 68 kg, height = 170 cm) 15 years' experience. This study was approved by the Australian Institute of Sport Ethics Committee (Approval No. 20130414).

Inter-examiner data was collected over two days during week one of testing. Intra-examiner, inter-week (female examiner only) data were collected on the same day and time one week apart. The participants were instructed to maintain their normal activity with the avoidance of upper body resistance training the day of, the week between, and prior to testing for both sessions. Isokinetic testing was undertaken following the dynamometry protocol on the same day and time of week two. To reduce this effect on the EFD and HHD all isokinetic tests were completed following the HHD and the EFD dynamometry. The participant test order was computer randomised for tester order, dynamometry method, test side (left or right) and rotation direction (internal or external). Both examiner and participants were blinded to the results. All participants had 10 min rest between each of the 3 methods of testing for both examiners.

Participants position for all strength tests was standardised (Fig. 1) to standing with feet shoulder width apart and slightly flexed knees and hips, elbow by the side but not touching the body and in 90°of flexion, wrist in anatomical neutral (palm facing midline). This position was demonstrated to the participants to ensure they did not use either excessive abduction or adduction and leverage over the trunk, to ensure isolated rotation. Participants were asked to brace themselves to avoid losing balance during testing. The dynamometer was placed such that the transducer head was aligned just proximal to the ulnar styloid process for both the EFD and HHD. Participants performed a sub-maximal practice test followed by 3 test efforts. HHD was conducted using a Chatillion (K DFX 200, Ametek Inc., USA) and a Power Track II Commander (PowerTrack ™ II Commander, JTECH Medical, USA) connected to a seatbelt and a glass suction handle (Model S338, CR Laurance of Australia Pty Ltd, Australia) was used for all EFD measures (Fig. 1). The isokinetic strength was measured on a Humac Norm (CMSI Humac/Norm testing and rehabilitation system Model 770, USA) which had been recently serviced and upgraded to the most recent software (HUMAC 2009v10.000.0039NORM). All dynamometry values were recorded in peak Newtons and converted to torque by multiplying the force by the lever length (m) as measured as the distance from the medial joint line of the elbow to

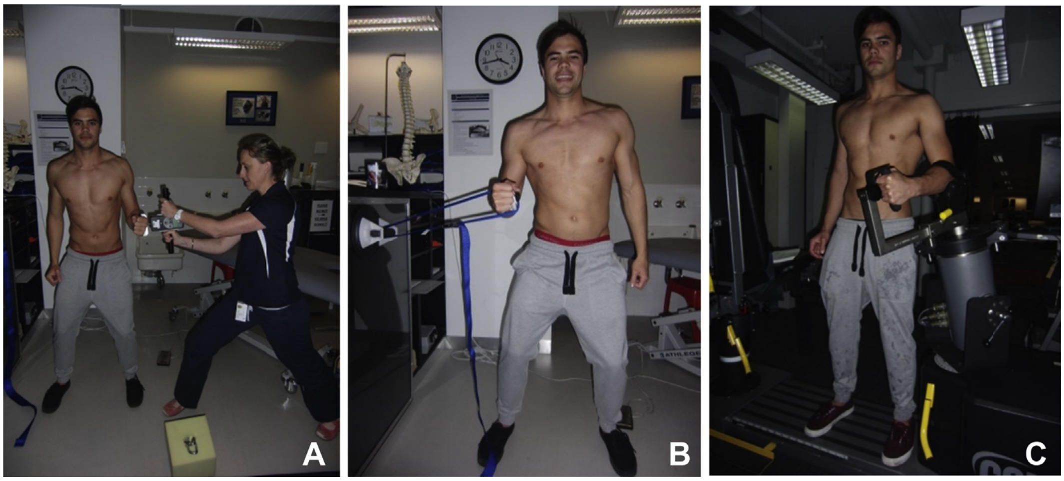


**Fig. 1.** Testing position and set up the three shoulder strength measurements. (A) External rotation strength measured via hand-held dynamometer; Internal rotation position is identical however the tester stands facing the opposite direction and the participant reverses the direction of the force (B) Internal rotation strength measured via externally-fixed dynamometry; External position is identical however the tester stands facing the opposite direction and the participant reverses the direction of the force (C) isokinetic.

the styloid process of the wrist.

EFD testing was conducted with a 5 s 'make' test, with a 10-s rest interval between repetitions, timed by a stopwatch. A monotonous voice with phrase "go ahead – push – push – push – push – push – relax" was used to ensure consistent encouragement (Thorborg et al., 2013b). The HHD dynamometry was performed using a 'break' test, with 10-s intervals were used between repetitions.

Isokinetic testing in the Humac Norm was conducted by a single examiner and set up and performed as per the manual instructions, with the participant standing on the monorail deck, feet shoulder width apart and knees slightly bent. The 'dyna height' was adjusted to allow for a slightly abducted shoulder, with the elbow supported on a stabiliser pad and secured with a Velcro strap in 90° flexion. The lever arm was adjusted to the length of the participant's forearm which was held in neutral position allowing the handle to be grasped. The dynamometer arm was gravity adjusted and the test ROM was set to 45° internal rotation to 45° external rotation. Concentric & eccentric contractions were tested at 3 speeds (60°/sec, 180°/sec, 240°/sec). Each participant performed a submaximal warm up test for each speed for familiarisation, followed by three maximal test efforts with a 10 s rest interval.

### *2.1. Data analysis*

Strength measurement reliability was investigated using absolute and relative indices. Intra-class correlation coefficients ($ICC_{2,1}$; two-way random model, consistency definition) and 95% confidence intervals (95% CI) were calculated to examine inter-rater reliability (Weir, 2005). Intra-rater reliability was analysed using intra-class correlation coefficients ($ICC_{3.1}$; two-way mixed model) (Weir, 2005). To account for differences in strength due to dominance, the data was stratified by side, with average and maximum strength values used for analysis. The reliability was evaluated in accordance with previously defined criteria (poor = 0.6–0.69, fair = 0.7–0.79, good = 0.8–0.89, high = 0.9–099) (Meyers & Blesh, 1962). SEM and MDC were calculated for each HHD and EFD test as described in previous reliability studies (Roy et al., 2009; Thorborg et al., 2013b; Wollin et al., 2016). SEM is calculated by SD x $\sqrt{1\text{-ICC}}$ (Weir, 2005), where SD is the SD of all scores from the participants. MDC was calculated as SEM x 1.96 $\times \sqrt{2}$ (Weir, 2005). Both SEM and MDC were converted to percentages of the mean results (SEM divided by mean results; %SEM, %MDC). SEM and MDC were deemed acceptable if less than 10%. The relationship between isokinetic and EFD or HHD was evaluated using the Pearson's correlation coefficient. A Bland-Altman plot was utilised to investigate the correlations between the measures with respect to the agreement and the existence of a standard bias between the values obtained from the two testers (Fig 2). Correlation was evaluated in accordance with previously defined criteria (0.00–0.19 very weak, 0.20–0.39 weak, 0.40–0.59 = moderate, 0.60–0.79 = strong, 0.80–1.00 = very strong) (Evans, 1996). All reliability calculations were performed using SPSS version 19 (SPSS Inc., Chicago, IL, USA). Statistical significance was set *a priori* at $p < 0.05$ for all calculations. *Post-hoc* power calculations indicate this study is appropriately powered to detect ICC > 0.60 ($\alpha = 0.05$; $\beta \geq 0.82$ for all correlations).

## 3. Results

The results of the inter-rater and intra-rater reliability tests are presented in Tables 1 and 2, respectively for both HHD and EFD. Internal and external rotation showed good to high inter-rater (range = 0.88 [95%CI 0.73–0.95] to 0.96 [95%CI 0.91–0.99]) and intra-rater (range = 0.91 [95%CI 0.88–0.98] to 0.97 [95%CI 0.93–0.99]) reliability. Inter-rater %SEM was acceptable (<10%) for all tests except right IR average measures for EFD (11%). The %SEM results for HHD (<10%) were superior to EFD across all tests. The range of inter-rater %MDC scores was lower for HHD (15.8%–23.7%) than EFD (18.4%–30.4%). Likewise, %MDC values for HHD (13.6%–23.24%) were lower for intra-rater testing, when compared with the range of scores for EFD (19.28%–29.03%).

All HHD and EFD tests were significantly correlated with the corresponding isokinetic tests and are presented in Table 3. HHD showed the highest correlation to isokinetic testing with EFD maximums being higher in only two tests (left ER concentric at 60°/sec, $r = 0.738$; right IR concentric at 60°/sec, $r = 0.708$). Maximum EFD results showed a higher correlation with concentric and eccentric isokinetic measures than the averaged results for all tests except left eccentric 240°/sec. Conversely, for HHD, both the average and maximum value had similar correlations to isokinetic testing.

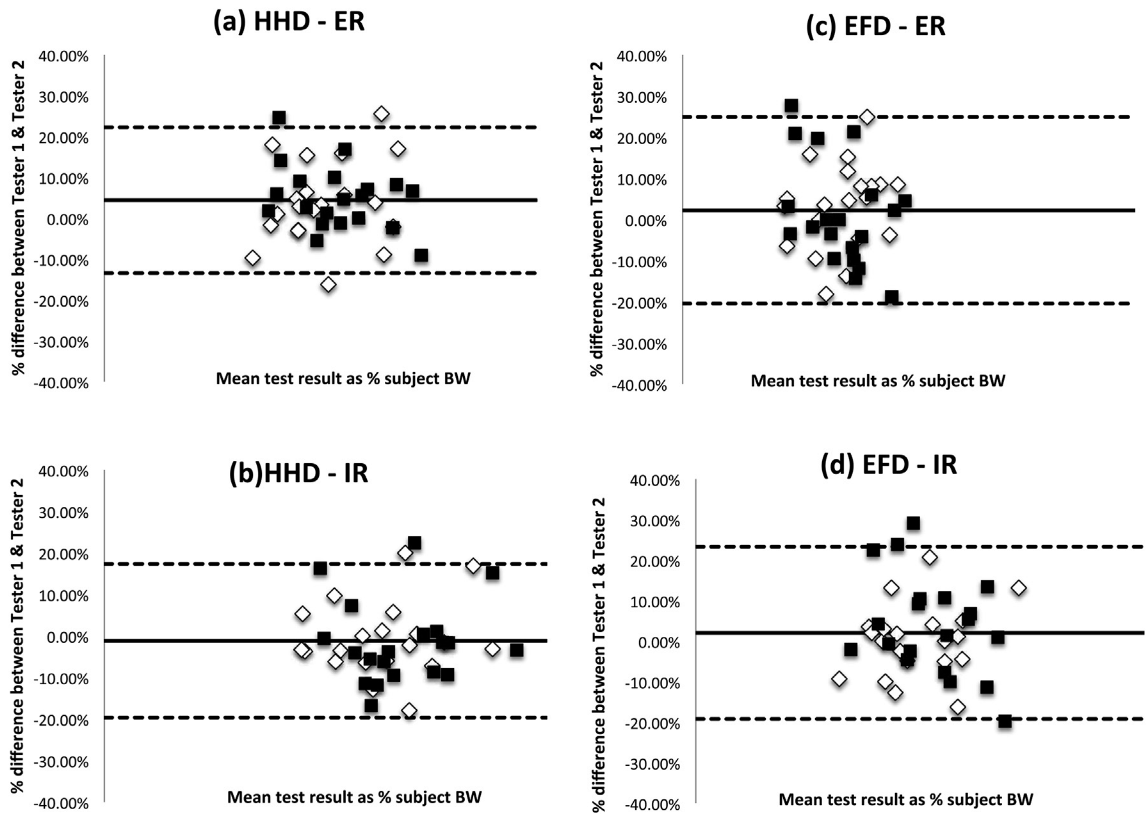


**Fig. 2.** Bland-Altman plots for HHD (IR & ER) and EFD (IR & ER) inter-rater testing. ■ right; ◊ left; - - upper and lower level of agreement (LOA); average difference (standard bias) in readings between the two testers.

## 4. Discussion

The results from this study demonstrate good to high reliability of HHD and EFD when measuring shoulder strength in healthy participants. These results support those of previous studies in both healthy (Dollings et al., 2012) and symptomatic patients (Hayes et al., 2002). This study shows that independent of gender, bodyweight, and years of post-graduate experience a reliable measurement of shoulder IR and ER is possible. Results for relative reliability for HHD and EFD were equivalent; however, HDD had a superior absolute reliability (%SEM and %MDC) and higher correlations to the isokinetic testing. Therefore, HHD was superior to EFD due to its higher reliability, and lower %SEM and %MDC. Furthermore, when comparing these methods to isokinetic dynamometry, HHD was superior to the EFD for both internal and external at all speeds except for two (left concentric ER at 60 deg/sec and right IR at 60deg/sec). As such, HDD may be a preferable substitute for strength measurements in the shoulder.

When assessing shoulder internal and external rotation strength, patients and athletes are commonly assessed by multiple

**Table 1**
Inter-rater reliability of externally-fixed and hand-held dynamometry.

| | Test | Side | ICC (95%CI) | Mean | SEM (95%CI) | %SEM (95%CI) | MDC (95%CI) | %MDC (95%CI) |
|---|---|---|---|---|---|---|---|---|
| $ER_{Max}$ | EFD | Left | 0.94 (0.84–0.97) | 26.92 | 2.39 (1.69–3.90) | 8.9 (6.3–14.5) | 6.62 (4.68–10.82) | 24.6 (17.4–40.2) |
| | | Right | 0.93 (0.84–0.97) | 26.19 | 2.20 (1.44–3.33) | 8.4 (5.5–12.7) | 6.11 (3.99–9.22) | 23.3 (15.2–35.2) |
| | HHD | Left | 0.92 (0.80–0.97) | 38.15 | 3.27 (2.00–5.17) | 8.6 (5.2–13.6) | 9.06 (5.55–14.33) | 23.7 (14.5–37.6) |
| | | Right | 0.96 (0.85–0.99) | 40.84 | 2.32 (1.16–4.49) | 5.7 (2.8–11.0) | 6.44 (3.22–12.45) | 15.8 (7.9–30.5) |
| $IR_{Max}$ | EFD | Left | 0.96 (0.91–0.99) | 37.15 | 2.47 (1.24–3.71) | 6.6 (3.3–10.0) | 6.85 (3.42–10.27) | 18.4 (9.2–27.6) |
| | | Right | 0.91 (0.78–0.96) | 40.3 | 3.93 (2.62–6.14) | 9.8 (6.5–15.2) | 10.91 (7.26–17.03) | 27.1 (18.0–42.3) |
| | HHD | Left | 0.96 (0.90–0.98) | 47.01 | 3.08 (2.18–4.87) | 6.6 (4.6–10.4) | 8.54 (6.04–13.50) | 18.2 (12.8–28.7) |
| | | Right | 0.95 (0.89–0.98) | 49.75 | 3.16 (2.00–4.69) | 6.4 (4.0–9.4) | 8.77 (3.63–9.25) | 17.6 (11.1–26.1) |
| $ER_{Avg}$ | EFD | Left | 0.95 (0.87–0.97) | 25.43 | 2.07 (1.31–3.34) | 8.1 (5.1–13.1) | 5.74 (3.63–9.25) | 22.6 (14.3–36.4) |
| | | Right | 0.95 (0.89–0.98) | 24.8 | 1.73 (1.09–2.57) | 7.0 (4.4–10.3) | 4.79 (5.29–11.83) | 19.3 (12.2–28.7) |
| | HHD | Left | 0.94 (0.85–0.97) | 36.44 | 2.70 (1.91–4.27) | 7.4 (5.2–11.7) | 7.49 (5.29–11.83) | 20.5 (14.5–32.5) |
| | | Right | 0.92 (0.69–0.97) | 38.8 | 3.23 (1.98–6.36) | 8.3 (5.1–16.4) | 8.96 (5.48–17.62) | 23.1 (14.1–45.4) |
| $IR_{Avg}$ | EFD | Left | 0.96 (0.91–0.98) | 35.22 | 2.43 (1.72–3.65) | 6.9 (4.9–10.3) | 6.74 (4.76–10.10) | 19.1 (13.5–28.7) |
| | | Right | 0.88 (0.73–0.95) | 37.89 | 4.15 (2.68–6.23) | 11.0 (7.1–16.4) | 11.51 (7.43–17.25) | 30.4 (19.6–45.5) |
| | HHD | Left | 0.96 (0.91–0.98) | 45.32 | 3.06 (2.16–4.59) | 6.7 (4.8–10.1) | 8.48 (6.00–12.72) | 18.7 (13.2–28.1) |
| | | Right | 0.96 (0.91–0.98) | 46.92 | 2.82 (1.99–4.23) | 6.0 (4.2–9.0) | 7.81 (5.53–11.72) | 16.6 (11.8–25.0) |

HHD: hand held dynamometry; EFD: externally fixed dynamometry; $IR_{Max}$: maximum of 3 repetitions of internal rotation; $ER_{Max}$: maximum of 3 repetitions of external rotation; $IR_{Avg}$: average of 3 repetitions of internal rotation; $ER_{Avg}$: average of 3 repetitions of external rotation; Mean; mean result for $ER_{Max}$, $IR_{Max}$, $ER_{Avg}$, $IR_{Avg}$; ICC: intraclass correlation coefficient; CI: confidence interval; SEM: standard error measurement; MDC: minimal detectable change; 95%CI: 95% Confidence Interval; %: percentage.

**Table 2**
Intra-rater reliability of externally-fixed and hand-held dynamometry.

| | ROM | Side | ICC (95%CI) | Mean | SEM (95%CI) | %SEM (95%CI) | MDC (95%CI) | %MDC (95%CI) |
|---|---|---|---|---|---|---|---|---|
| ERMax | EFD | L | 0.94 (0.86–0.98) | 26.92 | 2.28 (1.32–3.49) | 8.48 (4.89–12.95) | 6.32 (3.65–9.66) | 23.49 (13.56–35.88) |
| | | R | 0.93 (0.83–0.97) | 26.19 | 2.21 (1.44–3.44) | 8.42 (5.51–13.13) | 6.12 (4.00–9.53) | 23.35 (15.29–36.39) |
| | HHD | L | 0.92 (0.81–0.97) | 38.15 | 3.20 (1.96–4.93) | 8.38 (5.13–12.92) | 8.86 (5.43–13.66) | 23.24 (14.23–35.81) |
| | | R | 0.97 (0.93–0.99) | 40.84 | 1.96 (1.13–2.99) | 4.80 (2.77–7.32) | 5.43 (3.13–8.29) | 13.29 (7.67–20.30) |
| IRMax | EFD | L | 0.96 (0.91–0.99) | 37.15 | 2.65 (1.32–3.97) | 7.13 (3.57–10.70) | 7.34 (3.67–11.01) | 19.77 (9.88–29.65) |
| | | R | 0.91 (0.88–0.98) | 40.30 | 3.87 (1.29–3.41) | 9.59 (3.20–8.46) | 10.71 (3.57–9.45) | 26.59 (8.86–23.45) |
| | HHD | L | 0.96 (0.90–0.98) | 47.01 | 3.05 (2.16–4.83) | 6.50 (4.59–10.27) | 8.46 (5.99–13.38) | 18.01 (12.73–28.47) |
| | | R | 0.95 (0.89–0.98) | 49.75 | 3.20 (2.03–4.75) | 6.44 (4.07–9.55) | 8.88 (5.62–13.17) | 17.85 (11.29–26.47) |
| ERAvg | EFD | L | 0.95 (0.87–0.99) | 25.43 | 2.02 (0.91–3.26) | 7.96 (3.56–12.83) | 5.61 (2.51–9.04) | 22.06 (9.89–35.57) |
| | | R | 0.95 (0.88–0.98) | 24.80 | 1.78 (1.13–2.76) | 7.19 (4.55–11.14) | 4.94 (3.13–7.66) | 19.93 (12.61–30.88) |
| | HHD | L | 0.94 (0.85–0.98) | 36.44 | 2.59 (1.50–4.10) | 7.11 (4.11–11.25) | 7.19 (4.15–11.36) | 19.72 (11.38–31.18) |
| | | R | 0.94 (0.86–0.98) | 38.80 | 2.74 (1.58–4.18) | 7.05 (4.07–10.77) | 7.58 (4.38–11.58) | 19.54 (11.28–29.85) |
| IRAvg | EFD | L | 0.96 (0.90–0.98) | 35.22 | 2.45 (1.73–3.87) | 6.96 (4.92–11.00) | 6.79 (4.80–10.74) | 19.28 (13.63–30.48) |
| | | R | 0.89 (0.73–0.95) | 37.89 | 3.97 (2.68–6.22) | 10.47 (7.06–16.41) | 11.00 (7.42–17.42) | 29.03 (19.58–45.49) |
| | HHD | L | 0.96 (0.89–0.98) | 45.32 | 2.95 (2.09–4.89) | 6.25 (4.61–10.80) | 8.18 (5.79–13.57) | 18.05 (12.77–29.94) |
| | | R | 0.96 (0.90–0.98) | 46.92 | 2.93 (2.07–4.64) | 6.25 (4.42–9.88) | 8.13 (5.75–12.85) | 17.33 (12.25–27.40) |

HHD: hand held dynamometry; EFD: externally fixed dynamometry; $IR_{Max}$: maximum of 3 repetitions of internal rotation; $ER_{Max}$: maximum of 3 repetitions of external rotation; $IR_{Avg}$: average of 3 repetitions of internal rotation; $ER_{Avg}$: average of 3 repetitions of external rotation; Mean; mean result for $ER_{Max}$, $IR_{Max}$, $ER_{Avg}$, $IR_{Avg}$; L: Left side; R: Right side; ICC: intraclass correlation coefficient; CI: confidence interval; SEM: standard error measurement; MDC: minimal detectable change; 95%CI: 95% Confidence Interval; %: percentage.

**Table 3**
Correlation between EFD, HHD and isokinetic strength.

| | | | HHD | | | | EFD | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | $r_{Max}$ | p-value | $r_{Average}$ | p-value | $r_{Max}$ | p-value | $r_{Average}$ | p-value |
| ER L | Eccentric | 60 | 0.77 | 0.002 | 0.693 | 0.001 | 0.625 | 0.005 | 0.608 | 0.007 |
| | | 180 | 0.748 | 0.000 | 0.764 | 0.000 | 0.744 | 0.000 | 0.726 | 0.001 |
| | | 240 | 0.448 | 0.040 | 0.522 | 0.026 | 0.511 | 0.030 | 0.516 | 0.028 |
| | Concentric | 60 | 0.617 | 0.006 | 0.643 | 0.004 | 0.738 | 0.000 | 0.604 | 0.008 |
| | | 180 | 0.631 | 0.005 | 0.666 | 0.003 | 0.636 | 0.005 | 0.614 | 0.007 |
| | | 240 | 0.648 | 0.004 | 0.682 | 0.002 | 0.661 | 0.003 | 0.640 | 0.004 |
| ER R | Eccentric | 60 | 0.781 | 0.000 | 0.695 | 0.001 | 0.665 | 0.003 | 0.624 | 0.006 |
| | | 180 | 0.697 | 0.001 | 0.727 | 0.001 | 0.711 | 0.001 | 0.661 | 0.003 |
| | | 240 | 0.695 | 0.001 | 0.717 | 0.001 | 0.567 | 0.014 | 0.512 | 0.030 |
| | Concentric | 60 | 0.848 | 0.000 | 0.864 | 0.000 | 0.831 | 0.000 | 0.807 | 0.003 |
| | | 180 | 0.766 | 0.000 | 0.774 | 0.000 | 0.677 | 0.002 | 0.661 | 0.030 |
| | | 240 | 0.789 | 0.000 | 0.786 | 0.000 | 0.663 | 0.003 | 0.512 | 0.030 |
| IR L | Eccentric | 60 | 0.747 | 0.000 | 0.729 | 0.001 | 0.662 | 0.003 | 0.649 | 0.004 |
| | | 180 | 0.774 | 0.000 | 0.759 | 0.000 | 0.701 | 0.001 | 0.676 | 0.002 |
| | | 240 | 0.773 | 0.000 | 0.753 | 0.000 | 0.750 | 0.000 | 0.731 | 0.001 |
| | Concentric | 60 | 0.849 | 0.000 | 0.829 | 0.000 | 0.788 | 0.000 | 0.778 | 0.000 |
| | | 180 | 0.801 | 0.000 | 0.805 | 0.000 | 0.704 | 0.001 | 0.691 | 0.002 |
| | | 240 | 0.788 | 0.000 | 0.784 | 0.000 | 0.706 | 0.001 | 0.687 | 0.002 |
| IR R | Eccentric | 60 | 0.573 | 0.013 | 0.544 | 0.020 | 0.511 | 0.030 | 0.490 | 0.037 |
| | | 180 | 0.713 | 0.001 | 0.714 | 0.001 | 0.709 | 0.001 | 0.676 | 0.002 |
| | | 240 | 0.650 | 0.004 | 0.639 | 0.004 | 0.624 | 0.006 | 0.576 | 0.012 |
| | Concentric | 60 | 0.658 | 0.003 | 0.662 | 0.003 | 0.708 | 0.001 | 0.688 | 0.002 |
| | | 180 | 0.702 | 0.001 | 0.683 | 0.002 | 0.668 | 0.002 | 0.660 | 0.003 |
| | | 240 | 0.756 | 0.000 | 0.729 | 0.001 | 0.642 | 0.004 | 0.639 | 0.004 |

r: Pearson's correlation coefficient; HHD: hand-held dynamometry; EFD: externally-fixed dynamometry; L: left side; R: right side; ER: external rotation; IR: internal rotation; Max: maximum of 3 repetitions; Avg: average of 3 repetitions.

examiners. Strong inter-rater reliability is therefore important in order to account for the amount of error in a measurement (McGraw & Wong, 1996). Intra-rater reliability is important when a therapist is looking to monitor an athlete on a regular basis, or to determine the effectiveness of an intervention. A recent systematic review concluded that HHD testing for the upper limb showed acceptable intra-rater reliability for elbow measurements only (Schrama et al., 2014). However, research published after this review shows good inter and intra-rater reliability for shoulder rotation strength when tested in sitting with a 'make' (Dollings et al., 2012) and 'break' (Johansson et al., 2015) method employed. Likewise, this study, which employed HHD testing via a 'break' test, exhibited good to high reliability achieved in a standing position. The good to high reliability of the results in this study are likely explained by the standardisation of testing methods employed. Whilst these reliability results are comparable, the standing position may be preferable because it is easily transferable to a variety of clinical and sporting environments without the need for additional equipment.

The current results concur with earlier findings that EFD has excellent reliability for all shoulder movements (ICC > 0.80) (Beshay, Lam & Murrell, 2011). In situations where a trained physiotherapist is unavailable to assess shoulder strength with the preferred HHD method, it is a reasonable and reliable alternative to use an EFD and appropriate protocol. As technology has advanced and sports programs have evolved there is an increasing reliance on self-reported monitoring by athletes and practitioner independent methods of measurement are becoming necessary. Externally-fixed dynamometry is of interest for this purpose. Intra-rater reliability of the EFD method has the potential to allow an athlete or their coach/support staff to monitor changes in shoulder strength resulting from strength interventions or training. This study's results demonstrated high intra-rater reliability in agreement with a previous study of ICC 0.97 when using a stabilizing apparatus to secure a dynamometer for tests of shoulder internal and external rotation strength in sitting (Kolber et al., 2007).

One limitation of this study when comparing HHD and EFD with isokinetic dynamometry is the inability of HHD and EFD to test at more than one glenohumeral joint rotation angle. The peak force during HHD and EFD was recorded in a neutral shoulder rotation position whereas isokinetic testing determines force at multiple angles. Reliability results may have differed if HHD and EFD testing was conducted at different rotational angles; however this approach would be difficult to standardise and is time prohibitive. EFD can only be performed using a 'make' test, and as such the authors acknowledge the limitation of utilizing a break test in HHD. However, our research question was to determine whether HHD or EFD using the current methodology was a preferred clinical alternative to isokinetic testing, not whether a 'make' or 'break' test was a better measure of strength.

When utilizing strength tests it has been debated whether to use maximum values or the mean of the repetitions. Previously, when comparing the first of three tests to the mean of these three, better reliability was found using the mean (Dollings et al., 2012). The results of this study highlight that maximum values can be reliably measured, and have better correlations to isokinetic values for IR with negligible difference between the mean ER. Therefore, clinicians can confidently use maximum results using our methodology.

The SEM and MDC should be taken into account when determining the clinical utility of these measures. Our results are comparable with the only other study in the literature that has published SEM and MDC using HHD to measure eccentric shoulder internal and external rotation strength (Johansson et al., 2015). This allows the practitioner to determine the relevance of the measures recorded for the specific clinical case in which they are applying these measuring tools too.

The limitations of HHD and EFD also need to be considered. Two participants reported delayed onset of muscle soreness in the period of time following the testing procedure. It could be hypothesised that this is due to the fact that participants were also asked to perform maximal eccentric break tests during the HHD testing. Other previously suggested limitations of HHD testing, such as tester gender and strength, lack of stabilization and inconsistency of the testing procedure (Thorborg et al., 2013a; Wadsworth et al., 1992; Wikholm & Bohannon, 1991) were all negated by our methodological process and suggest these limitations are minimal in the dynamometry of the strength of internal and external rotation of the shoulder. Furthermore, the standardised methodology utilised in this study for HHD may explain the superior reliability over EFD, where the participant is required to perform a maximal effort.

It has been suggested that limitations of EFD in other joints include the need to regularly adjust the belt for limb length and joint angle (Thorborg et al., 2013b), as well as the equipment required to conduct the method (Beshay et al., 2011). When testing the shoulder, there is no need to change the belt length for alterations in lever length or joint angle as the belt remains fixed to the wall and the patient moves relative to the dynamometer. Despite the need for equipment during testing, the current EFD protocol allows a less bulky, more portable option than previously tested seated protocols (Beshay et al., 2011; Kolber et al., 2007).

A strength of this study is that absolute and relative reliability of both EFD and HHD were assessed in the same population thus allowing comparison of the methods. Furthermore, to evaluate which clinical test of shoulder strength is best, the same population was also assessed to determine which method has the highest correlation to isokinetic dynamometry, a form of laboratory measurement of strength, commonly referred to as the reference standard for strength assessment (Plotnikoff & MacIntyre, 2002; Stark et al., 2011).

## 5. Conclusion

The results of this study indicate that both EFD and HHD are suitable for clinical practice and research applications based on the good to high reliability and moderate to very strong correlations to isokinetic testing. Hand-held dynamometry is preferred due to its higher intra- and inter-rater reliability and smaller MDC and SEM. In situations where a suitable practitioner is unavailable, EFD is a viable alternative.

## Conflict of interest

None declared.

## Funding

None declared.

## Ethical approval

This study was approved by the Australian Institute of Sport Ethics Committee (Ethics Approval Number: 20130414).

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