Reliability of the ForceFrame With and Without a Fixed Upper-Limb Mold in Shoulder Rotation Strength Assessments Compared With Traditional Hand-Held Dynamometry

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Context: An imbalance between shoulder internal rotation (IR) and external rotation (ER) strength in athletes is proposed to increase the risk of sustaining a shoulder injury. Hand-held (HHD) and externally fixed dynamometry are reliable forms of assessing shoulder IR and ER strength. A new externally fixed device with an attachable fixed upper-limb mold (The ForceFrame) exists; however, its reliability in measuring shoulder strength is yet to be investigated. **Objective:** To determine the test–retest reliability of the ForceFrame, with and without the fixed upper-limb mold, in the assessment of shoulder IR and ER strength, as compared with HHD. **Design:** Test–retest reliability study. **Setting:** Laboratory, clinical. **Participants:** Twenty-two healthy and active individuals were recruited from the university community and a private physiotherapy practice. **Main Outcome Measures:** Maximal isometric shoulder IR and ER strength was measured using the ForceFrame and traditional HHD in neutral and at 90° shoulder abduction. Mean (SD) strength measures were calculated. Test–retest reliability was analyzed using intraclass correlation coefficients (3, 1). The SEM and minimal detectable change were calculated. **Results:** Good to excellent test–retest reliability was found for all shoulder strength tests across HDD and ForceFrame dynamometry (intraclass correlation coefficients [3, 1] = .854–.916). The minimal detectable changes ranged between 25.61 and 41.84 N across tests. Test–retest reliability was not affected by the dynamometer or testing position. **Conclusions:** The results from this study indicate that both the ForceFrame and HHD are suitable for measuring shoulder strength in clinical practice. The use of the fixed upper-limb mold with the ForceFrame does not improve reliability.

Keywords: hand-held dynamometry, ForceFrame, shoulder, reliability

In the overhead athlete, there is evidence that imbalance between internal (IR) and external rotation (ER) strength, either reported as absolute measures or a ratio between the 2, increases the risk of sustaining a shoulder injury.¹ The ability to accurately and effectively measure and monitor shoulder IR and ER strength may allow clinicians and coaches to identify those at an increased risk of injury. Accurate measures may also assist in guiding clinical practice and decision making regarding a return to sport following injury.

Hand-held dynamometry (HHD) and externally fixed dynamometry (EFD) are reliable forms of assessing shoulder IR and ER strength.² Both methods show good to excellent reliability^{2,3} and share strong correlations to the “gold standard” isokinetic dynamometry.² Using HHD to assess strength may be compromised in situations where the examiner is unable to match the force of the patient. While considered practical due to its size, cost, and portability, HHD is not without its limitations. Inconsistencies in the reliability of HHD have been attributed to variables in the examiner, including strength, sex, and/or experience.⁴ EFD has been shown to produce more consistent results than HHD in the upper extremity.⁵

A piece of equipment (The ForceFrame, Vald Performance, Brisbane, Australia) exists that utilizes load cells fixed to a frame to measure peak torque in standardized and repeatable positions. The ForceFrame is comprised of an adjustable rig fitted with 4

independent and custom-made uniaxial load cells. An attachable, prefabricated, fixed upper-limb mold can be used in conjunction with the ForceFrame to stabilize the shoulder while measuring muscle force. The reliability of the ForceFrame is high when measuring hip adduction strength (average intraclass correlation coefficient [ICC] = .94),⁶ but there is currently no research involving the use of the ForceFrame for measuring shoulder strength. This study aimed to evaluate the between-session intrarater reliability of the ForceFrame with and without the fixed upper-limb mold in shoulder rotation strength assessments as compared with traditional HHD. It was hypothesized that the ForceFrame would have better reliability compared with HHD and that utilizing the fixed upper-limb mold would yield better reliability than the ForceFrame alone.

Methods

Participants

Potential participants were recruited in a sample of convenience from the university community and a private physiotherapy practice. Both shoulders of each participant were tested where possible. Participant shoulders were excluded if they had any history of shoulder surgery or dislocation or had shoulder pain within the previous 2 months. The included participants were required to be healthy and active. The definition of healthy and active for the purpose of this study involved participating in at least 2.5 hours of physical activity per week. This was to ensure that the sample group was representative of an athletic population. Ethics approval was granted by the La Trobe University Human Ethics Committee

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(HEC19399), and all participants provided written informed consent.

Procedures

Strength assessments were conducted using the ForceFrame with and without the fixed upper-limb mold and traditional HHD (Commander; JTECH Medical Industries, Midvale, UT). With the participants lying supine, shoulder IR and ER strength were measured in 2 positions: shoulder in neutral (Figure 1A) and shoulder in 90° abduction (Figure 1B). The latter position was

replicated when using the fixed upper-limb mold (Figure 1C). HHD was conducted in the same 2 positions described above (Figure 1D and 1E). The dynamometer was positioned so that the load cell/transducer head was aligned with the wrist crease, distal to the ulnar styloid process. To standardize the testing position and reduce the contribution of other body segments during testing, the participants were instructed to keep their back and shoulder blade against the floor or plinth, legs straight, and their nontest arm outstretched by their side.

The participants performed a 3-repetition warm-up against a dynamometer in both rotation directions (IR/ER), followed by 3

Figure 1 — (A) ForceFrame testing position 1: neutral, (B) ForceFrame testing position 2: 90°, (C) ForceFrame testing position 3: 90° + fixed upper-limb mold, (D) HHD testing position 1: neutral, and (E) HHD testing position 2: 90°.

repetitions of the strength test for each rotation direction, in each testing position. The participants were asked to gradually build to a maximal contraction and maintain the effort over 5 seconds. A rest period of 10 seconds was given between repetitions and 60 seconds was given between test positions. The examiners provided strong verbal encouragement to ensure maximal effort.

Two examiners conducted the strength testing. Examiner A was a qualified physiotherapist with 5 years' clinical experience. Examiner B was a final year undergraduate physiotherapy student. Examiner A was the tester for HHD, and examiner B was the tester for the ForceFrame. This remained constant throughout the testing process.

The data were collected over 2 testing sessions for each participant, separated by 1 week. The participants were instructed to maintain their normal activity between testing. The strength test order was randomized for the dynamometry method, test side, and rotation direction. The testing order for each participant was repeated in the subsequent session.

Statistical Analysis

The maximum force value in newtons (N) from the 3 repetitions was recorded. From these data, the overall mean and SD were calculated for each strength test in each position across both sessions and used for analysis. Between-session test–retest reliability was analyzed using ICC_{3,1}; 2-way mixed model.⁷ Reliability was reported as excellent (ICC ≥ .90), good (ICC = .80–.89), moderate (ICC = .70–.79), or low (ICC < .70) in accordance with predefined criteria.⁸ To assess absolute reliability, the SEM ($SD_{\text{pooled}} \times [\sqrt{1 - \text{ICC}}]$) and minimal detectable change (MDC; $\text{SEM} \times 1.96 \times \sqrt{2}$) were calculated.^{4,7,9} To test for systematic error between strength scores with and without the fixed upper-limb mold at 90° abduction, independent *t* tests were conducted. Statistical analysis was performed using IBM SPSS Statistics (version 25; IBM Corp, Armonk, NY).

Results

Twenty-two participants were screened and included in the study (men = 11 and women = 11; age = 26.3 [5.4] y, height = 175 [10.6] cm, weight = 73.1 [13.2] kg; right arm dominant = 17).

For 2 participants, only 1 shoulder was tested, secondary to current shoulder pathology. There were no reports of shoulder pain during testing.

Good to excellent test–retest reliability was found for all shoulder-strength tests across the HHD and ForceFrame dynamometry tests (Table 1). The MDC ranged from 26 to 41 N across tests (Table 1). There was a significant difference (*P* values = .009–.012) in the IR strength measures with the addition of the fixed upper-limb mold to the ForceFrame measures at 90° abduction (Table 2). No such difference was observed in the ER strength measures.

Discussion

This study aimed to evaluate the reliability of the ForceFrame with and without the fixed upper-limb mold in shoulder rotation strength assessments as compared with traditional HHD. The results from this study demonstrate good to excellent reliability of HHD and the ForceFrame when measuring shoulder strength in healthy participants. Excellent reliability (ICC = .91–.92) was demonstrated using the ForceFrame for ER strength tests in neutral and at 90° abduction. The hypothesis that the ForceFrame would demonstrate better reliability compared with HHD was partially confirmed with slightly better results across all testing conditions except IR strength in a neutral position. The fixed upper-limb mold improved reliability in ER but not IR, contrary to our expectation that it would improve reliability overall.

Overall, the results are comparable to previously described studies of intrarater reliability between HHD (ICC = .92–.98) and EFD (ICC = .89–.98)^{2,5} when measured in neutral and standing or seated positions.^{2,5} Previously reported intrarater reliability for HHD in the supine position and 90° shoulder abduction (ICC = .92–.97) also had comparable results to this study.³

This study established a spread of SEM (9.24–15.10) and MDC (25.61–41.84) values that can be easily interpreted when using HHD or the ForceFrame in clinical practice. To be confident that a true strength change had occurred in your patient or athlete, rotation strength would need to change by >25 N. The MDC results from this study are greater than those reported in studies measuring isometric shoulder rotation strength in a supine position with HHD.³ This may be due to the heterogenous nature of participants

Table 1 Mean Scores, Test–Retest Reliability, SEM, and MDC

Test	Dynamometer	Shoulder position	Test 1, N Mean (SD)	Test 2, N Mean (SD)	ICC (95% CI)	SEM, ^a N	MDC, N
ER	HHD	Neutral	138.00 (33.77)	137.71 (31.99)	.87 (.78–.93)	11.52	31.92
		90°	145.51 (38.01)	149.93 (38.29)	.91 (.84–.95)	11.40	31.61
	ForceFrame	Neutral	122.44 (33.84)	117.00 (31.63)	.92 (.83–.96)	9.24	25.61
		90°	132.37 (39.62)	129.63 (36.55)	.92 (.85–.95)	11.02	30.54
		90° (mold)	134.61 (39.95)	130.22 (39.20)	.91 (.84–.95)	11.67	32.35
IR	HHD	Neutral	152.95 (39.51)	153.39 (37.53)	.92 (.85–.95)	10.97	30.39
		90°	137.66 (38.69)	139.56 (41.15)	.85 (.74–.92)	15.10	41.84
	ForceFrame	Neutral	120.98 (35.94)	119.27 (34.45)	.89 (.81–.94)	11.44	31.70
		90°	124.59 (35.92)	121.80 (32.82)	.85 (.75–.92)	12.93	35.85
		90° (mold)	119.07 (35.60)	115.07 (34.52)	.90 (.81–.94)	11.18	30.98

Abbreviations: CI, confidence interval; ER, external rotation; ICC, intraclass correlation coefficient; HHD, hand-held dynamometry; IR, internal rotation; MDC, minimum detectable change.

^aUsing pooled SD.

Table 2 Test 1 and Test 2 Mean Scores and P Values for ForceFrame Strength Measures at 90° Shoulder Abduction With and Without the Fixed Upper-Limb Mold

Test	Test session	90°, N Mean (SD)	90° + mold, N Mean (SD)	P value
ER	1	131.31 (39.72)	133.60 (40.00)	.273
	2	129.21 (36.21)	129.45 (39.04)	.908
IR	1	124.93 (35.54)	119.19 (35.17)	.012
	2	121.83 (32.42)	115.05 (35.00)	.009

Abbreviations: ER, external rotation; IR, internal rotation.

within this study. Previous studies have used homogenous participant groups of a tighter age range³ recruited from a specific setting.³ The variation in participant age and type within this study may be more reflective of clinical practice.

Strength tests performed at 90° shoulder abduction using the ForceFrame with the fixed upper-limb mold resulted in a slight decrease in IR strength. This may be attributable to the slight change in the abduction angle of the shoulder with the addition of the fixed upper-limb mold. The mean difference was <10 N at both testing sessions, so this difference is unlikely to be clinically relevant, but could influence IR/ER ratio calculations. Regardless, it is recommended that, if the fixed upper-limb mold is used in conjunction with the ForceFrame, it be used repeatedly during retesting. No statistically significant difference was observed with the ER tests.

Using HHD to assess strength may be compromised in situations where the examiner is unable to match the force of the patient. Inconsistencies in reliability of HHD have been attributed to variables in the examiner, including strength, sex, and/or experience.⁴ The ForceFrame may be preferable in some settings due to its consistency in producing reliable strength measures regardless of the examiner.

One limitation of the ForceFrame for measuring shoulder rotation strength is that participants can only be tested in the supine position. While there is a perception that it is less functional, the supine position has the advantage of reducing involvement from the trunk and leg muscles.

In comparison to other EFD, which may be limited to measuring strength in a neutral shoulder position,² the ForceFrame can measure shoulder IR and ER strength in neutral and 90° abduction. This may be of benefit when assessing the overhead athlete, as throwing, serving, and spiking movements involve IR and ER in 90° of shoulder abduction.

Conclusions

The results from this study indicate that both the ForceFrame and HHD are suitable for measuring shoulder strength in clinical practice. As HHD reliability may be affected by several variables in the examiner, the ForceFrame may be preferred due to its consistency, regardless of the examiner. The use of the fixed upper-limb mold with the ForceFrame is not required to improve reliability and might reduce IR strength results.

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