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Assessment of isometric strength of the shoulder rotators in swimmers using a handheld dynamometer: a reliability study

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Purpose: The purpose of this study was to determine the reliability of shoulder isometric strength assessment using the microfet 2™ dynamometer in adolescent swimmers. **Methods:** Twenty-nine participants (16.2 ± 1.2 years old; 59.05 ± 6.98 kg of body mass) were tested using the microfet 2™ dynamometer. Swimmers performed an isometric strength test (IST) in two distinct occasions with 7 days apart in order to calculate the reliability. All participants were asked to perform a maximal isometric contraction from the external and internal shoulder rotators in a prone body position. **Results:** The external and internal shoulder rotators showed an excellent intraclass correlation coefficients for both shoulders, with more than 0.90 and a low percentage of method error variation. The external/internal ratios reliability was good in dominant (ICC 0.80) and non-dominant (ICC 0.81) shoulders. The reliability using Bland–Altman method showed that systematic errors (mean difference between test-retest) were nearly zero and the 95% limits of agreement narrow, indicating a good reliability. **Conclusions:** It can be concluded that microfet 2™ is a reliable apparatus for measuring the strength of the external and internal rotation of the shoulder in swimmers. Its light weight and easy portable characteristics can help swimming coaches monitoring specific dry-land strength training programs for their swimmers.

Key words: handheld dynamometer; prone position; young swimmers; swimming

1. Introduction

The shoulder internal and external rotators muscles play an important role, providing stability and mobility to the glenohumeral joint, particularly in overhead athletes [25], [32]. The competitive swimming is considered an endurance sport, characterized by cyclical actions of the upper limbs, in which the shoulder complex plays a critical role [1], [15]. Water-training programs and competition sessions promote imbalances in swimmers' shoulder rotator muscles [1]. This is a consequence of the fact that shoulder internal

rotators (IR) become proportionally stronger, compared to their antagonist, increasing the agonist–antagonist muscle imbalance [1]. The successful prevention of shoulder injuries in swimmers can be achieved by establishing proper muscular balance.

Competitive swimmers perform, in their daily workouts, a large training volume, using mostly the freestyle swimming. If they take 8 to 10 cycles per 25 meters, they can reach 1 million shoulder rotations per week, increasing substantially the risk of shoulder injuries [13], especially considering the important propelling forces produced by the arms [17], [20]. Several studies showed that the IR are stronger, compared to the exter-

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nal rotators (ER) [19]. To better monitor training load and prevent injury is important to assess the shoulder rotators strength, detecting possible muscle imbalances.

The process of evaluating the isometric shoulder strength must have a valid and reliable methodology to be meaningful and interpretable in the study population [22], because the more reliable the evaluation, the more sensitive is to track clinical important changes. There are several evaluation methods to assess shoulder rotators strength, including the manual muscle testing (MMT), hand-held dynamometry (HHD) and isokinetic testing [16]. Although isokinetic test is considered the most accurate method, it is not often used, given the environment control (requires a laboratory) and the larger operating costs [6], [30]. The HHD is a more friendly method, easy to perform and is more objective than the MMT in assessing muscle strength changes [28]. Moreover, there are new HHD devices with light weight and easy portable characteristics that could help swimming coaches monitoring specific dry-land strength training programs for their swimmers. Nevertheless, its reliability must be ensured.

Some previous studies with HDD showed the importance of this method in the measure-of-strength tests, Rieman et al. [26] compared limbs and genders in 3 body positions (prone, seated and 30° diagonal position) with HHD, suggesting that the ER in prone position at 90° was stronger than in the seated for both genders. Regarding the IR, has demonstrated greater strength at the neutral position but only for women's. Katoh et al. [14] showed high reliability of isometric shoulder joint muscle strength measurements with an HHD and a belt in young healthy subjects, however recommended the application of 2 measurements to decrease the errors in the absolute reliability. McLaine et al. [18] compared the reliability of shoulder-strength tests comparing 3 body positions (prone, supine and sitting position) with HHD and found excellent intra-rater reliability for ER and IR strength tests performed in 90° shoulder abduction in all positions.

The reliability of ER and IR muscle strength measurements is essential for swimmers, being important in the training control and injury prevention [2]. However, this is a controversial issue because it is influenced by many factors (mechanical aspects, participants, joints, and testing protocols). The assessment position (shoulder posture and joint-axis alignment) and body position (sitting, supine, prone or standing and stabilization), appear to be determining factors [9], [24]. Therefore, our study aims to determine the reliability of shoulder internal and external rotation strength tests with an HHD using a prone body position in swimmers.

We hypothesised the novel method would exhibit good reliability in the quantification of isometric IR and ER shoulder strength in young swimmers in the prone position.

2. Material and methods

2.1. Experimental approach to the problem

The internal and external shoulder isometric strength of dominant and non dominant arms of the swimmers were monitored with a dynamometer microfet 2™. The variables selected were the maximal strength of internal and external rotation, and were obtained with a full isometric contraction (5 seconds). To analyse muscle balance, the ER/IR ratios were calculated.

2.2. Subjects

Twenty-nine swimmers (21 female and 8 male) (age: 16.2 ± 1.2 years, height: 164.8 ± 6.68 cm, body mass: 59.05 ± 6.98 kg) volunteered to participate in this study (Table 1). The inclusion criteria were: (1) no clinical history of upper limb disorders; (2) more than 4 weekly workouts; (3) competing at the national level.

Before data collection participants did not participate in any formal upper extremity strength, conditioning, or swim training. Main objectives and experimental procedures were described to all participants. The participants and their legal guardians gave their written consent to the participation in the study. The Ethics Committee of the seeding Institution (proceeding 16019/2016) gave their approval on all the procedures, which were under the Helsinki Declaration of 1975, amended by the 64th WMA General Assembly, Fortaleza, Brazil, October 2013.

Table 1. Sample Characteristics ($N = 29$) mean (SD)

Characteristics	Mean (SD)
Age [years]	16.2 (1.2)
Body mass [kg]	59.05 (6.98)
Height [cm]	164.8 (6.68)
Wingspan [cm]	168.6 (7.3)
BMI [kg/m ²]	21.58 (1.89)
Distance per week [km]	37.33 (10.40)
Years of training	7.17 (1.12)
Training per week	5.90 (0.88)

2.3. Procedures

For assessing the internal and external shoulder rotators strength we used the microfet 2™ Digital Handheld Muscle Tester (Hoggan health, Draper, UT, USA), which is an accurate, portable Force Evaluation and Testing (FET) device, with a sample frequency of 10 sample/second. It is a modern adaptation of the time-tested art of hands-on manual muscle testing, with wireless capability this HHD is battery operated, and is ergonomically designed to fit comfortably in the palm of the hand. Strain gauge elements within the transducer react independently to measure external forces from multiple angles. This system enables the gauge to detect even subtle changes in force regardless of the direction in which it is applied.

In order to calculate the test-retest reliability, the measures were performed on two separate occasions, 7 days apart, and the participants were asked to make absence of adaptations to the exercise during this period and also absence of training in the same day. The tests were conducted by one experienced tester (male, height 175 cm, weight 75 kg), with over 10 years of experience performing muscle strength measurement with an HHD.

First, all participants completed a questionnaire which included questions on hand dominance, shoulder injury, pain and swimming frequency. A five minutes of shoulder warm-up performed with articular mobility and resistance tubing in the same directions used for testing supervised by the tester.

Secondly, shoulder ER and IR strength tests were performed bilaterally in prone position with 90° of shoulder abduction and 0° of rotation with the elbow flexed to 90° (Figs. 1 and 2), according by Roddey et al. [28], Rieman et al. [26] and Cools et al. [6], [7]. The order of testing position, sides (dominant, non-dominant), and motions (internal rotation, external rotation) was randomized. The same order for the strength test was used for both sessions. The tester stabilized the humerus distally against the stretcher, and the participants used the opposite arm to grasp it next to the test table for support. The HHD was placed just proximal to the ulnar styloid process on the posterior surface of the forearm to assess ER strength, to assess IR strength the HHD was positioned using the same anatomical landmarks but on the anterior surface of the forearm. This position was chosen because of its similarity with the actions that swimmers perform in most of the swimming techniques and because it was used previously [25]. After

positioning, participants performed a warm-up protocol that consisted of 2 submaximal and 1 maximal isometric contraction in each direction, separated by 30 seconds of rest [25].



Fig. 1. Shoulder External Rotation measurement



Fig. 2. Shoulder Internal Rotation measurement

The maximal IR and ER isometric strength was evaluated with two repetitions for each shoulder and

each rotation ($2 \times \text{IR}$ and $2 \times \text{ER}$), using a make-type test in which the participants were instructed to slowly produce and sustain a full isometric contraction (5 seconds) of the involved muscle group until the examiner instructed them to relax. To analyse muscle balance, the ER/IR ratio $[(\text{ER}/\text{IR}) \times 100]$ was calculated [31]. All tests had a resting period of 10 seconds between each repetition and 60 seconds between each strength test. During the entire period of force production the tester motivated verbally the participants. The maximum value recorded from the two repetitions of each test session was used for analysis.

2.4. Statistical analyses

The overall mean and standard deviation (SD) in Newtons [N] were calculated for each strength test in prone body position.

Reliability analysis were performed following the literature recommendations [34]. Test-retest intraclass correlation coefficients (ICC) was determined using the ICC 3.1 (two-way mixed, single measures) with 95% confidence intervals for the two repetitions [12], [29].

We used the Bland and Altman method, which includes a scatter plot of the differences between test and retest against their mean, and was also used to define the magnitude of disagreement between test and retest values [3]. This method also includes the Limits of Agreement (LOA), which represent the mean difference between tests and its 95% Confidence Interval (CI).

To evaluate individual changes over time, the magnitude of the change has to exceed the inherent variability of the outcome. Within this context, the LOA can be used to assess a real change in an individual's performance (i.e., if the difference between

two measurements is outside the LOA, there is a true change in performance [3].

Absolute reliability was estimated by calculating the Standard Error of Measurement (SEM) and the Smallest Real Difference (SRD). The SEM was calculated as follows: $\text{SEM} = \text{SD} \sqrt{1 - \text{ICC}}$ where SD is the mean SD of the two repetitions. The SRD was $1.96 \cdot \text{SEM} \sqrt{2}$. SEM and SRD were converted into percentages to facilitate further comparisons with other studies.

All analyses were performed using the Statistical Package for Social Sciences (SPSS, version 16.0 for Windows; SPSS Inc., Chicago, IL), and the level of significance was set at 0.05. Reliability was reported as excellent ($\text{ICC} \geq 0.90$), good (ICC between 0.80 and 0.89), moderate (ICC between 0.70 and 0.79) and low ($\text{ICC} < 0.70$) [23].

3. Results

The IR showed excellent reliability (ICC 0.98) in dominant and non-dominant shoulders and a low percentage of SRD consistently below 10%. Regarding the ER, both shoulders demonstrated a smaller but equally excellent reliability (ICC 0.92–0.93) and low percentage of SRD 15.34% and 13.10% respectively (Table 2).

The ER/IR ratios reliability of dominant and non-dominant shoulders was good (ICC 0.80 and 0.81) (Table 2).

We can observe that the differences between test and retest plotted against their mean for each subject with 95% CI and 95% LOA (Fig. 3). The systematic errors (mean difference between test-retest) for analysed test were nearly zero and the 95% limits of agreement narrow, indicating a good reliability of the measurement (Fig. 3).

Table 2. Comparison of measurements ($N = 29$) obtained from the two testing sessions, mean (SD)

Shoulder Action	Max Test mean [SD]	Max R Test mean [SD]	ICC	SEM	SEM%	SRD	SRD%
IR_Dominant [N]	147.75 (36.99)	152.95 (39.36)	0.98 (0.89 to 0.99)	4.98	3.31	13.80	9.18
IR_Non-Dominant [N]	143.38 (36.95)	143.14 (33.81)	0.98 (0.95 to 0.99)	5.00	3.49	13.87	9.68
ER_Dominant [N]	118.41 (22.24)	118.36 (24.08)	0.92 (0.83 to 0.86)	6.55	5.53	18.16	15.34
ER_Non-Dominant [N]	110.18 (20.62)	110.48 (18.73)	0.93 (0.86 to 0.97)	5.21	4.73	14.45	13.10
Ratios_Dominant [%]	81.81 (10.29)	78.76 (8.95)	0.80 (0.55 to 0.91)	4.30	5.36	11.93	14.85
Ratios_Non-Dominant [%]	78.94 (11.74)	78.71 (9.36)	0.81 (0.62 to 0.91)	4.60	5.83	12.75	16.17

ER – external rotation, IR – internal rotation, Max Test – maximal test, Max R Test – maximal test re-test, ICC – intraclass correlation coefficients, SEM – Standard Error of Measurement, SRD – Smallest Real Difference, N – Newtons, Ratios $[(\text{ER}/\text{IR}) \times 100]$.

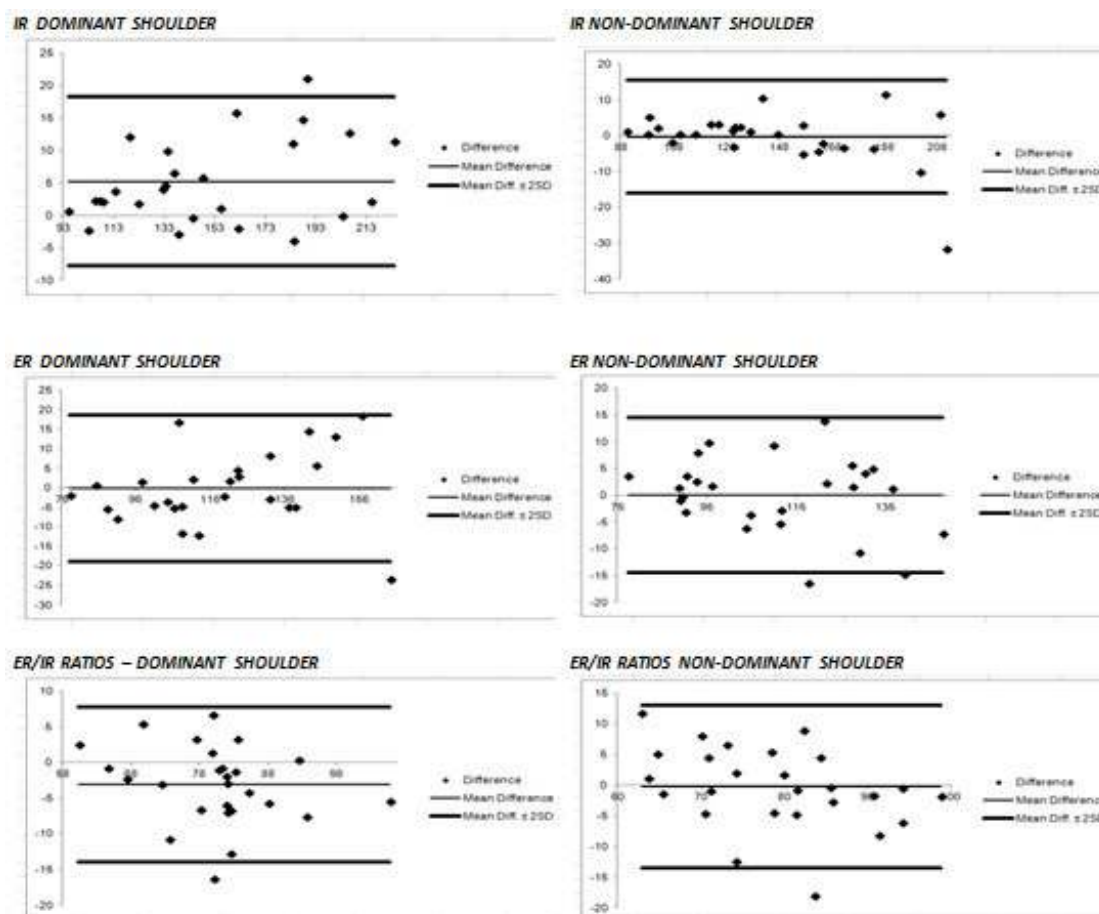


Fig. 3. Bland–Altman Plot of ER, IR and ratios dominant and non-dominant index scores in swimming athletes

4. Discussion

The results of this study clearly confirm the reliability of the microfet 2™ Digital Handheld Muscle Tester while evaluating the shoulder internal and external isometric strength in swimmers.

Previous studies performed retesting on the same day, others retested after 48 hours [10], [18], [26], or 7 days apart [12]. Our retest was performed 7 days after the first one in order to prevent muscle fatigue as well as the absence of adaptations to the exercise. It is important to reinforce that there was not any significant change in training volume and intensity in these two weeks of training, in addition to the verbal reinforcement in the first evaluation, we were maintaining contact with the athlete's trainers so that there were no changes in training volumes and loads.

Considering the assessment position, traditionally, shoulder rotators strength is evaluated in a seated, standing or supine position [2], [6], [9], [28], [30] with good or excellent ICC (more than 0.80). Previous studies described excellent ICC values (0.93–0.99) for

ER/IR strength tested at 90° shoulder abduction and forearm flexion in all positions, including the prone position [6].

Papotto et al. [21] assumed, at isolated measures (torque), high ICC values in isometric shoulder actions associated to SRDs varying between 6% and 23%. In our study, the SRD variations fluctuate between 9% and 13% associated with high ICC values.

Given that swimmers perform most of the technical executions in the prone position, it should be important to access shoulder strength ICC in this standard position. Our study showed excellent reliability for ER/IR strength tests performed in 90° of arm abduction and elbow flexion in prone position, and the minimal detectable change remained low. This is not in agreement with previous interventions that not used an external or manual stabilization [11]. We believe that the scapula stabilizing is a very important action to potentiate the strength of the muscles in action. Others studies indicate an ER/IR excellent reliability with stabilization of the upper arm, shoulder, scapula and trunk with manual fixation by the examiner's [6]. Similarly, another study assessed the strength of the shoulder ro-

tators with a HHD in the same prone position (arm at 90° of abduction, 0° of rotation and elbow flexed to 90°), and there was a concern to stabilize the scapula, which seems to have an essential importance [25].

The minimal detectable change values for ER/IR strength measured in this study are comparable to those previously reported at 90° shoulder abduction and prone position, below 15% [6], [18]. This enables establishing the percentage of real changes and helps clinicians or trainers to accurately evaluate the effectiveness of dry land or water strength programs.

Because of the reliance on the dynamic stabilizers for shoulder stability, absolute strength might not be as important as developing “balanced” ER/IR strength ratios [25]. The determination of these unilateral ratios is very important, since they characterize the quality of muscular balance [10], and are often correlated (low values, under 66%) with shoulder injuries [4]. Some studies even have reports that changes in the shoulder strength balance could lead to musculoskeletal dysfunction [5], [33]. In our study the reliability of the IR: ER ratios are good (ICC 0.80–0.81) with a % SEM about 5%. Edouard et al. [8] showed that the knowledge of the reliability of isokinetic or isometric evaluation will support the potential shoulder dysfunction diagnosis. Thus, to interpret a single measurement or to detect a real change between 2 measures of IR and ER and ER/IR ratios (dominant and non-dominant), the SEM it is the most important and significant issue to access [8].

Another issue is that the strength of the tester may affect the ability to stabilize the HHD and, therefore, may influence the reliability of the measurements [6], [18], [30]. However, McLaine et al. [18] stated that maybe the consistency of the HHD, the subject positioning, clear instructions to participants and familiarization with the tests by incorporating these as the warm-up movements are likely to have contributed to the reliability results achieved [18].

The results of this study can only be applied to assessments in prone position, indicate that both method and apparatus are reliable and functionally relevant for ER/IR shoulder strength tests in young swimmers, or other overhead athletes with shoulder problems and specific muscle strengthening needs.

Our study had some main limitation that is due to the shoulder ER/IR strength testing position. The results can only be applied in the prone position.

Implications

In order to define adequate training plans that maximize performance and minimize the risk of injury, it is essential to have an exhaustive knowledge

of the swimmers physical qualities, where strength plays a very important role. However, strength quantification is not always easy to obtain in a training context.

Strength assessment requires the presence of swimmers in specific laboratories, sometimes difficult to access and financially costly. Therefore, based on our results, we believe that the microfet 2™ Digital Hand-held Muscle Tester, being a portable Force Evaluation and Testing device, can be a relevant tool to shoulder-strength-testing protocol for the young swimming population.

5. Conclusions

Reliability of the IR and ER shoulder isometric torque is excellent and IR/ER ratios is good, using the microfet 2™ hand-held dynamometer in young swimmers in the prone position (arm at 90° of abduction, 0° of rotation and elbow flexed at 90°).

The hand-held dynamometer microfet 2™ can be used with confidence as an instrument for assessing muscle strength and monitoring changes due to rehabilitation or training interventions, mainly in non-laboratory environments.

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