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DIAGNOSTIC METHODS: ORIGINAL RESEARCH

Isokinetic assessment of shoulder complex strength in adolescent elite synchronized swimmers

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ABSTRACT

Children and adolescent participation in sport has increased in recent years. Synchronized swimming requires correct muscle balance in the shoulder complex. The purpose of this study was to establish isokinetic strength profiles and peak torque ratios of shoulder internal and external rotator muscles in a female high-level synchronized swimming team. Twenty-six adolescent female high-level synchronized swimmers, aged 12–14, participated in this study. Maximal bilateral shoulder concentric external and internal rotation force was measured at 60°/s (5 repetitions) and 180°/s (15 repetitions). The isokinetic concentric strength generated by the internal rotator muscles was significantly higher ($p < 0.05$) than by the external rotators in both limbs and at both velocities. Significant bilateral differences in the external rotation (ER):internal rotation (IR) strength ratio were noted at 60°/s. Isokinetic assessment is essential in sports medicine, since it is the only test capable of diagnosing any shoulder strength deficit.

1. Introduction

Children and adolescent participation in sport has increased in recent years (Hibberd et al., 2016). Participation at high competitive levels of youth and professional sports has increased injury incidence (Kocher et al., 2000; Kerssemakers et al., 2009). Musculoskeletal development of adolescent athletes is incomplete and, therefore, muscular imbalances may appear when two antagonist muscle groups have not achieved similar strength levels. Stability of the shoulder complex depends, among other factors, on muscular balance (Wong and Ng, 2009). Since such imbalances are shown to be associated with chronic injuries or deformities, their identification at an early stage is important.

Swimming is a demanding sport, especially with respect to the shoulder joint (Van de Velde et al., 2011). Sports with high overhead demands such as swimming often cause repetitive overuse injuries to the shoulder complex (Weldon and Richardson, 2001; Ong et al., 2002). Synchronized swimming is a symmetrical sport, since both upper limbs are used in a very similar way. Synchronized swimmers have larger passive range of motion in the shoulder joint and make fewer active joint repositioning errors (Cho et al., 2017). Between 40 and 89% of high-level swimmers have suffered shoulder pain at least once in their career (Olivier et al., 2008). The most frequent injuries in young swimmers are impingement syndrome and glenohumeral instability (Kocher et al., 2000). Changes in the shoulder muscular strength profile may reveal shoulder injuries, especially in athletes who practice overhead sports (Kocher et al., 2000; Stickley et al., 2008; Niederbracht et al., 2008). Stickley et al. (2008) and Huang et al. (2005) found shoulder injuries that were associated with weakness of the rotator cuff.

The purpose of this study was to analyze the isokinetic strength profile of the shoulder rotator muscles in adolescent synchronized swimmers in order to investigate the effects of training on strength, stability and muscle imbalance of the shoulder complex, in an attempt to improve rehabilitation and training protocols and to prevent related injuries.

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2. Methods

2.1. Participants

This study was conducted with the synchronized swimming team of the self-governing region of Madrid, who participate in the national league and in international competitions.

Twenty-six female elite synchronized swimmers, aged 12 to 14, participated in the study. All participants were right-handed. They completed a medical questionnaire detailing chronic diseases, surgical history, allergies and injury history, especially shoulder disorders. No shoulder injury was reported in the six months previous to the study. All participants had a similar skill level. They trained 6 days/week, 6 h/session, totaling 36 h per week. Training included shoulder-specific strength exercises. All participants and their legal guardians were informed about the study and they all signed an informed consent form. The study conforms to The Code of Ethics of the World Medical Association.

2.2. Test protocol

The tests were conducted at the Sports Medicine Center of the self-governing region of Madrid (Spain). A clinical examination of both shoulders was performed before the isokinetic assessment, which was carried out using a Biodex System 3 PRO (Biodex Medical Systems, Inc., Shirley, NY). The dynamometer was regularly calibrated during the study period.

The measurements were conducted in a sitting position, with two straps across the chest and one strap across the pelvis. The chair was rotated 90°. A modified neutral position was used with 45° of abduction and 30° of flexion in the glenohumeral joint, 90° of flexion in the elbow and the forearm in neutral prono-supination position (Dvir, 2004). The dynamometer axis was aligned with the longitudinal axis of the humerus, through the olecranon. The other hand held on to the stabilizing handle during the test. In agreement with several authors and the manufacturer's guide, a correction for gravity was used (Edouard et al., 2009; Buchanan and Vardaxis, 2003).

This position was used to increase participants' comfort (Stickley et al., 2008; Ellenbecker and Davies, 2000; Perrin, 1993) and to reduce the risk of anterior instability (Labriola et al., 2005) and subacromial impingement (Ellenbecker and Davies, 2000; Gozlan et al., 2006).

During the test, standardized verbal instructions were given to the participants but no visual feedback was provided (Olivier et al., 2008; Wong and Ng, 2009).

Participants were tested bilaterally, starting with the dominant shoulder. The arm that the participants used to throw a ball was determined to be their dominant arm.

All participants completed all data collection phases without reporting pain or discomfort in the shoulder. Strength was tested at 60°/s and 180°/s. Five repetitions were made at the lower angular velocity and 15 at the higher angular velocity. There was a 30-s rest period between angular velocities and a 5-min rest period between the dominant and the non-dominant shoulders.

The range of motion was 90°: 35° for external rotation (ER) and 55° for internal rotation (IR). Each participant warmed up for 20 min before the test and cooled-down for 10 min after the test. Exercises included 10 min cycling on a cycle ergometer and 10 min stretching the involved muscles. Subsequently, they completed submaximal familiarization trials.

Table 1
Demographic and anthropometric data, and training history.

	Mean (SD)	Min	Max
Age	13.2 (1.1)	12	14
Height (cm)	159.5 (5.8)	148	169
Body mass (Kg)	44.3 (7.1)	41	53
Years of training	6 (2)	4	8
Years of competition	3.6 (1.7)	1	5

Values are minimum (Min), maximum (Max), mean and standard deviation (SD), n = 26.

Table 2
Measurements of isokinetic concentric strength (Newton-meters).

Direction	Velocity	Dominant	Non-dominant
		Mean (SD)	Mean (SD)
External rotation	60°/s	14.57 (3.27)	13.49 (2.91)
	180°/s	15.38 (2.96)	15.008 (3.06)
Internal rotation	60°/s	20.28 (4.02)	20.0 (5.2)
	180°/s	19.96 (4.8)	20.44 (5.02)

Values are mean and standard deviation (SD), n = 26.

2.3. Statistical analysis

SPSS software (version 17.0; SPSS Inc., Chicago, IL) was used to analyze the data.

Since all data followed a normal distribution, parametric tests were used for statistical analysis. The data homogeneity was confirmed by using the Kolmogorov–Smirnov test. Means and standard deviations (SD) were calculated for demographic and anthropometric data, peak torque and standard ratio. Inter-limb differences were examined. The dependent Student's t-test was applied to compare the means of peak torque and ratio of the dominant versus the non-dominant shoulder. The level of significance was set at 0.05 for all statistical tests ($p < 0.05$).

3. Results

3.1. Demographic and anthropometric data

The means and standard deviations (SD) of the demographic and anthropometric data are shown in Table 1.

3.2. Inter-limb differences

The concentric internal and external rotation strength values (peak torque) at low (60°/s) and high angular velocity (180°/s) for the dominant and the non-dominant shoulders are shown in Table 2. The torque generated by the internal rotator muscles was significantly higher ($p < 0.05$) than by the external rotators in both limbs and at both velocities. Table 3 outlines the ER:IR standard ratios. There were no differences in the standard ER:IR strength ratios at high angular velocity (180°/s). However, significant differences ($p < 0.05$) were found at low angular velocity (60°/s), since the torque produced in the external rotation at 60°/s was higher in the dominant limb.

Table 3
Shoulder ER:IR standard ratios.

Velocity	Dominant		Non-dominant	
	Mean (SD)	%	Mean (SD)	%
60°/s	72.87 (15.6)	0.72	65.5 (9.3)	0.65
180°/s	78.98 (14.06)	0.78	75.5 (18.42)	0.75

ER: external rotation; IR: internal rotation. Values are mean and standard deviation (SD), n = 26.

4. Discussion

Many researchers have analyzed the shoulder rotator muscles in an attempt to identify any imbalances that may lead to injury. In this study we focused on the rotational strength of the rotator cuff in adolescent girls, since shoulder muscle strength interactions have not, so far, been thoroughly looked into in this particular group.

Both Secchi et al. (2015) in adults and Stickley et al. (2008) in adolescents have confirmed the reliability of the Biodex System® dynamometer to assess the strength of the shoulder rotator muscles in athletes.

Various populations of healthy high-level athletes have been widely studied using different protocols (Cools et al., 2007; Secchi et al., 2015). It is difficult to compare athlete populations since they have many special characteristics (Gozlan et al., 2006). Studies usually use a small sample size and there is a lack of normative data for this population (Codine et al., 2005; Gozlan et al., 2006). Furthermore, very few references were found in the literature regarding adolescent swimmers and no reference at all was found concerning synchronized swimming.

The test position is one of the factors that may affect standard ratio results. This ratio seems to be higher in the neutral modified position than with 90° of shoulder abduction (Codine et al., 2005).

Forthomme et al. (2005) recommended the lying supine position, since the seated position yielded an unacceptable coefficient of variation for ER peak torque (up to 19%). We preferred the seated position because it is recommended by Biodex manufacturers and it increases the participant's comfort during the testing procedure (Stickley et al., 2008).

Caution must be taken when interpreting results from isokinetic dynamometer systems (Dauty et al., 2003; Codine et al., 2005; Ellenbecker and Mattalino, 1997; Cotte and Ferret, 2003). Given the homogeneity of our sample, peak torque was considered instead of peak torque/body weight. External-to-internal shoulder rotation peak torque ratio was also used to represent the balance between antagonist muscle groups (Ellenbecker and Mattalino, 1997), as this parameter has been found to be related to injury prevalence (Stickley et al., 2008).

Since there is an increased eccentric activity of the external rotator muscles in overhead movements (Johansson et al., 2017), we could have studied the functional ER:IR strength ratio (ratio between the eccentric external rotation strength and the concentric internal rotation strength) as several authors have done (Wong and Ng, 2009; Stickley et al., 2008; Gulick et al., 2001; Bak and Magnusson, 1997; Ng and Lam, 2002). Nevertheless, we considered it quite difficult to explain the youngest subjects of our sample how to perform the eccentric external rotation. In addition, eccentric movements may cause muscle injuries, especially in youth (Lieber and Friden, 1999). Some researchers have studied the rotator cuff in adults by means of eccentric contraction exercises (Land et al., 2017). Therefore, in the present study, isokinetic strength measurements were carried out using the concentric mode.

Swimming and synchronized swimming are symmetrical sports. In asymmetrical sports, strength is usually higher in the dominant arm (Ellenbecker and Davies, 2000). No statistically significant differences in peak torque were found in this study at low or high velocities, or in the dominant or non-dominant shoulders.

In our sample, internal rotation strength was higher than external rotation strength. This is in keeping with Huang et al. (2005), who obtained similar results with athletes ranging from pre-pubescence to adulthood. Although many authors found increased shoulder internal rotation strength in overhead sport athletes (Huang et al., 2005; Ellenbecker and Davies, 2000; Gulick et al., 2001; Ellenbecker and Mattalino, 1997; Noffal, 2003), other researchers found no difference in shoulder strength and ratio values in women (Stickley et al., 2008; Gozlan et al., 2006) and in swimmers (Olivier et al., 2008; Codine et al., 2005). In the present study, significant differences were found in shoulder internal rotation strength at low and high velocity in all subjects. Higher internal rotation torque may be explained by the type of training commonly used among athletes that favors larger muscles such as the pectoralis major and the latissimus dorsi, which are the prime movers for internal rotation (Huang et al., 2005; Noffal, 2003). An increase in the internal rotation strength in swimmers, which creates a net force that pushes the humeral head backwards, may lead to muscle imbalance and, therefore, glenohumeral instability (Weldon and Richardson, 2001).

Many studies have shown a decrease in shoulder ER:IR standard ratio in overhead sport athletes compared with control subjects (Olivier et al., 2008; Wong and Ng, 2009; Bak and Magnusson, 1997). These ratios have been previously reported to range from 0.57 to 1.19 (Stickley et al., 2008; Ellenbecker and Mattalino, 1997; Bak and Magnusson, 1997; Noffal, 2003). Ellenbecker and Davies (2000) recommended a standard ratio of at least 0.66−0.75 to prevent shoulder injuries. The ratios obtained from our sample (0.65−0.78) are well within the range found in the literature. The highest ratio value found in our sample can be explained by the angular velocity (180°/s) and the sample's young age.

Regarding ER:IR standard ratio, most authors found lower values in the dominant arm (Huang et al., 2005; Ellenbecker and Mattalino, 1997), while others did not find any significant difference between arms. Unlike these studies, significant differences were found in our sample between both shoulders at the lower velocity (60°/s), the ratio being higher in the dominant arm. Conversely, no significant difference was found at the higher velocity (180°/s). These ratios should be interpreted with caution due to their moderate reproducibility (Dauty et al., 2003).

5. Conclusion

There were no significant differences in either internal or external rotation peak torque between the dominant and the non-dominant shoulders in adolescent female elite synchronized swimmers.

The agonist-antagonist ratio was higher in the dominant limb at both velocities, yielding significant differences at the lower velocity.

Isokinetic assessment is essential in sports medicine, since it is the only test capable of diagnosing any shoulder strength deficit. There is great potential for clinical research in synchronized swimming because of the paucity of published literature. This study may guide trainers in designing quality shoulder strength training, prevention and rehabilitation programs in overhead sports.

This is the first isokinetic study involving elite synchronized swimmers. Further studies are needed to obtain more accurate isokinetic shoulder strength values in this sport modality.

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