Is the Normal Shoulder Rotation Strength Ratio Altered in Elite Swimmers?

CRAIG BOETTCHER[1], MARK HALAKI[2], KYLIE HOLT[3], and KAREN A. GINN[4]

[1]Discipline of Biomedical Science, Faculty of Medicine & Health, The University of Sydney, AUSTRALIA; [2]Discipline of Exercise & Sports Science, Faculty of Health Sciences, The University of Sydney, AUSTRALIA; [3]Department of Physical Therapies, Australian Institute of Sport, AUSTRALIA; and [4]Discipline of Anatomy & Histology, Faculty of Medicine & Health, The University of Sydney, AUSTRALIA

ABSTRACT

BOETTCHER, C., M. HALAKI, K. HOLT, and K. A. GINN. Is the Normal Shoulder Rotation Strength Ratio Altered in Elite Swimmers? *Med. Sci. Sports Exerc.*, Vol. 52, No. 3, pp. 680–684, 2020. **Introduction:** It is commonly believed that the shoulder external rotation (ER) to internal rotation (IR) strength ratio is decreased in swimmers due to predominant IR loading during the pull-through (propulsive) phase which predisposes to shoulder pain. However, the evidence supporting this hypothesis is inconclusive. Therefore, the aim of this study was to examine shoulder rotation strength parameters in elite swimmers and investigate potential associations with shoulder pain. **Methods:** Sixty-eight (40 men; age, 19.9 ± 3.2 yr) elite swimmers provided demographic and shoulder pain history data before measurement of shoulder rotation strength. Mixed model analyses were used to examine differences in shoulder IR and ER strength normalized to body weight (BW) and the shoulder rotation strength ratio. A multinomial logistic regression model was utilized to examine associations between shoulder rotation strength parameters and shoulder pain. **Results:** Mean shoulder IR strength (BW) was approximately 0.29 for male swimmers and 0.26 for female swimmers. Mean shoulder ER strength (BW) was approximately 0.19 for male swimmers and 0.18 for female swimmer. The shoulder ER/IR strength ratio was approximately 0.70 bilaterally for all swimmers. There were no significant differences between dominant and non-dominant shoulders in IR or ER strength normalized to BW ($P \geq 0.547$). There were no associations between any shoulder strength parameters and shoulder pain ($r^2 = 0.032$, $P = 0.107$). **Conclusions:** Despite the high IR loading, optimal swimming technique does not alter the normal ER/IR strength ratio at the shoulder. Elite swimmers who report current or a history of shoulder pain demonstrate normal shoulder rotation strength ratios. The finding of symmetrical shoulder rotation strength points to side-to-side strength comparisons as a valuable clinical tool in managing swimmers with unilateral shoulder pain. **Key Words:** SHOULDER INTERNAL ROTATION STRENGTH, SHOULDER EXTERNAL ROTATION STRENGTH, SHOULDER ROTATION STRENGTH RATIO, SHOULDER PAIN

Shoulder pain is a significant burden to swimmers of all ages and ability. It is the most common injury reported in swimmers and the main cause of lost training hours and, in some cases retirement, in elite swimmers (1). The frequency with which it occurs is well illustrated by the term "swimmer's shoulder" being adopted as a common phrase for shoulder pain in this population of athletes (2). As a consequence, much research investigating potential contributing factors to swimmer's shoulder has been conducted over many years (3). Despite these investigations, an examination of the literature would suggest that the prevalence of shoulder pain in swimmers is not reducing and that ongoing research is warranted (1,4,5).

A potential causative factor of "swimmer's shoulder" that has received ongoing attention is shoulder rotation strength balance (6–8). The majority of these studies indicate that the shoulder external rotation (ER) to internal rotation (IR) strength ratio is decreased in swimmers. The common explanation for this decreased shoulder ER/IR ratio is that, because IR is performed during the pull-through (propulsive) phase of swimming strokes, shoulder IR strength increases proportionately more than ER strength in swimmers. It is believed that this rotation strength imbalance then leads to changes in humeral head positioning resulting in shoulder pain due to impingement (9).

An examination of this body of research, however, indicates that many of these studies have been performed on small cohorts (10–12), amateur or low-level swimmers (13), and that an association with shoulder pain has not been made (11,14,15). Furthermore, the one study that did examine shoulder strength in elite swimmers, albeit on a very small group, found contradictory results, with a relative decrease in IR strength in the shoulders of symptomatic swimmers (16). The conclusion, therefore, from a recent systematic review examining the risk factors for shoulder pain in swimmers was that there is insufficient evidence to make a definitive conclusion about the contribution that shoulder rotation strength imbalance might make to shoulder pain in swimmers (17).

Consequently, the primary aim of the current study was to examine shoulder rotation strength in an elite swimming cohort in order to determine if swimming results in changes in shoulder rotation strength parameters compared with published normative

Address for correspondence: Karen Ginn, Ph.D., School of Medical Sciences, Faculty of Medicine and Health, Room E316, Anderson Stuart Building (F13), The University of Sydney, NSW, 2006, Australia; E-mail: karen.ginn@sydney.edu.au.
Submitted for publication May 2019.
Accepted for publication September 2019.

0195-9131/20/5203-0680/0
MEDICINE & SCIENCE IN SPORTS & EXERCISE®

DOI: 10.1249/MSS.0000000000002177

data. This study was performed on elite level swimmers to eliminate any potential effects of errors in swimming technique on shoulder rotation strength. A secondary aim was to investigate potential associations between rotation strength parameters and past and/or current shoulder pain.

METHODS

Sixty-eight (40 men and 28 women) Australian swimmers 16 yr and older who were competing at an elite level were recruited for this study. The athletes were considered elite if they had qualified to compete in a minimum of two open-age national championships. This cohort included 39 of the Australian swimming team who competed at the 2013 World Championships. Remaining participants were recruited from the Australian Institute of Sport (n = 9) and New South Wales Institute of Sport (n = 20) swimming programs. All participants provided basic demographic data (age, sex, height, weight, hand dominance), as well as swimming event (sprint or distance) and self-estimated average weekly training load (the kilometers swum on average per week for the previous year). In addition, participants were asked if they were currently experiencing shoulder pain while swimming, if they had ever experienced shoulder pain which swimming, and the shoulder(s) affected. This study was approved by the Australian Institute of Sport Ethics Committee (approval number: 20130413), and consent was obtained from each subject and guardian, if applicable, before data collection.

Bilateral measurements of maximal shoulder IR and ER strength were measured as the maximum force recorded using a hand-held dynamometer (Chatillon DFX II; Ametek Inc.), in the one testing session, by the same two Sports Physiotherapists (Fig. 1). Test order was block randomized by side (dominant; nondominant). Testing was performed with the participants standing, shoulder in the neutral position, elbow by the side but not touching the body and flexed to 90°. The dynamometer was placed proximal to the ulnar styloid process on the dorsal side of the forearm for ER and the palmar side for IR measurements. Participants were asked to brace themselves by placing their feet shoulder width apart and bending their knees in order to avoid losing balance during testing. A break test was used with the force being applied gradually and increased over approximately a 5-s period until the subject could no longer resist the applied force. This procedure has demonstrated good to excellent intertester reliability (18). Three strength measurements were recorded and the highest used for analysis.

The normality of the distribution of the data was checked and confirmed using probability plots. Each shoulder was coded as 0, no pain; 1, current pain; 2, a history of pain. Mixed-model analyses were used to evaluate differences in IR and ER strength normalized to body weight (BW) and ER/IR strength ratios using the following fixed factors: dominance, dominant and nondominant; sex, male and female; and pain status, 0: no pain, 1: current pain 2: a history of pain in each shoulder. Bonferroni *post hoc* test was used to identify significant differences when significant main or interactions effects were found. Independent predictors of pain

FIGURE 1—Shoulder rotation strength testing setup.

(no pain, current presence of shoulder pain or a history of shoulder pain) were examined using a multinomial logistic regression model with a criterion of $P < 0.05$ using the following predictors: IR and ER strength normalized to BW and ER/IR strength ratio. Significance was set at $P < 0.05$. Statistica (Version 10; Statsoft Inc, USA) was used for all statistical analyses.

RESULTS

The average age of the swimmers examined was 19.9 ± 3.2 yr. The majority (88%) of elite swimmers examined were right-hand dominant. Twenty (29%) competed in sprint events, 31 (46%) in distance events and 17 (25%) in both sprint and distance events. Sixteen swimmers (24%) estimated their annual training load to be between 30 and 40 km·wk^{-1} with 7 (10%) training <30 km·wk^{-1} and 45 (66%) >40 km·wk^{-1}. Seventeen (25%) swimmers reported shoulder pain during competition and training at the time of testing with a further 35 (51%) reporting a previous history of shoulder pain. Sixteen (24%) swimmers reported neither current shoulder pain nor a history of shoulder pain.

Shoulder rotation strength data are illustrated in Figure 2 and summarized in Table 1. Results of the mixed *model analyses* for the shoulder rotation strength normalized to BW data indicated significant main effects for sex: male > female for IR (P = 0.002) but not for ER (P = 0.427) strength. Hand dominance was not significant ($P \geq 0.547$), pain status was not significant ($P \geq 0.755$), and there was no significant interaction effect of sex and hand dominance ($P \geq 0.295$), of sex and pain status ($P \geq 0.401$), nor of sex, hand dominance and pain status ($P \geq 0.394$) for either IR or ER. The ER/IR strength ratio was greater in women than men (P = 0.003) and again, hand

APPLIED SCIENCES

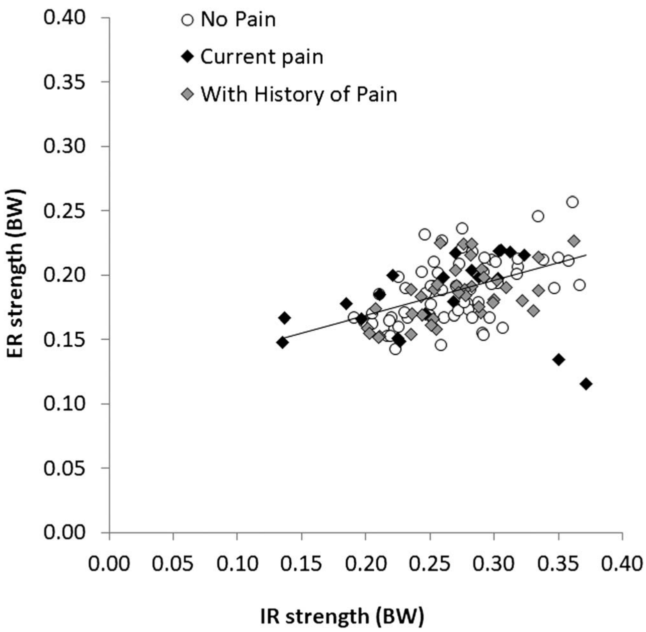

FIGURE 2—ER strength vs IR strength for both left and right shoulders for all elite swimmers with pain status indicated. Trend line provided for all swimmers regardless of pain status.

dominance was not significant ($P = 0.665$), pain status was not significant ($P = 0.657$) nor was the interaction of sex and hand dominance ($P = 0.568$), of sex and pain status ($P = 0.103$), nor of sex, hand dominance and pain status ($P = 0.508$).

The multinomial logistic regression analyses revealed no significant associations between pain status (no pain, current shoulder pain or a history of shoulder pain) and any of the shoulder strength parameters measured (Cox and Snell Pseudo $r^2 \leq 0.032$, $P \geq 0.107$).

DISCUSSION

The shoulder rotation strength (BW) and strength ratios in the large elite swimming cohort examined in this study do not support the theory that the shoulder IR loading predominant during swimming will necessarily result in differentially greater increases in shoulder IR strength compared with ER strength, that is, decreased shoulder ER/IR strength ratios. In the current study the elite swimming athletes had a shoulder ER/IR ratio of approximately 0.7, males; 0.68, bilaterally; and females, 0.73 (dominant side) and 0.76 (nondominant side). These ratios were not affected by whether the swimming athletes were experiencing shoulder pain during competition and/or training at the time of testing or whether they had a previous history of shoulder pain. These values are consistent with those reported in a large group of physically active college students age 17 to 21 yr using a similar methodology to the current study (19). Calculation of the ER/IR strength ratio from the mean strength (BW) values reported in this normative study indicate a shoulder ER/IR strength ratio in healthy age-related men of 0.72 and in women of 0.74 (19). It would seem that a normal shoulder ER/IR strength ratio is maintained in elite swimmers, presumably using optimal swimming technique, despite high training and competition loading.

Could the role of the rotator cuff muscles to stabilize the shoulder joint explain why swimming does not lead to a decreased shoulder ER/IR ratio? As well as high IR loading swimming also requires high shoulder extension loading during the propulsive pull-through phase. Shoulder extension from elevation is produced by latissimus dorsi, teres major, and notably, the sternal head of pectoralis major during the early stage of pull-through. Contraction of latissimus dorsi results in activation of the anterior rotator cuff (subscapularis which is a shoulder internal rotator) in a stabilizing role to counterbalance potential posterior translation of the humeral head (20). Contraction of pectoralis major on the other hand, results in activation of the posterior rotator cuff (infraspinatus and supraspinatus which are shoulder external rotators) to counterbalance potential anterior humeral head translation (21). Therefore, strength increases in both anterior (internal rotators) and posterior (external rotators) rotator cuff muscles can be expected during the swimming stroke when their stabilizer, as well as their rotation torque producing functions are considered.

The results of this study add to the growing evidence that most shoulder rotation parameters are not altered as a result of swimming with optimal technique. A recent study on a large cohort of elite swimmers has indicated that average humeral torsion values and passive shoulder IR range of motion are also within normal limits in these athletes (22).

The mean shoulder IR and ER strength (BW) values recorded for the male elite swimmers in the current study are similar to those reported in healthy age related individuals whose shoulder rotation strength was measured isometrically

TABLE 1. Shoulder rotation strength profile of elite swimming cohort.

			Side	Dominant			Nondominant			All
Variables			Sex	Male	Female	All	Male	Female	All	All
Mean strength (BW) ± SD	IR	Pain status	No pain	0.28 ± 0.04	0.25 ± 0.04	0.27 ± 0.04	0.28 ± 0.04	0.27 ± 0.04	0.27 ± 0.04	0.27 ± 0.04
			Current pain	0.31 ± 0.04	0.24 ± 0.03	0.28 ± 0.05	0.31 ± 0.06	0.22 ± 0.06	0.24 ± 0.07	0.26 ± 0.06
			Previous pain	0.28 ± 0.02	0.26 ± 0.06	0.27 ± 0.04	0.29 ± 0.03	0.25 ± 0.04	0.27 ± 0.04	0.27 ± 0.04
			All	0.29 ± 0.03	0.26 ± 0.04	0.27 ± 0.04	0.28 ± 0.04	0.25 ± 0.05	0.27 ± 0.05	0.27 ± 0.04
	ER	Pain status	No pain	0.19 ± 0.03	0.18 ± 0.02	0.19 ± 0.03	0.19 ± 0.02	0.19 ± 0.03	0.19 ± 0.02	0.19 ± 0.03
			Current pain	0.19 ± 0.04	0.18 ± 0.03	0.19 ± 0.03	0.18 ± 0.05	0.18 ± 0.02	0.18 ± 0.03	0.18 ± 0.03
			Previous pain	0.19 ± 0.02	0.19 ± 0.03	0.19 ± 0.02	0.19 ± 0.02	0.17 ± 0.02	0.18 ± 0.02	0.19 ± 0.02
			All	0.19 ± 0.03	0.18 ± 0.03	0.19 ± 0.03	0.19 ± 0.03	0.18 ± 0.03	0.19 ± 0.03	0.19 ± 0.03
Mean ratio Ext/Int Rot strength ratio ± SD		Pain status	No pain	0.69 ± 0.10	0.72 ± 0.10	0.70 ± 0.10	0.70 ± 0.11	0.72 ± 0.10	0.70 ± 0.10	0.70 ± 0.10
			Current pain	0.62 ± 0.14	0.76 ± 0.13	0.67 ± 0.14	0.59 ± 0.24	0.85 ± 0.19	0.79 ± 0.22	0.75 ± 0.2
			Previous pain	0.68 ± 0.08	0.74 ± 0.09	0.7 ± 0.08	0.67 ± 0.10	0.69 ± 0.06	0.68 ± 0.09	0.69 ± 0.08
			All	0.68 ± 0.09	0.73 ± 0.09	0.7 ± 0.09	0.68 ± 0.11	0.76 ± 0.14	0.71 ± 0.13	0.71 ± 0.11

in a similar position as the current study (19). Westrick et al. (19) reported shoulder IR strength values in these male control participants of 0.27 BW bilaterally and shoulder ER strength values of approximately 0.20 BW with similar standard deviations to the current study. Statistical analysis using the mean and standard deviation data reported by Westrick et al. indicate that the female elite swimmers in the current study were significantly stronger by approximately 20% compared with age-matched female control participants, but this strength (BW) increase was similar in both shoulder IR (0.26 BW compared with 0.21 BW) and ER (0.18 BW compared with 0.15 BW) (19).

Not only were normal shoulder rotation strength (BW) and rotation strength ratios maintained in this large cohort of swimming athletes who were competing at an elite level but also regression analysis did not reveal any significant association between shoulder pain and rotation strength. Neither shoulder rotation strength (BW) nor shoulder rotation strength ratios were associated with shoulder pain in the 76% of the elite swimming athletes who reported either current shoulder pain or a history of shoulder pain during training and/or competition at the time of testing. This result is in accord with previous smaller studies that have also reported no relationship between shoulder pain and rotation strength parameters in swimming athletes (14,15). Therefore, in swimming athletes who are able to compete while experiencing shoulder pain, the results of this study do not support the theory that swimming leads to increased shoulder IR strength and, consequently, a decreased ER/IR strength ratio, predisposing them to shoulder problems. Further research is required to determine if changes in the shoulder rotation strength ratio are associated with shoulder pain that prevents swimming athletes from competing in their sport.

No significant differences between dominant and nondominant shoulders were found in shoulder IR or ER strength (BW) or the shoulder ER/IR strength ratio in the elite swimming cohort examined in this study (Table 1). This finding of similar bilateral shoulder rotation strength is consistent with the bilateral demands swimming places on the upper limbs and supports the results of previous studies on swimmers, which also reported symmetrical shoulder ER/IR strength ratios (6,23,24). These results suggest that the detection of side-to-side differences in shoulder rotation strength and/or rotation strength ratios in swimmers is a significant finding, which has implications for the prevention and treatment of "swimmer's shoulder." For example, for swimmers with unilateral shoulder pain, shoulder IR and ER strength (BW) on the nonpainful side could be used to set valid rotation strength rehabilitation goals and to provide motivational feedback during rehabilitation.

The results of this study relate to shoulder rotation strength measurements performed in standing with the arms by the side, a position commonly used to measure shoulder rotation strength, and which allowed comparison with a large age-matched control group in whom shoulder rotation strength was measured in a similar manner. Further research is required to determine if rotation strength parameters measured in more elevated shoulder positions differ between swimming athletes and age matched control subjects.

The current study, to our knowledge the largest study investigating shoulder strength parameters in elite swimmers, indicates that shoulder rotation strength ratios are within normal limits in these athletes. It would seem, therefore, that optimal swimming technique does not predispose to the development of proportionately greater increases in shoulder IR strength (BW) compared with ER strength (BW) when measured with the arm by the side.

The authors would like to thank the Australian Institute of Sport, Swimming Australia and all the athletes who gave their time to participate in the study. This study was supported by a Biomedical Research Initiative Grant, Discipline of Biomedical Science, The University of Sydney.

The authors have no relationships with companies or manufacturers who will benefit from the results of the present study. The results of the present study do not constitute endorsement by ACSM. The authors declare that the results of the present study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

REFERENCES

1. McMaster WC, Troup J. A survey of interfering shoulder pain in United States competitive swimmers. *Am J Sports Med*. 1993;21(1):67–70.
2. Kennedy JC, Hawkins R, Krissoff WB. Orthopaedic manifestations of swimming. *Am J Sports Med*. 1978;6(6):309–22.
3. Johnston TR, Abrams GD. Shoulder injuries and conditions in swimmers. In: Miller TL, editor. *Endurance Sports Medicine A Clinical Guide*. Switzerland: Springer International Publishing; 2016. pp. 127–38.
4. Richardson AB, Jobe FW, Collins HR. The shoulder in competitive swimming. *Am J Sports Med*. 1980;8(3):159–63.
5. Rodeo SA, Nguyen JT, Cavanaugh JT, Patel Y, Adler RS. Clinical and ultrasonographic evaluations of the shoulders of elite swimmers. *Am J Sports Med*. 2016;44(12):3214–21.
6. McMaster WC, Long SC, Caiozzo VJ. Shoulder torque changes in the swimming athlete. *Am J Sports Med*. 1992;20(3):323–7.
7. Batalha N, Marmeleira J, Garrido N, Silva AJ. Does a water-training macrocycle really create imbalances in swimmers' shoulder rotator muscles? *Eur J Sport Sci*. 2015;15(2):167–72.
8. Batalha NMP, Marinho DA, Raimundo AM, Silva AJ, Fernandes ODJSM, Tomas-Carus P. Shoulder rotator isokinetic strength profile in young swimmers. *Rev Bras Cineantropom Desempenho Hum*. 2012;14(5):545–53. 2012v14n5p545.
9. Weldon EJ 3rd, Richardson AB. Upper extremity overuse injuries in swimming. A discussion of swimmer's shoulder. *Clin Sports Med*. 2001;20(3):423–38.
10. 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):2562–8.
11. Rupp S, Berninger K, Hopf T. Shoulder problems in high level swimmers—impingement, anterior instability, muscular imbalance? *Int. J. Sports Med*. 1995;16(8):557–62.
12. West D, Sole G, Sullivan SJ. Shoulder external- and internal-rotation isokinetic strength in master's swimmers. *J Sport Rehabil*. 2005; 14(1):12–9.
13. Ramsi M, Swanik KA, Swanik CB, Straub S, Mattacola C. Shoulder-rotator strength of high school swimmers over the course of a competitive season. *J Sport Rehabil*. 2004;13(1):9–18.
14. Harrington S, Meisel C, Tate A. A cross-sectional study examining shoulder pain and disability in division I female swimmers. *J Sport Rehabil*. 2014;23(1):65–75.

15. Beach ML, Whitney SL, Dickoff-Hoffman S. Relationship of shoulder flexibility, strength, and endurance to shoulder pain in competitive swimmers. *J Orthop Sports Phys Ther*. 1992;16(6):262–8.
16. Bak K, Magnusson S. Shoulder strength and range of motion in symptomatic and pain-free elite swimmers. *Am J Sports Med*. 1997; 25(4):454–9.
17. Hill L, Collins M, Posthumus M. Risk factors for shoulder pain and injury in swimmers: a critical systematic review. *Phys Sportsmed*. 2015; 43(4):412–20.
18. Holt KL, Raper DP, Boettcher CE, Waddington GS, Drew MK. 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. *Phys Ther Sport*. 2016;21:75–81.
19. Westrick RB, Duffey ML, Cameron KL, Gerber JP, Owens BD. Isometric shoulder strength reference values for physically active collegiate males and females. *Sports Health*. 2013;5(1):17–21.
20. Wattanaprakornkul D, Cathers I, Halaki M, Ginn KA. The rotator cuff muscles have a direction specific recruitment pattern during shoulder flexion and extension exercises. *J Sci Med Sport*. 2011; 14(5):376–82.
21. Wattanaprakornkul D, Halaki M, Boettcher C, Cathers I, Ginn KA. A comprehensive analysis of muscle recruitment patterns during shoulder flexion: an electromyographic study. *Clin Anat*. 2011; 24(5):619–26.
22. Holt K, Boettcher C, Halaki M, Ginn KA. Humeral torsion and shoulder rotation range of motion parameters in elite swimmers. *J Sci Med Sport*. 2017;20(5):469–74.
23. Batalha N, Raimundo A, Tomas-Carus P, Barbosa T, Silva A. Does a land-based compensatory strength-training programme influence the rotator cuff balance of young competitive swimmers? *Eur J Sport Sc*. 2015;15(8):764–72.
24. Magnusson SP, Constantini NW, McHugh MP, Gleim GW. Strength profiles and performance in Masters' level swimmers. *Am J Sports Med*. 1995;23(5):626–31.