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Original research

Humeral torsion and shoulder rotation range of motion parameters in elite swimmers

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ABSTRACT

Objectives: Optimal shoulder rotation range of motion (ROM) for swimming is unknown. The primary aim of this study was to examine shoulder rotation ROM in elite swimmers, including the influence of humeral torsion on rotation ROM, in order to establish optimal shoulder rotation parameters for swimming. In addition, we examined the relationship between rotation ROM and shoulder pain.
Design: Descriptive cohort study.
Methods: Seventy elite Australian swimmers provided shoulder pain history data prior to measurement of humeral torsion and passive and active shoulder rotation ROM. Repeated measure analyses of variance were used to investigate within and between participant differences for all variables. Associations between humeral torsion and rotation ROM were investigated using Pearson's correlation coefficient. Multiple regression analysis was utilised to examine the associations between rotation ROM and shoulder pain.
Results: Average humeral torsion angles of $27 \pm 10^\circ$ (dominant side) and $31 \pm 10^\circ$ (non-dominant side) were demonstrated in this elite swimming cohort. In general, increased humeral torsion was positively associated with increased internal rotation (IR) and decreased external rotation (ER) ROM. There were significant differences in both IR and ER ROM measured passively and actively ($F_{2,136} \geq 93.1$, $p < 0.001$) with passive ROM greater than active ROM ($p < 0.001$) and active IR ROM measured in supine greater than measured in prone ($p < 0.001$). There were no associations between any rotation ROM variables and current or history of shoulder pain ($r^2 = 0.058$; $p = 0.46$).
Conclusions: Humeral torsion angle and passive shoulder IR ROM were similar while passive ER ROM was greater in elite swimmers compared to reported normal population values.

1. Introduction

In order to perform a sporting activity effectively and efficiently an athlete should meet certain physical requirements. Being physically suited to a particular sport will in turn assist in the prevention of injury. For example, the throwing athlete requires large ranges of shoulder external rotation (ER) range of motion (ROM) during the throwing action. It has been shown that reduced shoulder ER ROM in a throwing athlete can lead to decreased performance[1] and increased chance of injury.[2,3]

Biomechanical analysis has shown that shoulder IR is the dominant movement during freestyle swimming,[4] the stroke most commonly swum by all swimmers.[5] Consequently, adequate shoulder IR ROM is believed to be important for both injury prevention and performance enhancement in the swimming population.[6] Active shoulder IR ROM of between 40–50° is considered to be ideal for swimming athletes.[6] However, little objective data are available to support this claim. Further examination of shoulder rotation ROM in elite level swimmers is, therefore, warranted to determine the ideal shoulder IR ROM required for swimming.

The orientation of the proximal end of the humerus (humeral torsion) can influence shoulder rotation ROM measurements.[7] Greater humeral retrotorsion will result in increased shoulder ER and decreased IR ROM with no change in the total shoulder ROM. In throwing athletes, greater humeral retrotorsion is seen in the throwing arm relative to the non-throwing arm.[8] It is believed that this change is due to the osseous torsional loading on the humerus during throwing, resulting in the increased shoulder ER

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Table 1
Humeral torsion and shoulder rotation range of motion profile of elite swimming cohort.

Variable		Dominant			Non-dominant		
		Male	Female	All	Male	Female	All
Torsion (degrees)		27 ± 11	27 ± 8	27 ± 10	33 ± 10	28 ± 9	31 ± 10
Passive ROM (degrees)	IR	59 ± 14	63 ± 13	61 ± 14	63 ± 12	63 ± 14	63 ± 13
	ER	104 ± 12	106 ± 13	105 ± 12	101 ± 13	106 ± 12	103 ± 13
	Total	164 ± 19	169 ± 18	166 ± 19	164 ± 17	169 ± 19	166 ± 18
Active ROM (supine) (degrees)	IR	49 ± 13	49 ± 12	49 ± 13	52 ± 11	51 ± 11	51 ± 11
	ER	89 ± 15	90 ± 12	90 ± 14	86 ± 12	90 ± 12	87 ± 12
	Total	138 ± 13	140 ± 16	139 ± 14	137 ± 15	140 ± 17	139 ± 16
Active ROM (prone) (degrees)	IR	32 ± 17	30 ± 15	31 ± 16	35 ± 15	32 ± 18	34 ± 16
	ER	89 ± 15	95 ± 14	92 ± 15	88 ± 13	91 ± 16	89 ± 14
	Total	121 ± 15	124 ± 16	122 ± 15	122 ± 13	123 ± 17	122 ± 15

ROM observed in the throwing arm of these athletes. Given the apparent need for shoulder IR ROM in swimming, it would seem logical that swimmers may have a tendency towards more humeral antetorsion and that humeral torsion would be symmetrical given the bilateral nature of swimming. Only one study has examined humeral torsion in swimmers.[9] This study examined 29 young swimmers (average age 15.9 years) and found increased humeral retrotorsion in the dominant limb i.e. a pattern similar to that found in throwers, albeit to a lesser extent. Given the relatively young age of the swimmers and small sample size, further examination of humeral torsion in elite level swimmers is needed to confirm the loading effects of swimming on humeral structure.

Elite athletes are crucial for understanding the optimal physical characteristics required for a particular athletic task so that the confounding variables of poor technique can be controlled. Only one small study has examined the shoulder rotation ROM characteristics in elite swimmers.[10] A much larger sample size is required to establish a normative database of the optimal shoulder rotation ROM for swimming in order to draw valid associations between variation in these parameters and the occurrence of shoulder pain.

Therefore, the aims of this study were to examine an elite swimming cohort in order to determine the humeral torsion and shoulder rotation ROM characteristics for effective and efficient swimming. A secondary aim was to investigate if there is an association between changes in these physical characteristics and shoulder pain in elite swimmers.

2. Methods

Seventy (41 male and 29 female) current elite Australian swimmers aged 16 years and older (mean ± SD age = 20.1 ± 3.3 years) were recruited. The athletes were considered elite if they had qualified to compete in a minimum of two all-age national championships. This cohort included 41 of the Australian swimming team who competed at the 2013 world championships. Remaining athletes were recruited from Institute of Sport swimming programmes in Australia. All athletes provided demographic data (age, sex, hand dominance) as well as swimming event (sprint or distance), self-estimated average weekly training load and current and past shoulder pain status. This study was approved by the Australian Institute of Sport Ethics Committee (Approval Number: 20130413) and consent was obtained from each athlete and guardian, if applicable, prior to data collection.

Bilateral measurements of humeral torsion and passive and active shoulder rotation ROM were taken in the one testing session. Test order was block randomised by side (dominant; non-dominant) and measurement (torsion, ROM).

Humeral torsion was measured in supine using a non-invasive ultrasound (US) technique[7] using two real time US machines (Xario XG and Toshiba XG SSA-680A) with 12 MHz linear transducer PLT-1204BT (Toshiba Medical Systems, Tochigi, Japan) each modified with the attachment of a spirit level on the US head.[7]

Internal and external shoulder rotation ROM were measured from digital photographs, with the humerus abducted to 90° in the coronal plane and elbow in 90° flexion.[11] Passive rotation ROM was measured in supine and active rotation ROM was measured in both supine and prone (Fig. 1). The scapula was stabilised manually by an examiner during passive testing. During active testing, athletes were required to rotate their arm to their maximal achievable IR and ER ROM while actively stabilising their scapula. Examiners provided verbal and tactile feedback to ensure correct scapula position during active ROM testing. Inter-rater reliability was calculated using a subset of the data (10 subjects) for all rotation ROM measures and indicated that there were high correlations between the two raters ($r \geq 0.976$) with smallest detectable difference <0.75° for all ROM measures.

The normality of the distribution of the data was checked and confirmed using probability plots. Two factor repeated measures analysis of variance (ANOVA) [within participant factor: dominance: dominant and non-dominant; between participant factor: sex: male and female] was used to examine differences in humeral torsion. Differences in IR and ER ROM were examined using three factor ANOVA [within participant factors: dominance: dominant and non-dominant; execution of rotation ROM: passive, active in supine, active in prone; between participant factor: sex: male and female]. Tukey post-hoc test was used to identify significant differences when significant ANOVA results were found. Effect sizes were calculated using Cohen's d with <0.2 indicating nil, 0.2 to <0.6 indicating small, 0.6 to <0.8 indicating medium and ≥0.8 indicating large effect sizes.[12]

Associations between the amount of humeral torsion and shoulder rotation ROM measures were investigated using Pearson's correlation coefficient (r). Independent predictors of pain (presence of shoulder pain or history of shoulder pain) were examined using multiple regression models with the following predictors: humeral torsion, IR and ER ROM. Significance was set at $p < 0.05$. Statistica (Version 10, Statsoft Inc., USA) was used for all statistical analysis.

3. Results

Data from one male swimmer during active ROM in prone were missing. Therefore, this athlete's data were excluded from the ROM ANOVA but included in all other analyses.

The majority (89%) of elite swimmers examined were right-hand dominant. Thirty percent competed in sprint events, 44% in distance events and 18% in both sprint and distance events. Thirty percent of swimmers estimated their annual training load to be between 30 and 40 km per week with 34% training <30 km per week

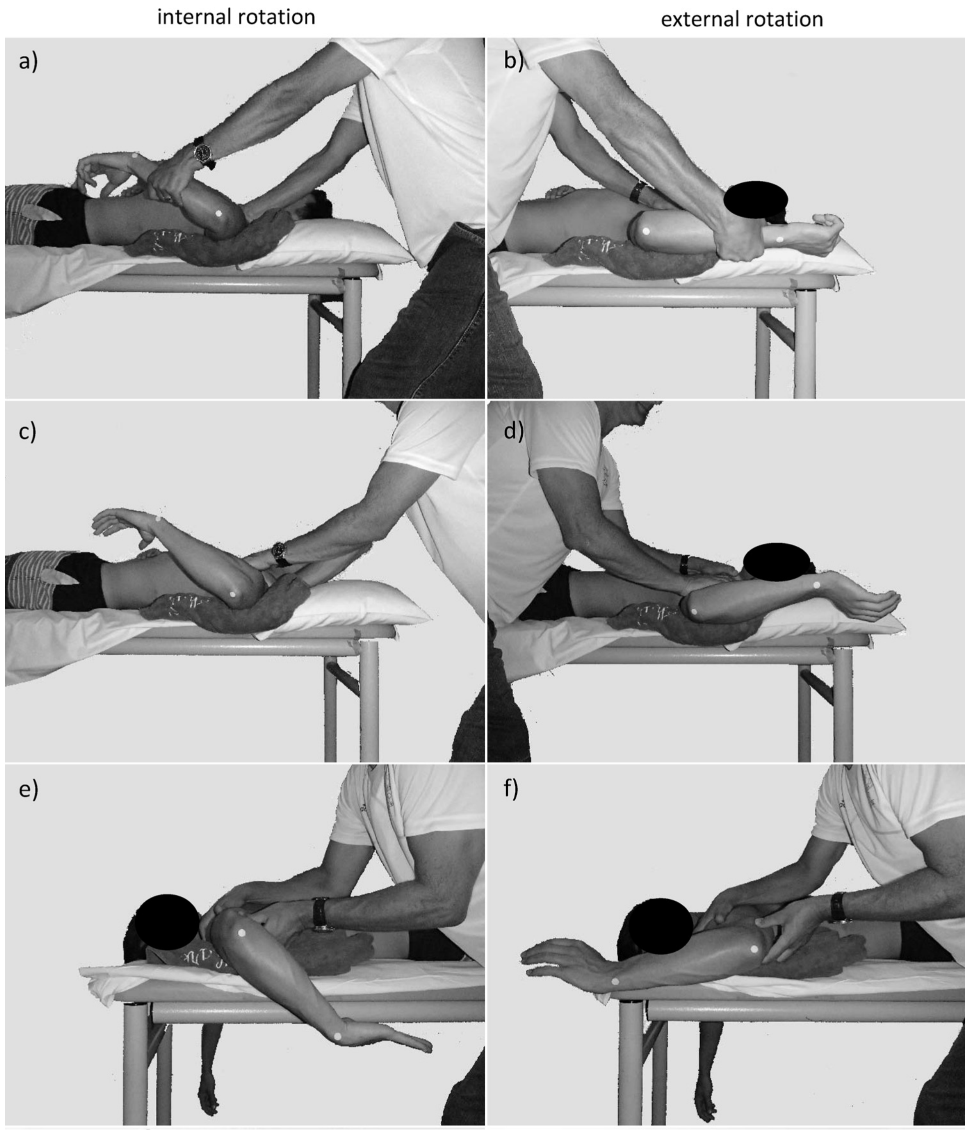

Fig. 1. Experimental setup for the measurement of (a) passive internal rotation (IR) range of motion (ROM), (b) passive external rotation (ER) ROM, (c) active IR ROM in supine, (d) active ER ROM in supine, (e) active IR ROM in prone, (f) active ER ROM in prone.

and 36% >40 km per week. Twenty-four percent reported shoulder pain during competition and training at the time of testing with a further 53% reporting a previous history of shoulder pain. The shoulder musculoskeletal profile data measured in this study are summarised in Table 1.

The mean (±SD) degree of humeral torsion bilaterally in this elite swimming cohort was 27 ± 10° on the dominant side and 31 ± 10° on the non-dominant side. There was a significant interaction between sex and hand dominance ($F_{1,68} = 7.34$, $p = 0.008$). Post hoc testing indicated less humeral torsion (average difference = 6.4°) in the dominant shoulder compared to the non-dominant shoulder of the male swimmers (Cohen's d = 0.6, small to medium effect size, $p < 0.001$) with no significant differences bilaterally (average difference = 1.0°) in female swimmers (Cohen's d = 0.13, nil effect size, $p = 0.904$) nor between male and female swimmers (dominant: average difference = 0.3°, Cohen's d = 0.03, nil effect size, $p = 0.999$; non-dominant: average difference = 5.7°, Cohen's d = 0.60, small to medium effect size, $p = 0.082$).

The mean (±SD) shoulder IR and ER ROM measured passively and actively in both supine and prone for dominant and non-dominant shoulders is illustrated in Fig. 2. There were significant ANOVA main effects for hand dominance for IR ($F_{1,68} \geq 4.13$, $p = 0.046$) and ER ROM ($F_{1,68} = 6.22$, $p = 0.015$) when all ROM measures were combined. However, there were no interactions between hand dominance and execution of rotation ROM ($p > 0.891$). There were no differences between dominant and non-dominant shoulders for any individual rotation ROM measure (average rotation ROM differences between 2.2° and 2.6°, Cohen's d = 0.16–0.19, nil effect size, $p \geq 0.120$).

There were significant ANOVA main effects for execution of rotation ROM: passive, active in supine and active in prone ($F_{2,136} \geq 93.1$, $p < 0.001$). Tukey post hoc analysis indicated that IR ROM measured passively was greater than measured actively (average difference = 20.8°, Cohen's d = 0.96–2.08, large effect sizes, $p < 0.001$) and actively measured in supine was greater than when measured in prone (average difference = 17.9°, Cohen's d = 1.30, large effect sizes, $p < 0.001$). External rotation ROM measured passively was greater than active ER ROM (average difference = 14.5°, Cohen's d = 0.99–1.19, large effect sizes, $p < 0.001$) with no differences in active range measured in supine and prone (average difference = 1.7°, Cohen's d = 0.13, nil effect size, $p = 0.313$). There were no sex differences (Cohen's d = 0.00–0.40, nil to small effect

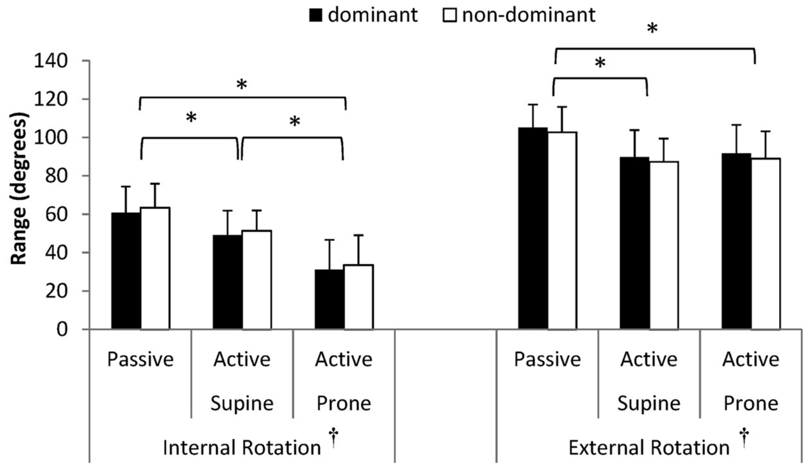

Fig. 2. The mean (±SD) internal and external shoulder rotation range of motion (ROM) measured passively and actively in both supine and prone for dominant and non-dominant shoulders. † indicates significant differences between dominant and non-dominant, * indicates significant differences between execution of rotation ROM: passive, active in supine, active in prone.

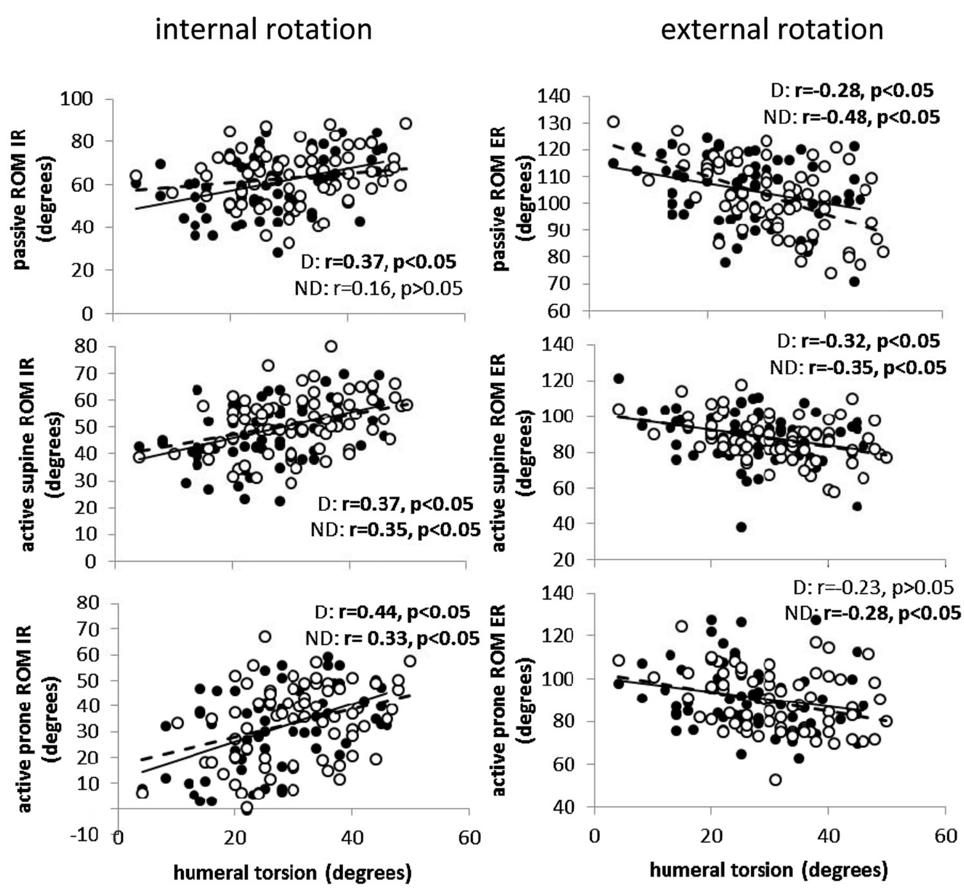

Fig. 3. Scatter plots of shoulder internal rotation (IR) and external rotation (ER) range of motion (ROM) measured passively and actively in both supine and prone versus humeral torsion for dominant (D) and non-dominant (ND) shoulders. Pearson's correlation coefficients (r) between each of the measures of ROM and humeral torsion and their significance value are provided. Bold—significant difference ($p < 0.05$). Black filled circles are D and white filled circles are ND.

sizes, $F_{1,68} \leq 1.67$, $p \geq 0.201$) nor any interaction effects ($p \geq 0.346$) for any ROM measures. Correlation analysis of humeral torsion and shoulder rotation ROM indicated that, in general, increased humeral torsion angle was associated with increased IR and decreased ER ROM except non-dominant passive IR range and dominant active ER range measured in prone (Fig. 3).

Multiple regression analysis revealed no associations between current shoulder pain or a history of shoulder pain with the degree of humeral torsion or any of the shoulder ROM variables measured ($r^2 = 0.058$, $p = 0.46$).

4. Discussion

This is the first study to measure the degree of humeral torsion in elite swimming athletes. Results indicate humeral torsion angles bilaterally of approximately 30° (dominant: 27 ± 10°;

non-dominant: 31 ± 10°) (Table 1). In general, increased humeral torsion angle was positively associated with increased IR ROM and decreased ER ROM (Fig. 3). This positive association between increased humeral torsion and shoulder rotation ROM measures highlights the clinical importance of measuring the total arc of shoulder rotation motion when examining an athlete's shoulder. Measuring shoulder IR or ER ROM in isolation may give the impression of restriction in one direction; however, this may simply reflect bilateral differences in the degree of humeral torsion rather than a soft tissue restriction.

As swimming is a bilateral sport that does not generate the levels of torsional stress on the humerus encountered during overhead throwing, it was predicted that these athletes would demonstrate larger humeral torsion angles than the dominant (throwing) arm of throwing athletes, which would not differ significantly from side to side. As expected, these elite swimmers did demonstrate a much higher degree of humeral torsion angle in their dominant shoulder than professional pitchers with an average humeral torsion of 27 ± 10° (Table 1) compared to values in pitchers between 5° to 10°.[8] In addition, there was no bilateral difference in humeral torsion angle in the female swimmers in the current study. However, contrary to expectation, there was a statistically significant, small to medium effect size, difference in the degree of humeral torsion bilaterally in the male swimmers for which no obvious explanation is immediately apparent. The non-dominant shoulder in males displayed a greater average humeral torsion angle (33°) than their dominant shoulder (27°) and than both shoulders in the female swimmers (dominant 27°; non-dominant 28°) (Table 1).

The elite swimming athletes in the current study demonstrated similar average humeral torsion values as normal participants. Mean humeral torsion of 26 ± 11° was reported in a study using CT to measure humeral torsion in 410 normal shoulders.[13] Measurements of humeral torsion in the non-dominant shoulder of elite overhead athletes, which would only be subjected to normal day to day activities, report mean values of between 23° and 29°.[8,14,16] The 6.4° mean difference in the degree of humeral torsion between dominant and non-dominant sides in the male swimmers in the current study is well within one standard deviation of normative humeral torsion values challenging whether this difference is functionally meaningful.[13] It would seem that, unlike throwing, the mechanical stresses associated with swimming do not influence the orientation of the humeral head on its shaft.

Average passive shoulder IR ROM measured in supine lying in this elite swimming cohort was slightly greater than 60° (dominant 61°; non-dominant 63°) and average passive ER range slightly greater than 100° (dominant 105°; non-dominant 103°) (Table 1). There were no significant differences, nil effect sizes, in passive shoulder rotation ROM between dominant and non-dominant sides. It would seem that, in this large cohort of swimming athletes currently competing at an elite level, passive shoulder rotation ROM adaptations are equal bilaterally consistent with the bilateral demands swimming places on the upper limbs.

Unfortunately it is not possible to compare the ROM results in the current study to the only other study examining shoulder rotation ROM in elite swimmers as no details are provided in this previous study on the method used to measure rotation ROM.[17] The passive shoulder rotation ranges recorded in the current study, however, are similar to other studies that have measured passive shoulder rotation ROM in swimmers in a similar manner. In a group of 37 female collegiate swimming athletes both with and without current shoulder pain, average passive IR ranges slightly higher than the current study (dominant and non-dominant: 67°) and passive ER ranges slightly lower (dominant 101°; non-dominant 96°) were reported.[18] In a small study of 20 older male recreational swimmers,[19] passive ER ROM was slightly greater than 100° (dominant 103°; non-dominant 101°) and passive IR ROM on the non-dominant shoulder averaged 65°, similar to the current study. However, average dominant shoulder passive IR ROM (53°) in these non-elite swimmers[19] was much less than that found in the current study. As swimming is not likely to be the main mechanical influence on humeral structure in a non-elite population, the decreased passive shoulder IR ROM reported in these recreational male swimmers may reflect a more retrotorted humerus due to the influence of other dominant arm activities such as throwing.

Consistent with our finding of bilateral measurements of humeral torsion that appear to be within normal limits, the passive shoulder IR ranges demonstrated by this elite swimming cohort are similar to age-related control participants who were also examined in supine lying. In a recent normative study of participants between the ages of 18–39 years, average passive shoulder IR rotation ROM in males was found to be between 62° (dominant) and 64° (non-dominant) and in females ranged between 69° (dominant) and 68° (non-dominant) with similar variability (standard deviations) to the current study.[20] However, passive shoulder ER ROM was greater in our elite swimming cohort compared with these control participants (Table 1). Both male and female control participants demonstrated between 14° and 16° less passive ER ROM in both dominant and non-dominant shoulders.[20] These results would suggest that, contrary to popular opinion, a selective increase in passive shoulder IR ROM bilaterally is not present in elite swimming athletes.[9] The increased shoulder rotation flexibility in the elite swimmers in the current study compared to age-related control participants was due to increased passive ER ROM. As humeral external rotation is required to achieve full shoulder elevation perhaps this finding reflects the repetitive movement into elevation required during most swimming strokes.

During swimming athletes must be able to reach extreme ranges of motion at the shoulder.[21] Therefore, active ROM i.e. the ability of the swimmer to utilise available ROM, has been considered to be of primary importance in assessing ROM in swimmers.[10,22,23] Active rotation ROM has most commonly been measured in the supine position utilised in the current study.[22–24] In our cohort of elite swimmers, both active IR and ER ROM measured in supine was less than passive rotation ROM measured in the same position (Fig. 2). Active IR ROM was 49° (dominant side) and 51° (non-dominant) compared with 61° and 63° when measured passively. Active ER ROM was 90° (dominant side) and 87° (non-dominant side) compared with 105° and 103° respectively when measured passively (Table 1). These active shoulder rotation ranges do not differ markedly in magnitude from those reported in other studies examining swimming athletes. Active IR ROM of 45–49° and active ER ROM of 100–102° have been reported in collegiate swimmers.[22] In a group of high school and collegiate swimming athletes average active IR ROM of approximately 55–60° and average active ER ROM of approximately 86–92° have been reported.[23] Similarly, average bilateral active IR ROM of approximately 54° and average bilateral active ER ROM of approximately 97° have been reported in 74 young swimmers (average age 15 ± 3 years).[24]

Shoulder IR ROM of between 40–50° is considered to be ideal for swimming athletes.[6] Elite swimmers in this study did demonstrate passive IR ROM and active IR ROM measured in supine within this required range (Table 1). The average active IR ROM measured in prone, however, was significantly less than that measured in supine and was less than the range considered to be necessary for swimming (Table 1, Fig. 2). Active IR performed in prone requires shoulder internal rotators to contract concentrically while active IR performed in supine involves eccentric contraction of shoulder external rotators. During swimming the required shoulder IR ROM is achieved by concentric contraction of shoulder internal rotators making prone the more functionally relevant position to assess active shoulder IR ROM in swimmers. Based on the active IR ROM measurements performed in the functionally relevant prone position in the elite swimmers in this study, it would seem that 30° of shoulder IR might be a more accurate description of the active IR ROM required for efficient swimming.

At the time of testing 24% of the elite swimming athletes reported current shoulder pain during training and/or competition and another 53% reported a history of shoulder pain but no current pain. Regression analysis did not reveal any significant association between shoulder pain (current or past) and any of the shoulder rotation parameters measured in this large cohort of swimming athletes currently competing at an elite level. These results support the findings of previous smaller studies which reported no relationship between shoulder pain and rotation ROM in swimming athletes.[10,18,22] The finding of no relationship between the degree of humeral torsion and current or past shoulder pain in the current study provides further evidence that rotation parameters at the shoulder are not predictive of shoulder pain in swimming athletes who are actively competing. It remains to be seen if differences in shoulder rotation ROM variables are present in elite swimmers whose shoulder pain prevents them from competing.

The strength of the conclusions that can be drawn from this study are enhanced by the size of the cohort examined and the stringent inclusion criteria employed to increase the likelihood that all participants were utilising optimal swimming biomechanics. To our knowledge this is the largest study investigating physical parameters at the shoulder in elite swimmers. To be eligible to participate, swimmers had to have qualified to compete at the Australian open-age national championships on at least two occasions and over half the cohort had represented Australia in international competition. Given the success of Australian swimming teams it would seem likely that the swimmers in this study are employing optimal swimming technique including optimal shoulder technique.

Practical implications

- Elite swimmers do not display a greater degree or humeral torsion or passive IR ROM than an age-related population not involved in competitive swimming. Therefore, therapy to maintain normal shoulder IR ROM is sufficient to enable effective and efficient swimming.
- Elite swimmers display approximately 15° more passive ER ROM than an age-related population not involved in competitive swimming.
- Active shoulder IR ROM of 30° measured in prone is sufficient for effective, efficient swimming technique.
- Humeral torsion and shoulder rotation ROM variables are not associated with shoulder pain in elite swimming athletes performing normal training and competing regimes.

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