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Shoulder extension strength: a potential risk factor for shoulder pain in young swimmers?

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ABSTRACT

Objectives: To determine the relationship and predictive value of isometric shoulder strength in the development of shoulder pain in young swimmers.
Design: Prospective, cohort study.
Methods: Shoulder flexion, extension, external and internal rotation strength tests were performed in elevation on 85 swimmers (14–20 years; 48 females) without current shoulder pain using a hand-held dynamometer. Following testing, swimmers were emailed questionnaires to determine if significant shoulder pain developed within 24 months subsequent to testing. The differences between shoulders that did and did not develop pain and the predictive ability of shoulder strength and strength ratios were investigated using Mann Whitney U tests and receiver operating characteristic curves.
Results: Thirty-seven swimmers (47%) returned questionnaires and 18 reported shoulder pain. A comparison of individual shoulders (27 with pain reported and 47 without) determined that shoulder extension strength was lower and flexion:extension strength ratio was higher for male swimmers (n = 36 shoulders) who reported shoulder pain compared to those who did not (p = 0.04). The predictive value of extension strength was fair (0.72; p = 0.03) for males with a cut-off value for extension strength calculated at 13.5% body mass. There were no differences between the two groups in shoulder rotation strength, age, training hours or previous pain history.
Conclusions: Shoulder extension strength, a functional test for swimmers, was associated with and predictive of the development of shoulder pain in male swimmers. Low shoulder extension strength may be a risk factor for the development of shoulder pain in swimmers, proposing a direction for injury prevention and future investigation.

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Practical implications

- Shoulder EX strength is a potentially useful measurement in young swimmers and may be associated with the development of shoulder pain.
- Identification of male swimmers with shoulder EX strength less than 13.5% of body weight may be helpful in the prevention of shoulder pain.
- Shoulder EX strength testing is functional for swimmers, as in addition to testing the capacity of the axioscapular and torque producing muscles, the rotator cuff muscles are tested in their role as shoulder stabilisers.

1. Introduction

The shoulder is the most commonly reported region of pain in swimmers, causing an impact on training, competition and swimming goals for many young swimmers.[1–3] In all cohorts, shoulder pain prevalence in swimmers is high, increasing with time in the sport and may range from 40 to 91% depending on the age group and definition.[1,2,4] Many modifiable risk factors have been investigated in the literature and include range of shoulder rotation movement, shoulder muscle strength, shoulder muscle imbalance, flexibility, scapular kinematics, core stability, use of equipment, training load, swimming technique, dry land exercise and breath-

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ing side.[5,7,8] Despite the investigation of numerous factors, many, including shoulder strength, have been evaluated to have a low level of certainty of predisposing a swimmer to shoulder pain, with no risk factor identified as having a high level of certainty.[6]

Injury prevention strategies are difficult to justify and may be misdirected when evidence regarding risk factors, such as shoulder strength, remains unclear. In some studies swimmers with shoulder pain have demonstrated reduced shoulder internal rotation (IR)[5] and shoulder external rotation (ER) strength compared to those without pain.[9] In contrast, no differences between swimmers with and without shoulder pain have been reported for shoulder IR or ER strength[10] and shoulder strength ratios (IR:ER).[11] The evidence is contradictory and has focussed on the association between variables rather than prediction analyses, which limits comment on risk.[12] Furthermore, the above-mentioned studies that examined the relationship between shoulder strength and pain reported shoulder strength values measured in the presence of pain. Therefore, it is not clear if any differences in strength are a consequence or a cause of shoulder pain or tissue damage, or indeed a result of different pain tolerance levels.[13] Maximal voluntary contraction values, for both static and dynamic muscle contractions, are reduced in the presence of pain,[14,15] in particular, the painful shoulder has demonstrated delayed recruitment[16] and a change in motor strategy due to pain inhibition.[17] Hence, when strength is tested in the presence of shoulder pain which may or may not be associated with tissue damage swimmers' true capacity to generate force (strength) may be underestimated, subsequently misrepresenting a potential causal link between shoulder strength and the development of pain.

Knowledge of shoulder strength measurements performed without pain in positions functional to swimming could help clarify any relationship between shoulder strength and the development of shoulder pain. Shoulder IR and ER strength and their ratios have commonly been reported in swimmers, with changes in these values suggested as risk factors for shoulder pain; however, as outcomes are varied, there is no clear direction provided for an injury prevention intervention.[5,11,18] In contrast, shoulder flexion (FL) and extension (EX) strength values have rarely been reported[19] and warrant further investigation, given the high propulsive EX forces generated by the swimmer in shoulder elevation and the ensuing challenge to the stabilising muscles of the shoulder.[20] Swimmers commonly report shoulder pain when force is generated in shoulder elevation, during early pull-through and the recovery position.[2,9] In the first half of the pull-through phase in freestyle, force is generated in elevation as the shoulder moves into EX, adduction and IR and the body is pulled over the arm, initially with a long lever. During this phase activity has been demonstrated in: pectoralis major, latissimus dorsi, deltoid, the rotator cuff muscles and axioscapular muscles, to both move and stabilise the humerus and scapula.[16,20,21] Functional, shoulder strength tests performed in positions similar to those where pain is experienced may help identify swimmers with reduced capacity to develop force at these ranges.

Prospectively tracking the development of shoulder pain after a pain-free assessment of shoulder strength, will add to our understanding of any relationship between shoulder strength and pain, without pain inhibition confounding the strength values. The aim of this study was to examine the association and predictive ability of clinically useful isometric shoulder strength tests (FL, EX, ER and IR) and the development of shoulder pain in young swimmers.

2. Methods

Isometric shoulder strength values for IR, ER, FL and EX, were recorded bilaterally using a hand-held dynamometer for 85 young swimmers (48 females; 37 males) without current shoulder pain. Young swimmers were defined as adolescent and young adult swimmers (14–20 years) for the purposes of this study.[22] Strength tests were performed in supine for shoulder FL and EX (in 140° abduction); and IR and ER (in 90° abduction) using a *make* test.[19] Shoulder strength ratios (IR:ER and FL:EX) were calculated from the relative shoulder strength values (reported as a percentage of body mass [BM]). In addition to training frequency, personal and anthropometric data, any previous shoulder pain history was recorded at the strength testing session. For the purposes of this study, shoulder pain was defined as pain that prevented the swimmer from participating in normal training or competition for two or more sessions. All swimmers were tested prior to normal, scheduled swim training. The study was approved by the Health and Medical Human Research Ethics Committee for the University (H0012936).

An online questionnaire (supplementary material) to investigate if shoulder pain had been experienced since testing was created and pilot tested with an athlete and physiotherapist to assess the questions for clarity. The questionnaire consisted of seven questions to determine if shoulder pain had developed and if so: which shoulder was affected; an estimation of the swimming sessions modified or missed due to shoulder pain; training history; and if the swimmer had stopped swimming, reasons why this was the case. A prospective timeframe of 24 months was chosen in which to capture the onset of shoulder pain and data was collected in a two-stage process. All swimmers were emailed a link to the questionnaire between nine and eighteen months after the strength testing session. The link was resent approximately 24 months after testing to non-responders and to swimmers who had reported that they had not experienced shoulder pain subsequent to strength testing in the initial questionnaire. Participants received a maximum of two reminders requesting completion of each questionnaire.

Data were collected via LimeSurvey (Limesurvey GmbH./LimeSurvey: An Open Source survey tool, Hamburg, Germany. URL http://www.limesurvey.org) and managed by a technical assistant supervised by the investigators. The shoulders of participants who responded to the questionnaire were grouped for side of pain or no pain (dominant, non-dominant and bilateral) then matched for analysis with the earlier recorded shoulder strength data for comparison.

Shapiro–Wilk tests for normality were performed and all analyses included data from only the swimmers who responded to the questionnaire. Mean age and estimated training times were normally distributed and investigated using t-tests to determine differences between the groups that reported shoulder pain and those that did not. Mann Whitney U tests investigated differences in the non-parametric shoulder strength data for swimmers who did and did not report subsequent shoulder pain and were used to determine differences between swimmers with and without a history of shoulder pain prior to testing. Receiver operating characteristic (ROC) curves were generated to investigate the ability of shoulder muscle strength variables to predict shoulder pain. Analysis of ROC curves examines a test's ability to classify subjects into groups by plotting the true-positive rate (sensitivity) and false-positive rate (1-specificity) along vertical and horizontal axes respectively.[23] For this study, the area under the curve (AUC) was calculated to report prediction accuracy, where a value of 1.0 is considered perfect; 0.9–0.99 excellent; 0.8–0.89 good; 0.7–0.79 fair; 0.51–0.69 poor and 0.50 is considered to be of no predictive value.[23] Youden's index (a summary measure for the ROC curve to enable the selection of an optimal threshold value, helpful in the selection of a cut-off point) was calculated for significant findings to determine optimum cut off points for strength variables.[23] A sample size of 30 was required for an area under the ROC curve of 0.80, set at alpha 0.05, beta 0.20 and null hypothesis value 0.50. Data analy-
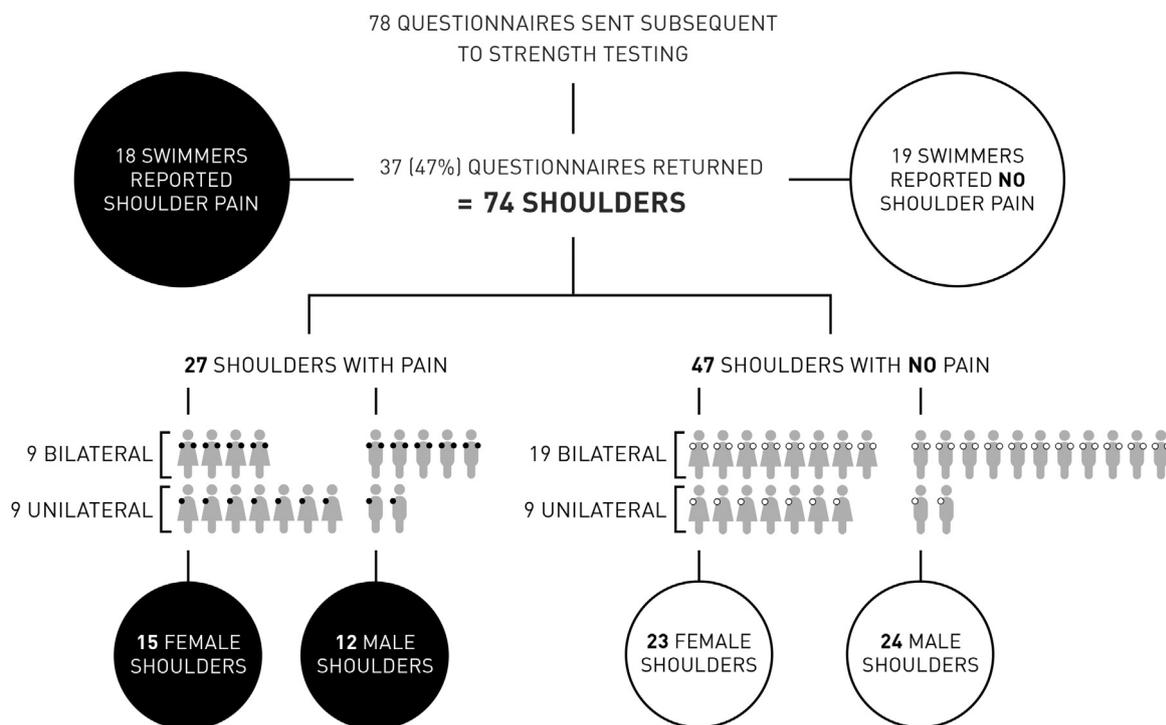
Fig. 1. Response to questionnaire: number of swimmers' shoulders (male and female) with reported pain or no pain subsequent to strength testing.

ses were performed with SPSS (Version 23, IBM Corp., Armonk, NY, USA) and Medcalc Software (Version 17.9, Ostend, Belgium).

3. Results

Of the 85 swimmers initially strength tested, 78 were successfully sent the questionnaire via an email link. Thirty-seven swimmers (47%) returned completed questionnaires and eighteen (n = 27 shoulders) of these swimmers reported the development of shoulder pain (nine reported bilateral pain) in the time subsequent to testing (Fig. 1). The average time for follow up and response subsequent to strength testing was 18 months (range 9–24 months). Swimmers who reported the development of shoulder pain had a similar estimated weekly training time to those that did not report pain (mean [SD] 10.3 ± 6.6 and 10.9 ± 6.3 h, respectively) and mean age (16.3 ± 2.1 and 16.4 ± 1.8 years, respectively). A previous history of shoulder pain was recorded prior to initial strength testing for eight swimmers who reported the development of shoulder pain and nine who reported no pain since strength testing. There was no relationship between a historical episode of shoulder pain (prior to strength testing) and the development of shoulder pain in this group of swimmers for any strength values ($p > 0.20$).

From the follow up questionnaire, pain was reported in 27 shoulders (15 female; 12 male) with no pain reported in 47 shoulders (23 female; 24 male). A comparison of strength values for the shoulders with and without pain is presented in Table 1. For male swimmers, EX strength was lower in shoulders which had developed pain (median 12.35% BM; range 7.06–28.06; $p = 0.04$) compared to those with no reported experience of shoulder pain (16.55% BM; 9.51–21.30; $p = 0.04$) with no difference in FL strength between these groups ($p = 0.16$). Consequently, for male swimmers the FL:EX strength ratio was higher for the shoulders with pain reported in the follow-up questionnaire, compared to those with no shoulder pain (median 1.00; range 0.59–1.64 and 0.85; 0.68–1.51 respectively; $p = 0.04$). There was no difference between the groups of males in IR ($p = 0.40$) or ER strength ($p = 0.30$) or IR:ER strength ratio ($p = 0.50$). For the female swimmers there were no significant

differences in shoulder muscle strength values (FL, EX, ER, IR) or ratios (IR:ER and FL:EX) between the shoulders that developed pain and those that did not ($p \geq 0.05$).

The predictive value (determined by the AUC) of EX strength and FL:EX ratio was 0.72 and 0.71 (fair predictive value) respectively for male swimmers (Table 2). No other shoulder strength tests for males or females demonstrated predictive values greater than 0.70 ($p > 0.12$). The optimal cut off value for shoulder EX strength, as a predictor for shoulder pain, for males was 13.5% BM, determined by the highest Youden's index (0.42). Male swimmers in this cohort with EX strength less than 13.5% BM had a fair chance of developing shoulder pain within the 24 month follow-up period.

4. Discussion

The results of this study suggest that shoulder EX strength and consequently FL:EX strength ratio have a significant relationship with the development of shoulder pain in young male swimmers. Further to this finding of association, predictive analyses indicate that shoulder EX strength, assessed in elevation when the swimmer is pain free, could be helpful in identifying young swimmers who may be at risk of developing shoulder pain, with low shoulder EX strength demonstrating fair predictive value for the onset of shoulder pain in this group.

The male swimmers who developed shoulder pain were weaker in relative shoulder EX (12.35% BM) than those males who did not develop shoulder pain (16.55% BM; $p = 0.04$), (Table 2). Furthermore, the AUC (0.72; $p = 0.03$) suggested that shoulder EX strength in the male swimmer was a fair predictor for the development of subsequent shoulder pain, that is, on average shoulder pain could be predicted correctly 72% of the time. Male swimmers with shoulder EX strength less than 13.5% were more likely to develop shoulder pain than those with higher strength values as suggested by the Youden's index. While the AUC was significant and an indicator of the quality of the analysis,[23] the Youden's index (0.46) is not strong but is clinically useful in the provision of a suggested shoulder EX strength threshold and deserves further investigation

Table 1
Median (range) isometric shoulder strength relative to body weight (%), flexion-to-extension strength ratio (FL:EX) and internal rotation-to-external rotation strength ratio (IR:ER) for male and female shoulders with and without pain subsequent to strength testing.

Strength variable	Female shoulders			Male shoulders		
	Pain reported n = 15	No pain reported n = 23	p	Pain reported n = 12	No pain reported n = 24	p
FL	9.94 (7.80–14.32)	11.22 (5.99–13.90)	0.22	12.66 (10.40–17.05)	13.48 (9.89–17.18)	0.16
EX	10.10 (6.29–20.57)	12.31 (5.99–19.61)	0.10	**12.35 (7.06–28.06)**	**16.55 (9.51–21.30)**	**0.04**
IR	17.52 (14.03–26.21)	20.25 (11.58–29.80)	0.21	25.43 (19.16–30.34)	26.12 (15.60–33.93)	0.40
ER	17.86 (13.48–26.57)	18.80 (11.07–25.16)	0.31	19.24 (16.92–27.39)	22.65 (15.60–26.53)	0.30
FL:EX	0.97 (0.50–1.64)	0.93 (0.63–1.17)	0.36	**1.00 (0.59–1.64)**	**0.85 (0.68–1.51)**	**0.04**
IR:ER	1.06 (0.68–1.28)	1.07 (0.59–1.43)	0.48	1.23 (0.97–1.47)	1.18 (0.93–1.46)	0.50

ER, external rotation; EX, extension; FL, flexion; IR, internal rotation.
Bold text indicates significance p < 0.05.

Table 2
Area under the ROC curve (Area), standard error (SE), asymptotic significance (p) and 95% confidence interval (CI) for male and female shoulder pain predictor variables: relative shoulder strength, flexion-to-extension strength ratio (FL:EX) and internal rotation-to-external rotation strength ratio (IR:ER).

Strength variable	Males				Females			
	Area	SE	p	CI	Area	SE	p	CI
FL	0.65	0.11	0.15	0.44–0.86	0.62	0.10	0.22	0.43–0.82
EX	0.72[a]	0.09	0.03	0.54–0.86	0.66	0.10	0.12	0.49–0.81
IR	0.59	0.10	0.38	0.39–0.79	0.62	0.09	0.20	0.44–0.81
ER	0.61	0.12	0.28	0.38–0.84	0.60	0.10	0.30	0.41–0.79
FL:EX	**0.71[a]**	**0.10**	**0.04**	**0.52–0.91**	0.59	0.10	0.36	0.39–0.79
IR:ER	0.43	0.10	0.49	0.23–0.63	0.43	0.10	0.49	0.23–0.63

ER, external rotation; EX, extension; FL, flexion; IR, internal rotation.
Bold text indicates significance p < 0.05.
[a] Fair predictive value.

with other cohorts. Given that findings of association and prediction were significant for low shoulder EX strength in males without shoulder pain and previously reported normative shoulder EX values for pain free male swimmers (n = 85) were approximately 15% of BM,[19] strengthening exercises could be beneficial in the prevention of shoulder pain in young male swimmers with shoulder EX strength less than 13.5% body weight.

In this cohort, male swimmers who developed shoulder pain recorded lower isometric shoulder EX strength than the group that did not develop shoulder pain, yet there were no differences between the groups in IR and ER strength. This is in contrast to previous studies that have reported differences in shoulder IR and ER rotation strength for swimmers with shoulder pain; however, the very presence of pain may have confounded results.[5,9] Resisted shoulder EX in elevation, requires the coordinated recruitment and control of extensor torque producing muscles, rotator cuff muscles and axioscapular muscles.[16,20,21] While the rotator cuff muscles will be recruited in their stabiliser role to counterbalance potential destabilising forces produced by the shoulder extensor muscles (sternal head of pectoralis major, latissimus dorsi, teres major), the axioscapular muscles will be recruited to both rotate the scapula and stabilise it against potential destabilising forces produced by both shoulder extensor and rotator cuff muscles. The results from the male cohort in this study suggest that resisted shoulder EX, a functionally relevant strength test that requires rotator cuff muscles to function in their stabilisation role, is better able to identify swimmers at risk of developing shoulder pain than resisted rotation in which the rotator cuff muscles are functioning to produce rotation torque.[24]

For this cohort of adolescents and young adults, diversity in developmental and growth stages involving change in upper limb lever length which may influence motor control and coordination around the shoulder is expected.[25,26] Shoulder EX strength was not associated with the development of shoulder pain in female swimmers, in contrast to the findings for males. This is perhaps a result of differences in strength changes in male swimmers compared to females and different developmental stages.[27] A change in body dimension was not recorded in this study; however, this is recommended for future investigations and could provide further understanding of risk factors for shoulder pain, which are no doubt multifaceted. Increases in the length of the upper limb will require not only increased shoulder EX strength for swimming but also increases in rotator cuff and axioscapular muscle strength which have to be well co-ordinated to counterbalance potential translation forces and maintain shoulder region stability.[24] We propose that if the ability to produce EX force via a long lever is reduced in the young swimmer, potentially, the capacity to achieve optimal shoulder joint stabilisation is reduced and the shoulder may be at risk of injury. The authors recommend monitoring young male swimmers with shoulder EX less than 13.5% BM as they may be at risk of developing shoulder pain. These swimmers may require training modifications and time to develop the strength, coordination and motor control required for swimming, particularly during rapid growth phases. Shoulder EX exercises in elevated positions may be helpful for this group.

The results of this study confirm that shoulder pain is common in a young swimming population. Approximately half of the 47% of swimmers who responded to the questionnaire reported the onset of shoulder pain within the two years subsequent to performing the strength tests when they were pain-free. Our results concur with other investigations that have reported high rates of shoulder pain in swimmers ranging from approximately 50%[4] up to 91%,[2,9] reinforcing the urgent need for shoulder pain prevention strategies in this population. Despite the high prevalence of shoulder pain, a previous history did not influence the development of shoulder pain in this population, in contrast to previous studies, which have shown a history of shoulder pain as a risk factor for shoulder pain.[8]

Conclusions to be drawn from this study need to be tempered in light of some limitations. The questionnaire, although previously trialled, was not tested for reliability and was reliant on the reporting accuracy of swimmers. Although shoulder pain was defined in the questionnaire, pain was self-reported, which may have influenced results. It is possible that both a history of pain and subsequent shoulder pain were under-reported as the majority of swimmers believe mild to moderate pain is normal and should be tolerated.[28] Although groups had a similar mean age, shoulder pain history and training time, other variables may have influenced the development of shoulder pain in these swimmers such as range of shoulder rotation, frequency of dryland sessions, training intensity, competition, core stability and growth.[9] However, to date, not one of these variables have been shown to have a high level of certainty in predisposing a swimmer to shoulder pain[6] and to our knowledge there are no other prospective studies that have investigated shoulder strength and the development of shoulder pain in swimmers.

Our findings suggest that further investigation of shoulder EX strength as a risk factor for the development of shoulder pain in swimmers is worthwhile. We propose that the investigation of shoulder EX strength in combination with other factors, both modifiable and non-modifiable, may enhance our understanding of risk factors for shoulder pain in swimmers and provide direction for injury prevention programs.

5. Conclusion

Preliminary evidence supports an association between low shoulder EX strength and the development of shoulder pain in young male swimmers. Furthermore, predictive outcomes suggest that low shoulder EX strength may be a risk factor for the development of shoulder pain. Shoulder EX strength tests are a functional measure of the ability to produce force and stabilise around the shoulder and may prove to be a useful clinical indicator for young swimmers at risk of developing shoulder pain.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.jsams.2018.11.008.

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