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Original research

Shoulder pain in swimmers: A 12-month prospective cohort study of incidence and risk factors

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ABSTRACT

Objective: To investigate shoulder pain incidence rates and selected risk factors for shoulder pain in competitive swimmers.
Design: 12-month prospective cohort study.
Setting: Five swimming clubs in Melbourne, Australia.
Participants: 74 (37 M, 37 F) competitive swimmers ranging in age from 11 to 27 years and performing at least five swim sessions per week.
Assessment of risk factors: Swimmers completed a baseline questionnaire regarding demographics, anthropometric features, swimming characteristics and training and injury history. Active shoulder internal (IR) and external rotation (ER) range of motion and passive joint laxity were measured.
Main outcome measurements: Shoulder pain was self-reported over 12 months with significant interfering shoulder pain (SIP) defined as pain interfering (causing cessation or modification) with training or competition, or progression in training. A significant shoulder injury (SSI) was any SIP episode lasting for at least 2 weeks.
Results: 28/74 (38%) participants reported SIP while 17/74 (23%) reported SSI. Exposure-adjusted incidence rates were 0.3 injuries and 0.2 injuries per 1000 swim km for SIP and SSI, respectively. Swimmers with both high and low ER range were at 8.1 (1.5, 42.0) and 12.5 (2.5, 62.4) times greater risk of sustaining a subsequent SIP, respectively and 35.4 (2.8, 441.4) and 32.5 (2.7, 389.6) times greater risk of sustaining a SSI, respectively than those with mid-range ER. Similarly swimmers with a history of shoulder pain were 4.1 (95% CI: 1.3, 13.3) and 11.3 (95% CI: 2.6, 48. 4) times more likely to sustain a SIP and SSI, respectively.
Conclusion: Shoulder pain is common in competitive swimmers. Preventative programs should be particularly directed at those swimmers identified as being at risk of shoulder pain.

1. Introduction

Shoulder pain/injury is the most common musculoskeletal problem experienced by competitive swimmers (McMaster, 1999; Mountjoy et al., 2010; Weldon & Richardson, 2001). Of the relatively few studies investigating shoulder injury incidence in this sporting population, reported rates vary widely depending on the specific injury definition employed (Chalmers & Morrison, 2003). Given its prevalence, numerous risk factors for shoulder injury in swimmers are proposed in the literature including glenohumeral joint range of motion and laxity, scapular dyskinesis, rotator cuff strength imbalances, gender, competitive swimming level, stroke, swim distance and hand paddle usage during swim training (Bak, 2010; Blanch, 2004; McMaster, Roberts, & Stoddard, 1998; McMaster & Troup, 1993; Richardson, Jobe, & Collins, 1980; Sein et al., 2010; Weldon & Richardson, 2001; Wolf, Ebinger, Lawler, & Britton, 2009). However, these have received limited prospective investigation (Gaunt & Mafulli, 2011).

Biomechanical three dimensional analysis of freestyle swimming supports the notion that adequate rotational shoulder range of motion is required to swim with correct technique and avoid shoulder impingement (Yanai & Hay, 2000; Yanai, Hay, & Miller,

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2000). However, cross-sectional studies investigating associations between shoulder injury in swimmers and shoulder internal (IR) and external (ER) rotation range of motion and glenohumeral joint laxity report mixed findings (Allegrucci, Whitney, & Irrgang, 1994; Bak & Magnusson, 1997; Beach, Whitney, & Dickoff-Hoffman, 1992; McMaster et al., 1998; Ozcaldiran, 2002; Rupp, Berninger, & Hopf, 1995; Sein et al., 2010; Zemek & Magee, 1996). Inferences regarding the role of joint laxity and range of motion in the aetiology of shoulder injury are difficult to draw from these studies as it is unclear whether deficits are pre-existing or sequelae of injury.

This study sought to (i) investigate shoulder injury incidence and exposure-adjusted injury rates and (ii) identify the predictive value of several risk factors for these injuries, with a particular focus on shoulder IR and ER range of motion and glenohumeral joint laxity, in competitive swimmers.

2. Methods

2.1. Setting and study design

A prospective cohort study was conducted involving competitive swimmers in Melbourne, Australia.

2.2. Participants

A sample of convenience was recruited. Swimmers from five competitive swimming clubs in Melbourne, Australia who competed at state, national or international level, performed at least five swim sessions per week and intended to continue this training level during the following 12 months were eligible to participate in this study. Swimmers were excluded if they had a history of shoulder surgery or dislocation, were suffering shoulder pain on the day of testing or had any other injury that would interfere with the test procedures. The study was approved by the institutional Human Research Ethics Committee and all participants or their parents/guardians provided written informed consent.

2.3. Procedures

Swimmers completed a baseline questionnaire regarding demographics, anthropometric features, swimming characteristics and training and injury history. Shoulder range of motion and laxity testing was conducted in a standardised order by the same sports physiotherapist (HW). Active shoulder IR and ER range of motion at 90° abduction was measured with a Dualer Inclinometer (J-Tech Medical, Salt Lake City) in supine with manual scapular stabilisation (Boon & Smith, 2000). Anterior-to-posterior glenohumeral translation was measured in prone at 90° shoulder abduction using a modified KT1000 arthrometer (MED-metric Corporation, San Diego) (Pizzari, Kolt, & Remedios, 1999). Glenohumeral joint translation in millimetres was recorded at 89 N of applied force as this was an appropriate pre-set level on the device for shoulder testing.

In a separate study, the intra-examiner reliability (ICC 2,3) standard error of measurement (SEM) and minimal detectable change at the 90% confidence level ($MDC_{90} = 1.65*SEM*\sqrt{2}$) of shoulder range of motion ($n = 17$) and laxity testing ($n = 14$) was examined in a subgroup of competitive swimmers ranging in age from 12 to 24 years (Table 1) (Haley & Fragala-Pinkham, 2006; Portney & Watkins, 2009). The results indicate good to excellent reliability for all measures with SEM of 2° or less and MDC_{90} of 5° or less.

The potential risk factors studied are detailed in Table 2.

Swimmers were instructed regarding the shoulder injury definition and underwent 12 months injury surveillance following baseline measurement. Swimmers were asked to complete, and submit, a weekly diary to report shoulder injury status. When diary forms were not submitted, swimmers were contacted directly each fortnight via SMS (short message service for mobile phones), telephone or email to ascertain shoulder injury status. Episodes of shoulder pain meeting the injury definition were self-reported using standardised injury report and severity forms. Injury severity was indicated by symptom duration (weeks) and the number of modified or missed training sessions. In most instances, injury report and severity forms were collected within two to four weeks of occurrence. Swim coaches supplied copies of swim training records from which weekly exposure in kilometres and the number of sessions completed were derived.

The shoulder injury definition used was based on previous research and defined a priori as significant interfering shoulder pain (SIP) that interfered with training or competition, or progression in training and caused cessation or modification of training or racing (McMaster et al., 1998; McMaster & Troup, 1993). In addition, a significant shoulder injury (SSI) was defined as any SIP episode lasting for at least two weeks. The use of two injury outcomes in this study allowed for the investigation of potential risk factors for both short- and longer-duration injury episodes.

2.4. Data analysis

Data were analysed using SPSS 11.0 for Windows. Range of motion and laxity data were categorised according to tertiles (low, middle, high) to examine potential non-linear relationships with shoulder injury, with the middle category the reference for analyses. Each variable was examined for side and gender differences and the significant differences for shoulder IR and laxity between

Table 1
Reliability of shoulder tests.

Shoulder tests		ICC 2,3 (95% CI)	SEM (°)	MDC_{90} (°)
Internal range of motion	Right	0.96 (0.90,0.99)	2	5
	Left	0.90 (0.72,0.97)	2	5
External range of motion	Right	0.95 (0.85,0.98)	2	5
	Left	0.94 (0.83,0.98)	2	5
Shoulder translation	Right	0.94 (0.81,0.98)	1	2
	Left	0.70 (0.34,0.93)	2	5

ICC = intraclass correlation coefficient.
SEM = standard error of measurement.
MDC_{90} = minimal detectable change.

Table 2
Variables examined for association with shoulder injury.

Category	Variable
Shoulder range of motion	Internal rotation at 90° abduction (°)
	External rotation at 90° abduction (°)
Glenohumeral laxity	Posterior to anterior translation at 89 N applied force (mm)
Injury history	History of significant shoulder pain in 12 months prior to study (yes/no)
Demographics	Height (cm)
	Weight (kg)
	Age (years)
	Handedness (left/right)
Competitive characteristics	Competitive level (state/national/international)
	Competitive swim distance (sprint/middle/long distance)
	Age commenced competitive swimming (years)
	Preferred stroke event (freestyle/butterfly/backstroke/breaststroke/individual medley)
Training in past year	Total yearly swimming distance (km)
	Frequency of use of hand paddles (times/week)
	Proportion of freestyle performed at swim training (%)

males and females were accounted for by gender-specific categorisations for these tests.

Preliminary bivariate logistic regression analyses identified those variables associated with SSI or SIP, and variables with p values <0.15 were retained for the multivariate analyses. The independent predictors of shoulder injury (SSI and SIP) were determined using backward stepwise binary logistic regression. The goodness of fit (Hosmer and Lemeshow test), adjusted odds ratios and 95% confidence intervals (CI) were calculated from the final logistic regression model.

3. Results

3.1. Cohort characteristics and shoulder injury incidence rates

Seventy five swimmers were recruited. One participant withdrew and was excluded from the analysis. As such, the study cohort comprised 37 female and 37 male swimmers ranging in age from 11 to 27 years. Nine swimmers ceased swimming and one moved interstate, nonetheless their data were retained as analyses included adjustment for swim training exposure. Table 3 detail swimmers' training, shoulder range of motion, laxity and demographic characteristics.

Compliance with completing the injury diary was low with only 12 swimmers submitting the diary for the 12 months. However, injury surveillance via fortnightly direct contact through SMS, email or telephone was very successful. Hence the overall injury surveillance rate was 87%. Swim squad averages were used to calculate individual training exposure data for 63 (85%) participants. Individual training mileage and attendance information was only available for 11 (15%) participants. Training data were unavailable for 122 (14%) of the 888 potential injury surveillance months. The average of each swimmer's available monthly swim kilometres was substituted for missing training data where required (Engels & Diehr, 2003; Tabachnick & Fidel, 1989). Overall, 19,043 swim training sessions and 91,838 km of swimming were calculated for the cohort during the surveillance period.

During the 12-month study, 28/74 (38%) participants reported SIP while 17/74 (23%) reported SSI. The exposure-adjusted incidence rates were 0.3 injuries per 1000 swim kilometres for SIP and 0.2 injuries per 1000 swim kilometres for SSI. More than one shoulder injury episode was reported by nine (32%) swimmers. The majority of SSI (74%) and SIP episodes (68%) reported were new injuries. Most injuries (90%) were sustained during swim training, specifically during the main set (74%) whilst performing the propulsive pull through phase of the freestyle stroke. Only five percent of injuries were reported during competition or after swim training. The duration of the worst shoulder injury episode was 4 ± 2 weeks for both SSI and SIP. The number of modified or missed swim sessions for the worst injury episode was 15 ± 21 for SIP and 22 ± 24 for SSI. The mean $\pm$ SD age of injured swimmers was 15 ± 3 years with shoulder injuries evenly distributed by side and gender.

Table 3
Participant characteristics given as the mean ± standard deviation or the number (percentage).

Characteristics	Female $N = 37$	Male $N = 37$	Total $N = 74$
Age (years)	15 ± 3	16 ± 3	15 ± 3
Age started swim competition (years)	10 ± 2	11 ± 3	10 ± 3
Height (cm)	166 ± 6	175 ± 14	170 ± 12
Hand dominance			
Right	34 (91%)	32 (86%)	65 (88%)
Left	2 (6%)	4 (11%)	7 (9%)
Equal	1 (3%)	1 (3%)	2 (3%)
Competitive level			
International	4 (11%)	8 (21%)	12 (16%)
National	11 (30%)	14 (39%)	25 (35%)
State	22 (59%)	15 (40%)	37 (49%)
Preferred event by stroke			
Freestyle	11 (30%)	11 (30%)	22 (30%)
Butterfly	8 (21%)	6 (16%)	14 (19%)
Backstroke	5 (13%)	9 (24%)	14 (19%)
Breaststroke	9 (24%)	7 (19%)	16 (21%)
Individual Medley	4 (12%)	4 (11%)	8 (11%)
Competition distance			
Sprint (50 m,100 m)	4 (12%)	7 (18%)	11 (16%)
Middle (200 m,400 m)	0 (0%)	0 (0%)	0 (0%)
Distance (800 m,1500 m)	0 (0%)	1 (3%)	1 (1%)
Sprint and Middle	26 (67%)	23 (61%)	49 (65%)
Middle and Distance	3 (9%)	2 (5%)	5 (7%)
All distances	4 (12%)	4 (13%)	8 (12%)
Swimming sessions/week (n)	8 ± 2	8 ± 2	8 ± 2
Average swimming distance/week (km)	43 ± 15	46 ± 15	44 ± 15
Average swimming distance/session (km)	6 ± 1	5 ± 1	6 ± 1
% Training time by stroke			
Freestyle	56%	60%	58%
Butterfly	14%	15%	15%
Backstroke	18%	18%	18%
Breaststroke	12%	9%	10%
Land sessions/week (n)	3 ± 3	3 ± 2	3 ± 3
Internal rotation range – Left (°)	56 ± 8	52 ± 8	54 ± 8
Internal rotation range – Right (°)	55 ± 9	52 ± 8	53 ± 8
External rotation range – Left (°)	97 ± 9	95 ± 9	96 ± 9
External rotation range – Right (°)	97 ± 8	97 ± 8	97 ± 8
Laxity – Left (mm)	31 ± 4	28 ± 3	29 ± 4
Laxity – Right (mm)	31 ± 4	27 ± 4	29 ± 4

3.2. Independent predictors of shoulder injury

Preliminary bivariate analyses results were the same whether adjusted or unadjusted for swim training kilometres. There was a significant association between a positive 12-month shoulder pain history and both injury outcomes (SIP: $p = 0.045$; SSI: $p = 0.006$), whereas ER range was significantly associated with SIP ($p = 0.015$) and met the multivariate model inclusion criteria ($p < 0.15$) for SSI ($p = 0.07$). These two variables were retained for the multivariate analysis to identify independent predictors of shoulder injury (Table 4). None of the other examined variables was associated with shoulder injury.

The significant independent predictors of shoulder injury, adjusted for swim training exposure, were ER range of motion (SIP: $p = 0.008$, SSI: $p = 0.02$) and previous shoulder injury history (SIP: $p = 0.02$; SSI: $p = 0.001$). The adjusted odds ratios indicated that swimmers in both the low and high ER range of motion groups were at elevated risk of developing a shoulder injury than those in the mid-range group. Similarly swimmers with a history of shoulder pain were 4.1 (95% CI: 1.3, 13.3) and 11.3 (95% CI: 2.6, 48. 4) times more likely to sustain a subsequent shoulder injury for SIP and SSI respectively. Swim training distance was not a significant predictor of shoulder injury (SIP: $p = 0.07$; SSI: $p = 0.1$). Both ER (SIP: $p = 0.008$, SSI: $p = 0.02$) and previous shoulder history (SIP: $p = 0.02$; SSI: $p = 0.001$) were significant predictors when analyses were not adjusted for swim training exposure (km).

4. Discussion

This study utilised a prospective cohort design to investigate shoulder injury incidence and selected risk factors for shoulder injury in Australian competitive swimmers. Our findings of shoulder injury incidence rates ranging from 23% to 38% confirm the notion that shoulder injuries in competitive swimming are common (Mountjoy et al., 2010; Richardson et al., 1980). Prior retrospective surveys report SIP incidence rates of 29%–49% over a 12 month period (Burchfield, Cofield, & Cofield, 1994; Hall, Stewart, & Rogers, 1995) and 62% over a swim career (McMaster

Table 4
Independent predictors of shoulder injury.

Variable	Categories	n	% of total participants in injured group n (%)	Adjusted for swim km		Unadjusted for swim km	
				OR (95% CI)	p value	OR (95% CI)	p value
Significant shoulder injury (SSI)							
ER	Middle (reference)	25	1/74 (1%)	–	0.02[a]		0.02[a]
	Low <93°	25	8/74 (11%)	32.5 (2.7, 389.6)		24.9 (2.3, 262.6)	
	High ≥100°	24	8/74 (11%)	35.4 (2.8, 441.9)		23.0 (2.2, 236.8)	
Past History[b]	No (reference)	48	6/74 (8%)	–			
	Yes	26	11/74 (7%)	11.3 (2.6, 48.4)	0.001[a]	10.0 (2.5, 39.2)	0.001[a]
Swim km		74		1.0 (1.0, 1.0)	0.11		
Significant interfering shoulder pain (SIP)							
ER	Middle (reference)	23	3/74 (4%)		0.008[a]		0.009[a]
	Low <93°	27	15/74 (20%)	12.5 (2.5, 62.4)		11.1 (2.4, 51.6)	
	High ≥100°	24	10/74 (14%)	8.1 (1.5, 42.0)		5.9 (1.3, 28.05)	
Past History[b]	No (reference)	48	14/74 (19%)				
	Yes	26	14/74 (19%)	4.1 (1.3, 13.3)	0.02[a]		0.02[a]
Swim km		74		1.0 (1.0, 1.0)	0.07		

ER = external rotation range of motion; km = kilometres.
[a] significant at $p < 0.05$.
[b] history of shoulder injury in past 12 months.

& Troup, 1993). Prevalence rates reported for SIP range from 20% to 38% (Capaci, Ozcaldiran, & Durmaz, 2002; McMaster & Troup, 1993). Surveys using injury definitions other than SIP report shoulder injury incidence of 42%–62% (Stocker, Pink, & Jobe, 1995). Our findings are most consistent with previously reported SIP prevalence rates, highlighting the need for consistency of injury definition to allow for valid comparison between studies (Brooks & Fuller, 2006).

In our study, shoulder injury rates ranged from 0.2 to 0.3 injuries per 1000 km of swimming depending on the definition used. The incidence of all swimming injuries has been reported as 0.9 injuries per 1000 swim hours (Bak, Bue, & Olsson, 1989), 3.78 to 4 injuries per exposures (Wolf et al., 2009) and 21.8 injuries per 1000 female swimmers (Mountjoy et al., 2010). In practical terms, a squad of 20 swimmers that trains 50 km each week may sustain five SIP and three SSI events during a 16-week training phase. Thus shoulder injuries are a liability for swimming programs and attention to preventative strategies are needed (McMaster, 1999; Mountjoy et al., 2010).

Recurrence of shoulder injuries in swimming is frequent (Bak et al., 1989). This study confirms the significant independent association between a positive past history of shoulder injury and subsequent shoulder injury risk, concurring with research from other sports (Emery, 2003). The reason for this relationship is unclear but may relate to pre-existing risk factors or insufficient rehabilitation of shoulder injuries. While history of shoulder injury is a non-modifiable risk factor, it can be used as a marker to identify swimmers at risk of injury in whom preventative efforts should be particularly directed.

Measurement of shoulder rotational range of motion and laxity in an abducted position is a recommended component of clinical examination for overhand athletes (Blanch, 2004; McQuade & Murthi, 2004; Reinhold & Gill, 2009), despite the controversy in the literature regarding the underlying mechanisms for alterations in shoulder joint motion or laxity, particularly the respective roles of capsular tightness, muscle stiffness and humeral torsion (Huxel et al., 2008; McQuade & Murthi, 2004; Torres & Gomes, 2009; Whiteley, Ginn, Nicholson, & Adams, 2009).

In this study, swimmers with high (≥100°) or low (<93°) shoulder ER range of motion were at increased risk of developing a shoulder injury than those with mid-range motion, irrespective of whether the results were adjusted for swim training exposure. This supports the hypothesis that there is an ideal range of flexibility needed to swim without developing a shoulder injury (Blanch, 2004). Previous cross-sectional studies investigating the relationship between rotational range of motion and shoulder pain in swimmers are conflicting with results showing either no significant correlation between either IR and ER and SIP (Bak & Fauno, 1997; Beach et al., 1992) or significantly greater total rotational range of motion in swimmers with shoulder pain, compared with controls (Ozcaldiran, 2002). Another report demonstrated a trend towards reduced IR in swimmers with shoulder injuries (Bak & Magnusson, 1997). Differences in cohort characteristics, injury definitions and study design most likely explain the disparate results.

Despite the statistically significant findings for ER as a risk factor for shoulder injury in this study the application of these findings to the clinical setting requires consideration. The intra-tester reliability of range of motion measurement was good to excellent (ICC: 0.90–0.96) with SEM and MDC_{90} for all rotation tests of 2 and 5°, respectively. The minimal detectable change of ER testing was smaller than the range of scores delineating mid-range ER (7°), low-range (21°) and high-range (14°) indicating that, in this research context, the range of scores was detectable by the measurement method employed (Haley & Fragala-Pinkham, 2006; Kolber, Vega, Widmayer, & Cheng, 2011; Portney & Watkins, 2009).

Biomechanical analyses of freestyle swimming have indicated that shoulder impingement may occur when swimmers exceed their available shoulder range of motion during the freestyle stroke, dependent on the swim technique employed (Yanai & Hay, 2000; Yanai et al., 2000). Swimmers impinge their shoulders most frequently during the recovery phase of the freestyle stroke (Yanai & Hay, 2000) wherein the shoulder abducts and externally rotates, passing through the clinically defined 'painful arc' of impingement (Neer, 1983). Cadaveric studies suggest that sufficient ER is required to prevent internal impingement of the humeral head with the superior glenoid during abduction (Edelson & Teitz, 2000) and limited ER range of motion has been associated with the development of subacromial impingement syndrome (Kim & McFarland, 2004; Lin, Lim, & Yang, 2006; Michener, McClure, & Karduna, 2003). There is sufficient evidence from animal and human studies that overuse loading of the shoulder, during the swimming stroke action, precipitates rotator cuff tendon thickening and tendinopathy (Bey, Song, Wehrli, & Soslowsky, 2002; Carpenter, Flanagan, Thomopoulos, Yian, & Soslowsky, 1998; Lee, Nakajima, Luo, Zobitz, Chang, & An, 2000; Mihata, Lee, McGarry, Abe, & Lee, 2004; Murrell, 2002; Reilly, Amis, Wallace, & Emery, 2003a; Reilly, Amis, Wallace, & Emery, 2003b; Sein et al., 2010; Soslowsky et al., 2002; Soslowsky et al., 2000). These changes may affect the potential for extrinsic tendon impingement in swimmers' shoulders (Sein et al., 2010). It is possible that swimmers with limited ER who performed their stroke at the end of their available range were at increased risk of impingement during arm recovery, particularly in the presence of overuse-related tendon thickening.

Swimmers in this study with greater ER motion ($\geq 100^{\circ}$) were also at increased risk of sustaining a shoulder injury. It is possible that the high ER range of motion observed in some swimmers reflects detrimental changes to the shoulder passive restraints and, potentially, its neuromuscular control. In healthy individuals, less subscapularis activity is observed in response to ER perturbations with the shoulder in maximal ER compared with neutral ER, whilst joint stiffness remains unchanged for both positions, indicating that structures other than the rotator cuff are providing stability (Huxel et al., 2008). Application of a non-destructive ER stretching protocol to cadaveric inferior glenohumeral ligaments results in significant increases in ligament length (Pollock et al., 2000) and ER range (Mihata et al., 2004) as well as subtle increases in anterior translation (Mihata et al., 2004). In vivo, such repetitive microtrauma to the shoulder stabilising structures may result in subtle anterior shoulder instability, secondary impingement of the rotator cuff and biceps tendons (Belling Sorensen & Jorgensen, 2000), as well as altered glenohumeral kinematics (Huffman, Tibone, McGarry, Phipps, Lee, & Lee, 2006). Increased ER range is also associated with reduced kinaesthetic sense in the dominant shoulders of overhead athletes, attributable to microtraumatic damage to the shoulder joint capsule and receptors (Allegrucci, Whitney, Lephart, Irrgang, & Fu, 1995) and this altered proprioceptive input may affect the stabilising function of the shoulder musculature (Nyland, Caborn, & Johnson, 1998). Certainly, altered neuromuscular control has been identified as an important factor in the aetiology of secondary impingement in swimmers (Blanch, 2004). A further consideration is that twisting and lengthening of the anterior portion of the supraspinatus tendon has been observed in cadavers during ER (Nakajima, Hughes, & An, 2004). These authors suggest that axial rotation may impair tendon perfusion under tension, thereby providing a rationale for studies citing external rotation as a risk factor for rotator cuff injury (Nakajima et al., 2004). Theoretically, swimmers with increased ER range may be susceptible to greater intrinsic tendon injury.

Loss of IR range of motion due to tightness of the posterior capsule is frequently cited as a risk factor for shoulder injury in overhead athletes (Levine, Brandon, Stein, Gardner, Bigliani, & Ahmad, 2006; Myers, Laudner, Pasquale, Bradley, & Lephart, 2006; Warner, Micheli, Arslanian, Kennedy, & Kennedy, 1990), however there was no association between IR range and swimming shoulder injuries in this study. Most likely, insufficient less eccentric loading of the rotator cuff and posterior capsule occurs during swimming than in other overhead sports such as throwing or tennis, to cause the loss of IR associated with injury. Alternatively, IR may not be useful for injury prediction given that it can vary considerably diurnally in swimmers (Blanch, 2004) and in an associated study on the current cohort, right sided internal rotation was the least stable variable in non-injured swimmers over a six month period.

There was no association between joint laxity measured at baseline and subsequent shoulder injury. These findings are in contrast to previous reports whereby shoulder hyperlaxity was reported to be a factor in the aetiology of shoulder injury in competitive swimmers (Bak, 2010; Bak & Fauno, 1997; McMaster et al., 1998; Zemek & Magee, 1996). A significant correlation between current interfering shoulder pain and joint laxity was reported in competitive swimmers where glenohumeral laxity was assessed using clinical laxity tests and apprehension ratings (McMaster et al., 1998). However, the use of subjective apprehension rating in a composite score for joint translation has been questioned (Blanch, 2004) and there is debate surrounding the reliability of clinical laxity testing at the shoulder (Bahk, Keyurapan, Tasaki, Sauers, & McFarland, 2007; Levy, Lintner, Kenter, & Speer, 1999). Furthermore, there is debate in the literature as to whether joint laxity or muscle stiffness is being tested (Huxel et al., 2008; McQuade & Murthi, 2004). One study reported a significant difference in quantitatively measured shoulder joint translation between swimmers and controls, however the applied forces were not standardised (Tibone, Lee, Csintalan, Dettling, & McMahon, 2002). Conversely, another study reported no difference in translation between swimmers and controls or with respect to shoulder pain history when tested at a higher level of force, 150 N (Borsa, Scibek, Jacobson, & Meister, 2005). An important consideration is the direction of shoulder laxity testing utilised in the current study, being anterior-to-posterior translation. Laxity testing in other directions or more extreme ranges of shoulder ER may yield different results and further research is warranted. Nevertheless, the finding of this study that shoulder laxity was not associated with shoulder injury is not surprising given that considerable shoulder capsule laxity may be present without symptomatic shoulder instability (McFarland, Garzon-Muvdi, Jia, Desai, & Petersen, 2010; McFarland, Kim, Park, Neira, & Gutierrez, 2003; Richards, 2003).

Exposure to repetitive overhead arm motion during training is cited as a contributing factor in the development of shoulder pain in competitive swimmers (Ciullo & Stevens, 1989; Sein et al., 2010; Weldon & Richardson, 2001), however, this study did not demonstrate an association between shoulder injury and training mileage. In contrast, a prior cross-sectional study reported that swimmers completing >35 km per week of swim training were four times more likely to have supraspinatus tendinopathy (Sein et al., 2010). In this study, a considerable portion of swim training exposure data (85%) was derived from squad averages, which limits its usefulness given that swim coaches' reports of mileage have low validity compared with direct observation of training by researchers (Stewart & Hopkins, 2000). A limitation of many longitudinal studies is participant drop out and missing data (Twisk & de Vente, 2002). Training data were missing for 14% of the injury surveillance period and was imputed by averaging the available training data of these participants. This method is deemed to be one of the best methods for treatment of missing data in a longitudinal study (Engels & Diehr, 2003). Furthermore, similar results were obtained when the results were not adjusted for swim training kilometres. Another consideration is that training exposure was examined as a continuous variable in the current study, precluding identification of a non-linear relationship with shoulder injury. Given these limitations, the role of overuse loading in the aetiology of swimming-related shoulder pain should not be discounted.

There are a number of considerations when interpreting our results. In comparison with prospective research in other sports a small cohort was investigated (Emery, 2003). Swimmers with a previous shoulder injury are more likely to volunteer, increasing the likelihood of overestimation of injury incidence and risk factor association. Injuries were self-reported, hence, individual differences in pain tolerance and recall may have impacted reporting (Hanita, 2000). Furthermore not all injuries may have been reported. Swimmers did not undergo diagnostic examination and it is possible that some injuries were attributable to structures other than the shoulder. Finally, the contribution to the understanding of the aetiology of shoulder injury in swimming is limited to the specific risk factors investigated.

5. Conclusions

The incidence of shoulder pain reported in this study for Australian competitive swimmers is comparable to published injury rates and provides a benchmark for the future evaluation of preventive programs. Of the examined potential risk factors, only previous history of shoulder pain, and high or low shoulder ER range of motion were significantly associated with shoulder injury. These findings can be applied practically to identify swimmers who may be at increased risk of developing shoulder pain and who may benefit from prevention strategies.

Conflict of interest

None declared.

Ethical approval

Ethical approval was granted for this project by the University of Melbourne Human Research Ethics Committee.

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