THE SHORT TERM EFFECT OF SWIMMING TRAINING LOAD ON SHOULDER ROTATIONAL RANGE OF MOTION, SHOULDER JOINT POSITION SENSE AND PECTORALIS MINOR LENGTH.

KEYWORDS

Shoulder pain; Shoulder injury; swimmers; range of motion; joint position sense; pectoralis minor

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ABSTRACT

Background: Shoulder pain or injury is the most common issue facing elite competitive swimmers and the most frequent reason for missed or modified training. Literature suggests that highly repetitive upper limb loading leads to inappropriate adaptations within the shoulder complex. The most likely mal-adaptations to occur are; variations in shoulder rotational range of motion (ROM), reduction in joint position sense (JPS) and shortened pectoralis minor length (PML). This has yet to have been confirmed in experimental studies. The aim of this study was to investigate the short term effects of swimming training load upon internal and external rotation ROM, JPS and PML.

Method: Sixteen elite swimmers training in the British Swimming World Class programme participated. Measures of internal and external ROM, JPS error score and PML were taken before and after a typical two hour swimming session.

Results: Following swimming training shoulder external rotation ROM and PML reduced significantly (-3.4°, p=<0.001 & -0.7cm, p=<0.001 respectively), JPS error increased significantly (+2.0° error angle, p=<0.001). Internal rotation ROM demonstrated no significant change (-0.6°, p=0.53).

Discussion: This study determined that elite level swimming training results in short term maladaptive changes in shoulder performance that could potentially predispose them to injury.

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INTRODUCTION

Shoulder pain or injury is by far the most common injury issue faced by elite level swimmers and the most frequent reason for missed or modified training (1,2). Seventy-five percent of elite level swimmers have been found to report a history of shoulder pain throughout their swimming career (1). With elite swimmers completing over 10,000 meters per day and performing over 30,000 shoulder rotations per week, the high incidence of shoulder pain is of no surprise (3). The most common reason for shoulder pain in this population is thought to be a result of impingement of the soft tissue structures that cross the subacromial space (2). Rodeo et al. (4) found signs of subacromial impingement in 84% of the USA 2008 Olympic swimming team using ultrasound. Subacromial impingement is either a result of structural adaptation, or dysfunctional movement patterning of the shoulder complex (5). The shoulder is an extremely mobile joint, allowing function through a large ROM. Coordinated contractions of the muscular system surrounding the joint (rotator cuff and scapular stabiliser muscles) maintain a centred humeral head position upon the glenoid fossa, thus avoiding subacromial impingement (6). During swimming training the shoulder is placed under highly repetitive overhead loading. It is this repetitive load that is thought to cause adaptations to the joint complex (7). Dysfunctional movement patterns occur as a result, causing incorrect or excess movement of the humeral head that leads to pain or injury (8).

In elite swimmers the factors that lead to the development of shoulder pain have received limited investigation with inconsistent results (9,10). This appears to be due to a lack of high quality longitudinal retrospective studies that adequately show cause and effect relationships for the shoulder pain. However, emerging themes suggest maladaptive changes caused by the high swimming training load, increase the risk of developing shoulder pain (11). It is important for practitioners working with swimmers to have in-depth understanding of these adaptations so that preventative strategies can be put in place. Research to date lacks understanding of the acute impact of swimming training load upon the shoulder complex. It is assumed based on research from various other overhead sports that the adaptations most likely to occur from swimming training load include: changes to rotational range of movement (ROM), joint position sense (JPS) and pectoralis minor length (PML) (12).

Suboptimal rotational ROM has frequently been regarded as a risk factor for shoulder symptoms in swimmers (10,13). However, there is conflicting information regarding whether hypomobility or hypermobility places swimmers more at risk (13). Beach et al. (13) found that reduced internal rotation (IR) ROM was a common long-term adaptation in swimmers, which in other sports has been found to increase the likelihood of developing impingement symptoms (16). Variation in the range of external rotation (ER) has been less commonly discussed in swimmers. However, a reduction in ER has been found to increase risk of shoulder pain in other overhead sports (17). Only one study has looked into the effect of acute swimming load upon shoulder rotational ROM. Matthews et al. (11) found that ER ROM significantly reduced following a fatiguing swimming load, however IR ROM was not affected. Literature from various other overhead sports, has found contradictory results in which post fatigue IR ROM significantly decreased whereas ER ROM remained the same (16,18). This highlights a lack of consistency in the understanding of how swimming load could affect rotational ROM.

In order to avoid injury, optimal proprioception is required at the shoulder joint (19). During functional movement the shoulder relies heavily on its dynamic stabilisers to prevent unwanted movement of the humeral head and provide stability throughout its full ROM. The dynamic stabilisers use proprioceptive feedback loops through a combination of kinaesthesia (movement sense) and JPS (20). Once fatigued JPS has been found to reduce, thus impeding proprioception (6,7). This leaves the shoulder vulnerable to functional instability, translation of the humeral head and thus injury. Matthews et al. (11) is the only study to have investigated the effect of acute swimming load upon JPS, they found a significant decrease in JPS following the fatiguing swimming set. Further evidence is needed to support the conclusions drawn because of the relatively small sample size.

A shortened PML has been found to increase the risk of impingement in those exposed to repetitive shoulder overhead motion (21). It is suggested that due to the dominance of the internal rotator and adductor muscles during the swimming stroke a forward shoulder posture can develop. Overtime this can cause the anterior shoulder structures, predominantly the pectoralis minor, to become shortened (22). The shortened PML is understood to prevent adequate posterior tilt of the scapular during elevation of the upper limb motion; this leads to reduced subacromial space and impingement. To the researchers knowledge there have been no published studies investigating the effect of acute swimming load or any other overhead activity upon PML.

Based on current literature it could be that swimming training load causes immediate adaptations in shoulder rotational ROM, JPS and PML thus increasing the risk of shoulder injury. However, this has yet to be confirmed with high quality experimental research. It is important for practitioners working with elite swimmers to have in depth understanding of the adaptations that can occur as a result of the swimming training load. This enables affective preventative strategies to be put in place. The aim of this study was to explore the acute effect of swimming training load upon: (1) shoulder rotational ROM, (2) JPS error and (3) PML, amongst elite level swimmers. The null hypothesis was that no significant change would occur between pre and post-swimming load for all of the measurements investigated.

METHODS

Participants

Sixteen elite level swimmers were recruited from a Swimming World-Class Programme National Centre. Nine males and seven females were invited to take part in the study, their characteristics are shown in Table 1. The inclusion criteria included only those swimming within the World-Class Swimming Programme between the ages of 17-25. The exclusion criteria were swimmers with current shoulder injury or pain preventing them from full training, those with a history of shoulder surgery or swimmers who tested positive with a Hawkins-Kennedy test. This study did not exclude all participants with a history of shoulder pain or injury because of the high prevalence in this population potentially limiting the sample size. All swimmers that met the criteria gave written consent to take part. All procedures performed involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Institutional ethical approval was given from the university ethics board.

Table 1: *Participant characteristics*

	Male n=9	**Female n=7**	**Total n=16**
Age (years)	20±2.3	20±1.0	20±1.8
Height (cm)	186±6.5	173±6.3	180±9.3
Weight (kg)	77.7±7.0	61.8±4.8	71±9.0

*Means ± Standard deviation

Procedures

All testing was conducted at the same training centre. The same researcher (E.H.) recorded all the measurements. For each swimmer, measurements were recorded before and after a typical two-hour swimming session. The measurements were taken in the same order prior to and after the session; right IR, ER, JPS and then PML, then repeated for the left. The baseline measurements were recorded following a standardised 30-minute land-based warm up, within three minutes of the start of the swimming session. Following the swimming session the second set of measurements were taken within three minutes, ensuring any immediate adaptations were recorded. Due to the single clinician availability it would have been impossible to test all sixteen athletes in one session, therefore testing was conducted over 6 weeks. All data was collected from the same session each week (Tuesday afternoon). This ensured time of day and position in training week remained the same for all the swimmers. All measurements were taken outside of taper or competition weeks, due to variation in training on these weeks.

Internal and external rotation

Rotational ROM was measured using a digital inclinometer (The Saunders Group Inc, Chaska, MN). Participants positioned in supine with the shoulder abducted to 90° and elbow flexed to 90° with the forearm and wrist in neutral (palm of hand facing caudally). They were positioned so that approximately three quarters of the upper limb was supported on the plinth, preventing shoulder extension. The inclinometer was zeroed at 90° (neutral) on a level surface between participants and then placed on the forearm, proximal to the ulna styloid (dorsal surface for IR and ventral surface for ER). For IR a hand was placed upon the humeral head to avoid anterior displacement. The researcher instructed participants to internally rotate until the arm naturally stopped with resistance at end range. This position was held for 2 seconds and the reading recorded. The arm was then returned to neutral for two further trials. For ER, from the neutral position the participant was asked to externally rotate and readings were taking in the same manner but without manual stabilisation, with 90° shoulder abduction maintained throughout testing.

Joint position sense

For JPS testing participants attempted to reproduce a 45° ER angle. Participants were positioned as described for ROM measurement. The IPhone 7 app ‘get my ROM’ digital inclinometer was used to measure the angles, the iPhone securely attached to participants forearms using a strap with the screen facing the tester. The participant was instructed to close their eyes throughout testing. The arm was passively rotated to 45° ER and held in this position for 3 seconds. The participant was asked to remember this position. Following the return to neutral the participant was asked to actively return the arm back to the angle shown. The amount of degrees away from 45° was recorded. This method was repeated twice more and an average taken.

Pectoralis minor length

PML was measured using a similar technique to that was described in the study completed by Mackenzie et al. (23). Participants were positioned in supine; a pillow placed under their head, without impacting upon the shoulder position. Both arms relaxed by their sides, elbows were extended with the palm of the hand against their thighs. The medial border of the anterior aspect of the coracoid process was palpated and then the forth rib (anterior-inferior edge, at junction between the rib and sternum). The measurement was taken with a tape measure (accuracy of: 1mm) between these points. The tape measure was removed before two further measurements were then repeated and the average taken.

Statistical analysis

The data was recorded with Microsoft Office Excel 2011 and analysed using SPSS Mac version 23 (SPSS Inc., Chicago, IL, USA). Prior to statistical analysis a visual evaluation of the histograms and results from Shapiro-Wilk test for normality demonstrated that the data from each measurement were of normal distribution. Paired t-tests were conducted on the data to determine if there were any significant differences between pre and post swimming training measurements and Cohen's *d* effect sizes were calculated and interpreted with 0.2 and below being a small effect size; 0.5 being a medium effect size; 0.8 and above being a large effect size. The critical alpha level was set at 0.05.

Reliability of measurements

To evaluate reliability of each measurement, the intra-rater reliability was investigated upon fifteen elite swimmers in a pilot study. Each measurement was taken before and after a 10-minute rest period on the same swimmers. Reliability analysis was conducted to compare before and after measurements. The results of this study are shown in Table 2, presented are the intraclass correlation coefficient (ICC), standard error of measurement (SEM) and minimal detectable change (MDC_{95}) values for each measurements. These show good to excellent reliability for all the measurement taken.

Table 2: *Intra-class correlation coefficient values with (95% CI), SEM and MDC values for each of the clinical tests*

Clinical measure	ICC (95% CI)	SEM	MDC_{95}
Internal rotation (°)	0.94	1.5	4.2
External rotation (°)	0.96	1.9	5.2
JPS error (°)	0.89	0.7	1.8
PML (cm)	0.94	0.6	1.5

*CI: Confidence intervals, SEM: SD (pooled) x √ (1-ICC), MDC (at 95% Confidence intervals): SEMx1.962√2

RESULTS

All of the sixteen swimmers recruited met the inclusion criteria and were included in the study. A total of thirty-two shoulders were tested for each measurement. The results for the comparison between pre and post measurements are shown in table 3.

Internal and external rotation

The paired t-test demonstrated that there was a significant decrease in ER ROM following the swimming training load (p=<0.001) with a small to medium effect size. The value of the change in ER ROM did exceed the SEM for the measurement but not the MDC_{95}. There was no significant difference found between pre and post measurements for IR ROM (p=0.528).

Joint position sense

The pared t-test showed a statistically significant increase in mean JPS error following the swimming training load (p<=0.001) with a large effect size. On average the JPS error increased by approximately 2° following the training session, this value exceeded the $MDC_{95.}$

Pectoralis minor length

For PML, the pared t-test revealed a statistically significant decrease following the training session (p=>0.001) with a small to medium effect size. The value of the change in PML did exceed the SEM for the measurement but not the MDC_{95}.

DISCUSSION

The aim of this study was to determine the immediate effect of swimming training load upon rotational ROM, JPS and PML. The results demonstrate statistically significant differences between pre and post swimming for ER ROM, JPS error and PML. Therefore the null hypothesis for these three clinical measures was rejected. No significant differences were found in IR ROM in keeping with the null hypothesis for that parameter.

Table 3: *Mean results, with standard deviation from pre swim and post swim*

Clinical measure	Pre swim	Post swim	Mean difference	Percentage difference	Effect size	t-test
Internal rotation (°)	60.0±7.4	59.3±8.8	-0.6	-1.2%	0.1	0.528
External rotation (°)	97.2±9.9	93.8±9.6	-3.4	-3.5%	0.34	<0.001
JPS error (°)	1.8±1.0	3.8±1.1	+2.0	+111.0%	2.11	<0.001
PML (cm)	17.8±2.1	17.1±2.2	-0.7	-4.0%	0.33	<0.001

*Means ± Standard deviation

Rotational range of motion

This study demonstrates that following a swimming training session there was no significant change in IR ROM from baseline measurements. These results are consistent with a similar study by Matthews et al. (11), in which no significant differences were found in IR ROM following a controlled swimming load. This study found statistically significant reduction in ER ROM following swimming. These results are also consistent with those from Matthews et al. (11), in which ER ROM significantly reduced after a fatigue inducing swimming set. The reduction of 3.4° of ER ROM found post swimming is considered a 'small' effect size. Whereas in Matthews et al. (11) the effect size was found to be 'moderate to large'. The larger effect size obtained by Matthews et al. (11) could have been due to all swimmers completing the same, high intensity training session with blood lactate levels monitored to confirm fatigue. From the results of this study we can be confident that the change of -3.4° was of statistical significance (p=<0.001), however due to lack of relevant literature, the clinical impact of this change is not known. Clinical relevance of change to rotational ROM has only been investigated upon baseball pitchers. Wilk et al. (24) indicated that a reduction of >5° of ER + IR ROM was enough to increase risk of shoulder injury; however clinical significance of reduction in ER alone was not mentioned. Another consideration is that the change of -3.4° did not reach the MDC_{95} value of 5.2°, thus we cannot be 95% confident that the change was not the result of measurement error.

Reduced ER ROM which occurred might be as a result of specific biomechanics of the swimming stroke. Greater hypertrophic changes occur in the internal rotator and adductor muscles compared to the external rotators and abductors, due to the larger force production required from these muscle groups to propel the body through water (22). As a result, imbalances occur in the shoulder muscles. Electromyography studies have shown internal to external rotation strength ratios in competitive swimmers at 1.89:1 compared to 1.35:1 in non-swimmers (22). If this imbalance is present it is feasible to suggest that due to the contraction from the stronger IR muscles, the humerus is held more in an internally rotated position. Additionally as the external rotators fatigue during a session, it is proposed that the inability to overcome internal rotation torque increases.

In a retrospective longitudinal study Walker et al. (25) found that those swimmers who had reduced ER (<93°) were at greater risk of shoulder pain over the 12-months of the study. These results are consistent with those from other overhead sports in which reduced ER has been shown to increase shoulder injury risk by 2.3x (24). Cadaver studies have also demonstrated that if ER ROM is reduced, shoulder impingement is more likely on full upper limb elevation (16). This highlights possible implications of reduced ER. It is therefore suggested that preventative land-based training programs provide exercises specifically aimed at developing ER strength and fatigue resistance, counteracting the imbalances between internal and external rotation. As lack of endurance rather than peak torque has been found to place swimmers at greater risk of shoulder pain, specific protocols that develop muscular endurance are advised (13). Alongside this program stretching exercises performed pre and post swimming sessions should be considered to ensure that full ER ROM is maintained or restored.

Joint position sense

Following the swimming session a significant increase in JPS error was found, with the increase of 2.0° post swim being considered a 'large' effect. With the MDC_{95} value of 1.8°, we can be 95% confident that +2.0° is true change and not resulting from measurement error. In a similar investigation, Matthews et al. (11) also found an increase in JPS error following swimming load. However, statistical significance was only reached in right shoulders. For the purpose of this study right and left shoulders were analysed together. It was suggested that the variance between left and right found in Matthews et al. (11) could be due to the dominant arm acting mainly for propulsion, whereas the non-dominant arm provides the control. Results from this study are also supported by those studies that have investigated JPS pre and post fatigue. Carpenter et al. (26) found that following fatiguing rotational effort, shoulder JPS error increased by 73%. This same increase in JPS error was found in two other studies post fatigue (6). Though these studies support results from this investigation, it must be considered that the fatiguing tasks conducted were not overhead functional actions.

Elite swimmers have been shown to have increased shoulder laxity when compared with recreational swimmers (27). This increase in shoulder laxity has been identified in the literature to correlate with a higher injury risk (2). McMaster et al. (1) indicated that there is a threshold to which clinical laxity is beneficial to performance, before it causes instability during the swimming stroke (27). Due to this increased laxity and the nature of the overhead load in swimming, functional dynamic stability is imperative. This maintains a centred humeral head in order to avoid impingement (28). What is implied from this study is that due to the reduction in JPS during swimming the mechanoreceptors of the joint may provide incorrect joint position feedback. This could impede the ability of the dynamic stabilisers to provide accurate compensatory contraction to avoid excessive translation of the humeral head. This neuromuscular deficit places the shoulder at increased risk of injury (28).

In order to manage this reduction in JPS, preventative programs with the aim of increasing shoulder proprioception are suggested. Specifically, Lephart et al. (17) recommends the integration of exercises developing both JPS and kinaesthesia, alongside neuromuscular control and dynamic joint stabilisation critical to the overhead athlete. They propose positional sense practice to develop cognitive level processing, upper limb weight-bearing exercise to stimulate muscular co-contraction for dynamic stabilisation and plyometric exercises to stimulate reflexive activity. Additionally, more recently Salles et al. (29) conducted a randomised controlled trial, providing evidence that high intensity upper limb strength-training programs led to a significant increase in JPS. They recommended multiple joint exercises involving the large muscles of the shoulder.

Pectoralis minor length

To the researchers knowledge this is the first study to have investigated the acute effect of swimming load upon PML. The study demonstrates a significant decrease in PML following swimming load, but the decrease in mean PML of 0.7cm could be considered a 'small' effect. The need for further experimental studies is indicated. It is suggested that those future studies use more precise PML measurement methods than those used in this study. Such as the method using callipers by Rondeau et al. (30), which demonstrated lower measurement error values (SEM 0.3cm rather than SEM of 0.55). This is suggested to be due to the small scope of change in PML, therefore a method with smaller measurement error is more likely to detect these minimal changes.

Tate et al. (3) and Harrington et al. (31) provide evidence from cross-sectional studies showing that swimmers who have shortened PML had a stronger association with shoulder pain than those without. Due to their study designs, cause and effect relationships between pain and PML cannot be confidently determined. However, it has been frequently documented in the literature that due to the pectoralis minor's attachment to the anterior scapular, a shortened PML prevents optimal movement patterning of the scapular. A lack of scapular posterior tilting during elevation causes the subacromial space to be narrowed and thus impingement is more likely (21). Though the results from this study are not yet supported by other literature, if further research provides consistent outcomes, it would be suggest that preventative programs and specific post-training stretching regimes would be appropriate.

Limitations of the study

This study has a number of limitations. The sample size was small. However, using only elite swimmers means that results are generalizable to the elite population. Another limitation from testing this population is that we were unable to implement a controlled swimming session due to strict training plans. This allowed uncontrollable variables from differences in training sessions. As clinical measures were taken directly following the swimming, what cannot be elicited from this study is the longevity of these adaptations. Clinically it would be beneficial to understand how long these adaptations last for, monitoring for possible increase in risk for the next swimming or land training session. It is suggested that future studies monitor the adaptations over a longer time frame to understand whether the effects are transient or progressive. Similarly the effect of swimming particular strokes on outcome would also need investigating.

CONCLUSION

The results from this study provide a greater understanding of the direct effect of swimming load upon the shoulder complex. This information can help practitioners and coaches working with elite swimmers to implement prevention methods to avoid or reduce these adaptations. From the current available evidence and results from this study, it is suggested that prevention exercise programs should include; ROM maintenance; ER strengthening aiming to enhance endurance capacity; JPS and proprioception development; and stretches aimed at maintaining PML. Further research is required to understand the longevity of the adaptations of swimming load and whether prevention programmes are capable of significantly reducing or counteracting these effects. This would enable better planning of training schedules and pre-habilitation with the aim to reduce the prevalence of shoulder pain and injury amongst swimmers.

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