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Title:
The effect of swimming volume and intensity on changes in supraspinatus tendon thickness
Abstract

Objectives: To compare the change in supraspinatus tendon thickness (STT) following a high volume (HV) and high intensity (HI) swimming practice in shoulders of elite swimmers.

Design: Repeated measures design.

Setting: Non-clinical, state swim team training facility.

Participants: A convenience sample of eight non-injured state and national level swimmers from a regional swim team were recruited for this study.

Main outcome measures: Ultrasound measures of STT were collected in response to the two swimming practice sessions. Measures were taken prior to each swim practice; immediately after practice; 6-hours post practice and 24-hours post practice.

Results: A significant increase in STT resulted from both the HI and HV (p < 0.05) practice immediately post practice. For the HI practice, the STT remained significantly thicker than pre-practice measures at the 6-hour post practice test (p < 0.05) however no longer significant 24-hours post practice. The difference in the change in STT between the HI and HV practice was significantly different immediately post practice and 6-hours post practice (p < 0.05) however no longer significant 24-hour post practice.

Conclusion: HI swimming creates greater change in STT and slower return to pre practice STT measures, compared with HV swimming.

Keywords: Rotator Cuff; Swimming; Shoulder pain; Ultrasonography
Introduction

Shoulder pain among swimmers is a significant issue, with the prevalence rates reported between 38-91% of all swimmers. Shoulder pain accounts for the greatest amount of lost training time for elite swimmers. Recently, a number of soft tissue structures have been suggested to contribute to the phenomenon of ‘swimmers shoulder’ including supraspinatus, subscapularis, long head of biceps and the anterior superior and posterior superior labrum. While other structures may also contribute to the condition, the supraspinatus tendon is a recurrently affected tendon among swimmers. An imaging study of elite Australian swimmers, found 69% of all swimmers tested showed signs of supraspinatus tendinopathy. While previously thought to be due to the compression of the tendon, more recent studies have seen a link between high training loads and overuse tendon loading on internal injury mechanisms of the tendon. While, the absolute tensile load experienced by the rotator cuff tendons are relatively low compared to those of lower limb tendons, it is suggested that repeated loading in the shoulder during swimming is far more devastating than the absolute load itself.

Swimmers typically engage in high volumes and high frequency of training including multiple sessions per day and up to 10-12 sessions per week. The incidence of tendinopathy has been found to be related to the hours and distance swum per week. Elite swimmers who trained more than 15hr/week were twice as likely to have tendinopathy as those who trained for less time. Similarly, elite athletes who swam more than 35km/week were four times more likely to have tendinopathy than those who swam fewer kilometres.

Recently, two studies have examined the response of supraspinatus tendon in shoulders with a history of shoulder pain and or rotator cuff tendinopathy. Findings have demonstrated that subjects with painful rotator cuff tendinopathy had a significantly greater increase in supraspinatus tendon thickness (STT) at one and six hours following a loading protocol. Further to this it has been found that STT changes following a swimming practice are significantly different in those swimmers with a history of shoulder pain. While both pain free shoulders and shoulders with a history of pain increased in STT following practice, those shoulders with a history of pain showed a greater increase in STT following practice and remained thicker at six hours post practice. Given that STT responds to swimming load and its capability to return to baseline may be compromised in individuals with a history of shoulder pain, it is postulated that monitoring the thickness of the tendon could be an effective tool for assessing the response of the shoulder to a given training load.

Previously, the tendon response to a single swimming practice was examined to improve understanding of how it responds to training but did not account for differences in volume and intensity of swimming practice. Therefore,
understanding how a tendon responds to various training volumes and intensities is necessary to ensure appropriate planning and programming that optimises performance and mitigates the chance of tendon overload.

The primary aim of this investigation was to determine whether manipulations in the intensity and volume of a swimming practice affect the supraspinatus tendon response and the time required for the tendon to return to baseline thickness. It is hypothesised that high intensity, low volume swimming practice will result in greater changes in STT and slower rate of return to baseline compared to that of higher volume, low intensity practice.

Methods and Materials

Subjects

A convenience sample of eight state and national level injury free swimmers (16 shoulders) aged between 13 and 17 years old (14.38 +/- 1.61) were recruited for this study. Swimmers with a history of diagnosed shoulder injury or significant interfering pain that had resulted in disruption to training or competition within the previous six months were excluded from the study. The study was approved by the University Human Research Ethics Committee of XXXX and all participants and guardians read and signed a consent form before participation.

Ultrasound Measurement

Ultrasonographic measurements of swimmers’ supraspinatus tendon thicknesses (STT), in millimetres, were obtained using a Mindray DP-20 Ultrasound machine in conjunction with a 38mm 7.5MHz Mindray 75L38EB linear transducer (Mindray, Shenzhen China). All ultrasound images were obtained by a single examiner using the technique previously described. The examiner had undergone advanced training in musculoskeletal ultrasound imaging and demonstrated excellent test-retest reliability measures for STT (ICC = 0.99, 95% CI = 0.98-1.00, SEM = 0.09 mm) and corresponding minimal detectable change 0.25 mm.

Ultrasound Testing Timeline

To determine the effect of the two different swimming practice sessions, data was collected at four time points for each condition, being pre practice, immediately post, 6 hours post and 24 hours post practice. The pre practice baseline measurement was obtained after a 24-hour period of no training just prior to a morning practice. Data collection session two was conducted immediately following the morning practice. Data collection session three was conducted 6 hours after the completed practice while the fourth session was completed 24 hours post practice. This process was repeated for the second training condition. The second practice was conducted at the same time of the day, separated by seven days, to standardise loading and fatigue. The order of the swim practice sessions
was the same for all participants and all completed each practice session on the same day, in order to best align with the swimmers’ normal training habits.

Swimming Loads

The high volume (HV) practice was characterised by a 100% increase in volume compared to the high intensity (HI) practice. The main sets for each practice were chosen as they represented two typical training sessions for these swimmers. The interval times were chosen using a work to rest ratio model, and maximal effort intervals were based on the swimmer’s personal best times. The details of both practice sessions are outlined in Table 1. All swimmers completed the main set as freestyle.

Table 1

<table>
<thead>
<tr>
<th>Details of the HV and HI practice sessions</th>
<th>High Volume</th>
<th>High Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Distance (Km)</td>
<td>7</td>
<td>3.5</td>
</tr>
<tr>
<td>Time in water</td>
<td>2 hours</td>
<td>2 hours</td>
</tr>
<tr>
<td>Main Set</td>
<td>40 x 100s (10 sec rest)</td>
<td>6 x 25 Max Effort, 4 x 50 Max Effort, 2 x 75 Max Effort, 1 x 100 Max effort</td>
</tr>
<tr>
<td>Work to Rest Ratio (of main set)</td>
<td>1 : 0.1</td>
<td>1 : 4</td>
</tr>
<tr>
<td>Percentage of session (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pull only</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>Kick only</td>
<td>33</td>
<td>11</td>
</tr>
<tr>
<td>Swim</td>
<td>60</td>
<td>80</td>
</tr>
<tr>
<td>Average Reported RPE</td>
<td>6.9</td>
<td>8.8</td>
</tr>
</tbody>
</table>

Swimmers reported a rate of perceived exertion (RPE) using the category ratio 10 point scale (CR-10) modified by Foster following both practice sessions. The participants were familiarized with the CR-10 scale prior to the testing sessions. The RPE score was obtained 30 min after each practice, following the completion of the ultrasound assessment. The swimmers were asked to respond to the question “how hard was your workout?” and select the associated descriptor and a number from 0 to 10, which could also be provided in decimals (e.g. 7.5). The swimmers recorded their response privately on a piece of paper to avoid external influence. The RPE scores
were averaged across the cohort. Previous research has confirmed the validity of the RPE as a measure of exercise intensity during swimming.

**Statistical Analysis**

A power analysis was conducted using G*Power for F-test (ANOVA: Repeated measures, within-between interaction), using an effect size of 0.5, for 2 groups, and 4 measurements indicated a sample size n = 12 per group at 98% actual power. The sample size of 16 shoulders was determined to be sufficient to detect a meaningful change.

Three images of STT were taken and measured with the average of the three measures used for analysis. Data were analysed using Statistical Package for the Social Sciences (SPSS) for Windows. All variables were examined for normality using Kolomogorov-Smirnov normality tests. The difference between STT following the HI and HV practices was established using a repeated measures ANOVA for within subjects and between group effects and paired t-tests were conducted for post hoc analysis. Effect sizes were calculated using Cohen’s $d_z$ for correlated groups.

**Results**

Maulchly’s test indicated that the assumption of sphericity had been violated $\chi^2 (5) = 24.30$, $p = 0.000$, therefore degrees of freedom were corrected using Greenhous-Geisser estimates of sphericity ($\varepsilon = 0.71$). The results showed there was a significant effect of practice session on the change in supraspinatus tendon thickness (STT), $F(2.12, 63.63) = 7.87$, $p = 0.001$.

Post hoc results, as detailed in Table 2, show a significant increase in STT following both the HI (mean diff = 0.53 mm, 95% CI [0.41, 0.64], $p = 0.000$) and HV (mean diff = 0.24 mm, 95% CI [0.11, 0.37], $p = 0.001$) practice sessions immediately post practice. For the HI practice session, the STT remained significantly thicker than pre practice measures at the 6-hour post practice test (mean diff = 0.33 mm, 95% CI [0.21, 0.44], $p = 0.000$) however this was no longer significant at the 24-hour post practice test (mean diff = 0.11, 95% CI [0.01, 0.22], $p = 0.066$). For the HV practice session, STT was no longer significantly different from pre practice levels at either the 6-hour (mean diff = 0.08, 95% CI [0.04, 0.20], $p = 0.165$) and the 24-hour post practice tests (mean diff = 0.03, 95% CI [0.01, 0.06], $p = 0.164$).
Table 2

STT measurement at each ultrasound test session for the HI and HV

<table>
<thead>
<tr>
<th></th>
<th>Pre STT</th>
<th>Post STT</th>
<th>P</th>
<th>d</th>
<th>Pre 6 hrs post</th>
<th>P</th>
<th>d</th>
<th>24 hrs post</th>
<th>P</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td></td>
<td>M</td>
<td>SD</td>
<td></td>
<td>M</td>
<td>SD</td>
<td></td>
</tr>
<tr>
<td>HI</td>
<td>7.98</td>
<td>0.56</td>
<td>8.51</td>
<td>0.66</td>
<td>0.000*</td>
<td>2.39</td>
<td>8.31</td>
<td>0.59</td>
<td>0.000*</td>
<td>1.54</td>
</tr>
<tr>
<td>HV</td>
<td>7.94</td>
<td>0.66</td>
<td>8.18</td>
<td>0.69</td>
<td>0.001*</td>
<td>0.97</td>
<td>8.02</td>
<td>0.69</td>
<td>0.165</td>
<td>0.36</td>
</tr>
</tbody>
</table>

* denotes a significant p value, d - Effect size calculated as Cohen’s D

Figure 1

This figure demonstrates the difference in the change in STT from pre practice thickness at, immediately post (Pre_Post), 6-hours post (Pre_6 hour) and 24-hours post (Pre_24 hour). * denotes a significant (p<0.05) difference between the HV and HI practice session.

As visually represented in Figure 1, the difference in the change in STT between the HI (M = 0.53 mm, SD = 0.22) and HV (M = 0.24 mm, SD = 0.24) practice was significant immediately post practice (mean diff = 0.28 mm, 95% CI [0.13, 0.43], p = 0.001, d = 1.02). The difference in STT between sessions remained significantly different at the 6-hour post practice test (HI - M = 0.33 mm, SD = 0.21; HV - M = 0.08 mm, SD = 0.22) (mean diff = 0.24 mm, 95% CI [0.08, 0.41], p = 0.006, d = 0.83). However was no longer significant at the 24-hour post
practice test (HI - M = 0.11 mm, SD = 0.21; HV - M = 0.03 mm, SD = 0.07; mean diff = 0.08 mm, 95% CI [0.05, 0.21], p = 0.210, \(d = 0.33\)).

**Discussion**

The current study’s primary aim was to investigate how differences in volume and intensity of a swimming practice differentially effect the supraspinatus tendon response in a cohort of non-injured elite swimmers. The results demonstrate that both HI and HV practice produced a significant increase in STT immediately post practice (\(p < 0.000\)). This is consistent with previous work \(^9\) reporting a significant increase in STT immediately following a single swimming practice session, wherein the average swim distance completed was 5467 meters (min = 3800m, max = 6750m) of average duration 115 minutes. However, this earlier study did not assess the comparative effects of high volume or high intensity swim practice on the STT response.

The current study demonstrated that following a HV practice, the STT returned values at 6- and 24-hours post practice that were not significantly different to those obtained at baseline. Whilst the practice in the current study covered a greater distance (7000m), these findings are consistent with previous work reporting that shoulders without a history of pain return to pre practice thickness following 6-hours recovery \(^9\). However, the cumulative effect of repeated HV practice sessions on STT across a training week remains unknown. Conversely, following the HI practice session, the increase in STT remained significantly greater at the 6-hour post practice test (\(p = 0.000, d = 1.54\)), despite the reduced swim volume (3500m). There was no significant difference in STT at 24 hours post practice, compared to baseline, following the HI swim practice (\(p = 0.066\)).

Immediately post, and 6 hours post practice, there was a significant difference between the HI and the HV practice sessions, with respect to STT, with the HI practice creating a significantly greater change in STT. Further the effect sizes (\(d = 1.02 \& 0.83\)) suggests a large practical significance between practice sessions. At 24 hours post practice the change in STT was no longer significantly different between the two practice sessions. These results demonstrate that HI swimming practice creates a greater increase in STT, and slower rate of recovery back to pre-practice thickness compared to HV swimming practice.

High repetition of the swim stroke arm action is frequently postulated to contribute to the development of shoulder pain. The stroke count of 15 per 25m of swimming has been used to estimate that swimmers may complete up to 2 million arm strokes in a swimming year \(^{14}\). In the current study, if a similar stroke count of 15 per 25m is utilised for comparison, swimmers completed approximately 4,200 strokes during the high volume and 2,200 strokes during the high intensity practice. Despite individual swimmers’ inherent variation in stroke count during a session,
it is feasible that up to 50% fewer strokes were utilised within the high intensity session whilst swimming half the
distance. This represents a substantially lower number of “exposures” of each shoulder to overhead, end of range
motion during the high intensity session, thus demonstrating that intensity of effort exerted at the shoulder may
be a more important consideration when determining and managing shoulder tendon loads in swimmers.
The current findings are consistent with those in other sports showing particularly high tendinopathy incidence in
both elite and recreational athletes in activities with high tensile strains such as those with predominantly
plyometric loading. Thus, it is not surprising that higher swim speeds attained by generating greater propulsive
force during the higher intensity swim practice resulted in greater STT changes than those produced by the lower
intensity, higher volume practice.
These results have important implications for coaches’ planning the periodisation of HI and HV training. Given
that elite swimmers often train twice a day, and up to seven days per week, the frequency of, and recovery time
allocated following HI sessions should be considered to allow for recovery of STT to baseline measures, which
may mitigate overload of the shoulder tendons. Insufficient recovery between swimming practice may exacerbate
the acute tendon response and result in intrinsic pathogenic mechanisms of the tendon, onset of pain and
extracellular matrix degradation. The results from this study suggest a 24-hour recovery period is required
following a HI practice and, potentially, post competition swimming. Results from the HV, lower intensity
practice suggests 6-hours is sufficient recovery time for swimmers without a history of pain or injury, and this
information is beneficial when prescribing multiple practices on the same day. The recovery time frame required
for swimmers returning from injury or experiencing shoulder pain may be longer as previous work demonstrates
that the tendon recovery rate is slower than that of swimmers without a history of pain.
The assessment of STT by the ultrasound measures described in this study and that reported in previous work
suggests that these measures may be useful in assessing a swimmer’s readiness to train, and specifically, undertake
HI training and or competition. Future research should investigate the prospective relationship of an altered
supraspinatus tendon response post swim practice to the development of swimming related shoulder pain.
Similarly, the collection of longitudinal data of the effect of a periodized swim program on the STT would
elucidate whether the observed tendon changes are cumulative.

Limitations
A number of limitations of the current study were identified. Firstly, the age of participants may have affected the
response to loading as it has been suggested that maturation is a potential risk factor for the development of both
tendinopathy and musculotendinous imbalances in young athletes. As such, the results of this study are specific
to the group investigated and generalisability of results to a wider swimming population should be undertaken with caution. Secondly, the results of this study may have been affected by selection bias, given the non-random selection of participants. The cohort investigated may have been pre-conditioned to this type of swim practice and other competitive swimmers unfamiliar with these volumes and intensities of swim practice may demonstrate different STT changes.

Conclusion

The results of this study demonstrate that both HV and HI prescribed swim practice sessions result in significant increases in STT immediately post practice. High intensity swim practice produces significantly greater post practice STT changes and longer recovery times to baseline thickness measures, compared with HV swim practice. Non injured swimmers’ STT returns to baseline levels after 6-hours of rest following HV practice, whereas HI swim practice requires 24 hours of rest for the same effect. The current study provides some parameters to assist with management of swim loads for common and challenging shoulder pain presentations in swimmers. At present there are few valid and practical tools for monitoring internal training load of the swimmer’s shoulder. The application of the findings of this study may allow coaches to monitor swimmers’ training periodisation to prevent overload of the shoulder tendons.
REFERENCES


