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Original Research

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

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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: Cohort Study.
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: Ultrasound measures of STT following different swimming volumes and intensities may provide information on shoulder tendon loads.

1. Introduction

Shoulder pain among swimmers is a significant issue, with the prevalence rates reported between 38 and 91% of all swimmers (Hibberd & Myers, 2013; Sein et al., 2010; Walker et al., 2012). Shoulder pain accounts for the greatest amount of lost training time for elite swimmers (McMasters et al., 1993). 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 (Boettcher et al., 2017). 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 (Sein et al., 2010). 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 (Fredberg & Stengaard-Pedersen, 2008; Magnusson et al., 2010). 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 (Boettcher et al., 2017).

Swimmers typically engage in high volumes and high frequency of training including multiple sessions per day and up to 10–12

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sessions per week (Hibberd & Myers, 2013; Pink & Tibone, 2000). The incidence of tendinopathy has been found to be related to the hours and distance swum per week (Sein et al., 2010). Elite swimmers who trained more than 15 h/week were twice as likely to have tendinopathy as those who trained for less time. Similarly, elite athletes who swam more than 35 km/week were four times more likely to have tendinopathy than those who swam fewer kilometres (Sein et al., 2010).

Recently, two studies have examined the response of supraspinatus tendon in shoulders with a history of shoulder pain and rotator cuff tendinopathy (McCreesh et al., 2017; Porter et al., 2020). Findings have demonstrated that subjects with painful rotator cuff tendinopathy had a significantly greater increase in supraspinatus tendon thickness (STT) at one and 6 h following a loading protocol (McCreesh et al., 2017). 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 (Porter et al., 2020). 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 6 h post practice (Porter et al., 2020). 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 (Porter et al., 2020), 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 if 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 a greater change in STT and slower rate of return to baseline will occur from high intensity, low volume swimming practice compared to low intensity, high volume practice.

2. Methods and materials

2.1. 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. The sample included five males and three females, with a mean body mass of 69.6 kg, average training volume of 34.1 km per week and average swimming sessions of 6.2 per week. 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.

2.2. 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 38 mm 7.5 MHz Mindray 75L38EB linear transducer (Mindray, Shenzhen China). All ultrasound images were obtained by a single examiner using the technique previously described (Porter et al., 2020). 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 (Porter et al., 2020).

2.3. Ultrasound testing timeline

To determine the effect of the two different swimming practice sessions, the testing was conducted during season to best examine the tendons' response under normal load. Data was collected at four time points for each condition, being pre practice, immediately post, 6 h post, and 24 h 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 h after the completed practice while the fourth session was completed 24 h post practice. No afternoon practice was completed following the session of investigation. 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.

2.4. 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. All swimmers completed the main set as freestyle. 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. Rest periods were passive and were calculated from the swimmer's interval times. The work to rest ratios were chosen to best represent an aerobic and an anaerobic main set (Toussaint & Hollander, 1994). The details of both practice sessions are outlined in Table 1.

Swimmers reported a rate of perceived exertion (RPE) using the category ratio 10 point scale (CR-10) modified by Foster (Foster et al., 2001) 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 (Wallace et al., 2009).

2.5. Statistical analysis

A power analysis was conducted using G*Power (Faul et al., 2007) 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

Table 1
Details of the HV and HI practice sessions.

	High Volume	High Intensity
Total Distance (Km)	7	3.5
Time in water	2 h	2 h
Main Set	40 × 100 m (10 s rest)	6 × 25 m Max Effort, 4 × 50 m Max Effort, 2 × 75 m Max Effort, 1 × 100 m Max effort
Work to Rest Ratio (of main set)	1 : 0.1	1 : 4
Percentage of session (%)		
Pull only	7	9
Kick only	33	11
Swim	60	80
Reported RPE (Mean ± SD)	6.9 ± 1.5	8.8 ± 0.8

RPE – rate of perceived exertion; Pull - arms only swimming; Kick – legs only swimming; Swim – traditional stroke using both arms and legs.

Statistical Package for the Social Sciences (SPSS) 11.0 for Windows. All variables were examined for normality using Shapiro-Wilks 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 (<0.2 = trivial effect; 0.2–0.5 = small effect; 0.5–0.8 = moderate effect; > 0.8 = large effect) (Cohen, 2013).

3. Results

Mauchly's test indicated that the assumption of sphericity had been violated χ^2 (5) = 24.30, p = 0.000, therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (ε = 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). Between group differences, also detailed in Table 2, show 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). The magnitude of the difference of reported RPE scores between sessions was calculated using effect size (*d* = 1.5).

4. 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 (Porter et al., 2020) reporting a significant increase in STT immediately following a single swimming practice session. 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 (7000 m), compared to previous work wherein the average swim distance completed was 5467 m (min = 3800 m, max = 6750 m) of average duration 115 min both reported that shoulders without a history of pain return to pre practice thickness following 6-hours recovery (Porter et al., 2020). 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 (3500 m). There was no significant difference in STT at 24 h post practice, compared to baseline, following the HI swim practice (p = 0.066, *d* = 0.57). This result suggests that 24 h may be a sufficient recovery time following HI swimming practice to mitigate tendon overload.

Immediately post, and 6 h 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) suggest a large practical significance between practice sessions. At 24 h post practice the change in STT was no longer significantly different

Table 2
STT measurement at each ultrasound test session for the HI and HV.

	Pre STT		Post STT		Within group difference		Between group difference		6 h post		Within group difference		Between group difference		24 h post		Within group difference		Between group difference	
	M	SD	M	SD	P	*d*	P	d	M	SD	P	*d*	P	d	M	SD	P	*d*	*P*	*d*
HI	7.98	0.56	8.51	0.66	**0.000***	2.39	0.001	1.02	8.31	0.59	**0.000***	1.54	0.006	0.83	8.10	0.55	0.066	0.57	0.210	0.33
HV	7.94	0.66	8.18	0.69	**0.001***	0.97			8.02	0.69	0.165	0.36			7.96	0.66	0.164	0.30		

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

between the two practice sessions and effect sizes suggested only a medium effect ($d = 0.33$). This is expected as STT values were no longer significantly different from baseline at the 24-hour test for both 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 25 m of swimming has been used to estimate that swimmers may complete up to 2 million arm strokes in a swimming year (Ciullo & Stevens, 1989). In the current study, if a similar stroke count of 15 per 25 m is utilised for comparison, swimmers completed approximately 4200 strokes during the high volume and 2200 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 (Lian et al., 2005; Zwerver et al., 2011). Whilst forces exerted by the upper limb during swimming are difficult to quantify, participants did report higher RPE values for the HI sessions ($d = 1.5$), indicating higher internal loads. 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 (Ackermann et al., 2016). 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 (Porter et al., 2020).

The assessment of STT by the ultrasound measures described in this study and that reported in previous work (Porter et al., 2020) used in combination with other measures (well-being, psychological and physical) 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.

4.1. Limitations

A number of limitations of the current study were identified. Firstly, the small sample size ($n = 8$) and specific population are a limitation of the current study. 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 (Mersmann et al., 2017). 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. Finally, the multifactorial nature of shoulder pain is noted and STT may be only one possible factor contributing to swimmer's shoulder pain, however the feasibility to monitor STT in clinical practice may provide one easy tool to contribute to the understanding of the condition.

5. 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 h 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 swimmers' shoulder tendons. The application of the findings of this study may allow coaches to monitor swimmers' training periodisation to prevent overload of the shoulder tendons.

Ethical approval

This study was approved by the University Human Research Ethics Committee of Queensland University of Technology (Approval number: 1,500,000,798). All participants and guardians read and signed a consent form before participation.

Declaration of competing interest

None Declared.

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