Electromyographic Analysis in Elite Swimmers with Shoulder Pain during a Functional Task

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Abstract

The purpose of study was to determine and compare electromyographic activity of selected shoulder girdle muscles in elite swimmers with and without shoulder pain. Twelve professional swimmers with shoulder pain (mean age: 18.55±3.16 years, body mass: 74.33±2.91 kg, and height: 179.00±5.29cm) and twelve swimmers without pain (mean age: 18.11±1.61 years, body weight: 73.33±6.06 kg, height: 178.33±5.07cm) were recruited. Surface electromyography signals were collected from seven upper limb muscles during a task: participants were instructed to mark points with a pen within each of the 3 circles counterclockwise. The normalised root-mean-square value was used to determine the muscular activation. Swimmers with shoulder pain demonstrated greater activation of the upper trapezius (pain group mean: 28.04±10.37, control group mean: 13.40±06.04; p=0.002, partial eta square: 0.455), serratus anterior (pain group mean: 30.78±20.09, control group mean: 13.30±5.52; p=0.023, partial eta square: 0.283) and latissimus dorsi (pain group mean: 27.05±17.87, control group mean: 4.99±3.90; p=0.002, partial eta square: 0.450) muscles. There was no difference (p>0.05) in the activation of the middle and lower trapezius, middle deltoid and sternocleidomastoid. The altered muscle activation patterns may contribute to the painful shoulder in elite swimmers and need to be considered within the rehabilitation interventions.

Key Words: Swimming; EMG; Mechanical Shoulder Pain; Muscle Activation

Introduction

The multi-axial ball and socket-synovial glenohumeral joint (GHJ) with acromioclavicular, sternoclavicular, and scapulothoracic articulations is the most mobile joint in the human body (Kelkar et al., 2001). Due to the minimal bony structure of the GHJ, a balanced activation of muscles is essential to achieve functional stability during overhead movements. A disproportionate contraction of strong shoulder mobilisers such as deltoid and pectoralis major during overhead movements may lead to the painful translation of the humeral head within the glenoid fossa. Hence, an efficient concomitant dynamic interaction from stabilising muscles is essential to counterbalance the destabilising effect of these strong muscles (Poppen & Walker, 1978). Balanced activation of the scapular muscles is also crucial in maintaining the center of glenohumeral rotation and subacromial space during overhead motions. These underpin the need for a delicate balance of GHJ mobility and stability in elite swimmers in order to meet the functional demands of repetitive multidirectional overhead motions and humeral circumduction (Tovin, 2006).

It has been reported that 90% of elite swimmers experience some levels of shoulder pain during their involvement in profession sport, it particularly affects younger athletes (Sein et al., 2010; Tate et al., 2012). The term 'Swimmers’ Shoulder' is commonly used to describe shoulder pain experience in elite swimmers in relation to wide-ranging pathologies such as tendinopathies, impingement, instability, and mechanical pain (e.g. Hidalgo-Lozano et al., 2012). The pain experience usually leads to functional impairments, non-participation in daily and sporting activities, and disabilities (Allegrucci, Whitney & Irrgang, 1994). While repetitive overhead arm movement has been linked to the development of Swimmers’ Shoulder (Heinlein & Cosgarea, 2010), altered motor control and muscle activation patterns have been suggested to play a major role in the development of shoulder pain in elite swimmers. Scovazzo, Browne, Pink, Jobe & Kerrigan (1991) investigated the muscle activity during swimming motions (front crawl stroke) in athletes with and without shoulder pain and reported a significant decrease in the activity of serratus anterior (SA) and middle deltoid (MD). Increased activity of upper trapezius (UT) has been previously reported in elite swimmers suffering from painful conditions such as impingement syndrome (Kamkar, Irrgang & Whitney, 1993; Fu, Harner & Klein, 1991). Ruwe, Pink, Jobe, Perry & Scovazzo (1994) investigated muscle activity in 12 shoulder muscles during breaststroke in elite swimmers with and without painful shoulders and reported increased activity of the UT and latissimus dorsi (LD) in swimmers with shoulder pain. Authors also reported a consistent activity of SA ($\geq$15% MVC) which would predispose this muscle to fatigue and pain. Perry et al., (1992) measured muscle activity of shoulder girdle muscles in painful and normal shoulders of elite swimmers during backstroke and reported increased activity of LD in swimmers with painful shoulders. Pink et al., (1993) compared muscle activity of shoulder girdle muscles in competitive swimmers with painful and normal shoulders and reported a higher level of SA activation during the front crawl swimming cycle. Hidalgo- Lozano et al., (2012) examined muscle activity (RMS) of the sternocleidomastoid (SCM) and UT in elite swimmers during a functional upper limb task and found no difference between those with and without shoulder pain.

This study aimed to explore differences in the activation of selected glenohumeral and scapular muscles in young elite swimmers with and without shoulder pain during a low-load functional upper limb task. It is hypothesised that elite swimmers with shoulder pain would demonstrate altered muscle activations as compared with elite swimmers who have no shoulder pain.

Methods

Participants

This study consisted of 24 elite male swimmers: 12 healthy (mean age: 18.11±1.61 years) and 12 with shoulder pain (mean age: 18.55±3.16 years). There was no significant difference in the anthropometric characteristics of the two groups (Table 1). All participants were professional elite swimmers and members of the Iranian national team who trained at least 3 days per week covering 40 km. All participants first swimming specialty was front crawl. All were ≥18 years of age, had been clinically diagnosed with mechanical shoulder pain and had experienced pain for at least 3 months prior to the testing according to the Cornell Musculoskeletal Discomfort Questionnaire (average or higher levels) (Afifehzadeh-Kashani et al., 2011). Those with a history of surgery or fracture of the shoulder area and steroid injections or any type of treatment of neck/shoulder area in a previous year were excluded. Healthy controls included sex- and age-matched pain-free elite swimmers of the same level with no history of shoulder pain or injuries, shoulder surgery, and other upper limbs injuries. The study received ethical approval from the University of Karaj Institutional Review Board and participants gave written consent prior to participation in the study.

Electrodes were placed by touching bony landmarks and performing maximum voluntary isometric contraction (MVIC) following the established guidelines: UT: midway between the spinous process of the seventh cervical vertebrae and acromion process; MD: in the upper quarter between acromion and olecranon in the middle part; lower trapezius (LT): obliquely between the spinous process of the scapula and seventh thoracic process; middle trapezius (MT): in the line from spinous process and the second thoracic vertebrae; latissimus dorsi (LD): 4 cm below the bottom of the scapula, one-half of the distance between the spinous and the lower edge of the body on 24-degree angle and the reference electrode was also installed on the 11th thoracic vertebrae;

SCM: on the second distance of the mastoid process and funnel chest while the head is rotated; and SA at 90 degrees of distance and the electrodes were vertically put in the mid-axillary line between the ribs 6 and 8 (e.g. Hermens et al., 1999) (Figure 1).

Data Collection

<u>Surface Electromyography (EMG)</u>

Muscle activity was measured using ME6000 Biomonitor EMG System (Mega Electronics System, Finland). Skin was cleaned with an alcohol tissue paper and the Ag/AgCl surface electrodes (skintact, Innsbruck, Austria) were attached to seven muscles in line with muscle fibers. The electrodes were 4×2.2 cm with 2 cm inner electrodes distance (Figure1). Muscles were identified during manual muscle testings (MMTs) according to established guidelines (e.g. Hermens et al., 1999): UT- sitting on a chair in a perpendicular position and not leaning on the seatback while the arm was kept in 90° abduction and the neck bent towards the same hand and rotation was on the opposite side; MT- in a horizontal position with arm stayed at an angle of 90° to the body (shoulders is horizontally away while having an external rotation) and the thumb was upward; LT- in side-lying position with the arm kept on the head and in the direction of the LT fibers; SA- in supine position with 90° of flexion and extension in shoulder and elbow; MD- in sitting on a chair with the shoulder in 90° abduction; LD- in a prone position with the arm at 30° of extension and abduction and palms upward; and SCM- in supine position with head bent to the same side. EMG signals were recorded during a 5s MVC for each individual muscle for 3 times with 30s rest between each of them with average of three trials calculated for normalisation (Ekstrom, Soderberg & Donatelli, 2005; McCabe, Orishimo, McHugh & Nicholas ,2007; Kendall, McCreary & Provance, 1983).

Functional Upper Limb Task

The functional upper limb task has been previously described by (Falla, Bilenkij & Jull, 2004; Hidalgo-Lozano et al., 2012) (Figure 2). The test was applied to the dominant side (i.e. the side preferred for daily activities like writing, eating, and handling heavy objects). All elite swimmers in the pain group had their dominant side affected. Each participant was seated on an adjustable chair with their feet flat on the ground throughout the functional task. Table height adjusted to the height of the elbow of each participant. The non-affected forearm rested on each participant's lap. Circles with dimensions of 70mm, which formed the corners of an equilateral triangle, were drawn with a distance of 23cm between their centers. Each participant was instructed to mark points with pen within each of the 3 circles counterclockwise and in coordination with the metronome set at 88 beats/min. EMG signals were recorded during the functional task which continued for a duration of 150s (Hidalgo-Lozano et al., 2012).

Data Analysis and Statistics

The raw EMG signals were band-pass filtered (20-480 Hz) and analog to digital converter at a sampling rate of 1000 Hz and the root mean square values (RMS) of EMG signals were then calculated over 1-second epoch during the functional task using MegaWin 2.0 software (Mega Electronics Ltd, Kuopio, Finland). The first and last 20s of the EMG recording were discarded and RMS was quantified at 3s intervals of 21-24, 42-45, 63-66, 84-87, 105-108, and 126-129s with the average of these 6 intervals taken for the final analysis (Tucci et al., 2011). The absolute RMS values were normalised with respect to the RMS values obtained during the MVC for each individual muscle (%MVC) (Soderberg & Knutson 2000).

The SPSS 20 (SPSS INC, Chicago, IL, USA) was used for the statistical analysis. Kolmogorov-Smirnov test was used for assessing the normal distribution of data. Multivariate analysis of variance (MANOVA) and Bonferroni adjustment were used to identify and compare differences in the muscle activation of individual muscles between the two groups. There is one dependent variable (RMS) values obtained for each muscle in professional swimmers with and without shoulder pain. Effect size was calculated using the Partial Eta Square method. The Partial Eta Square was considered to be small (0.05-0.1), moderate (0.1-0.2) or large (greater than 0.2) (Cohen 1988). Significance level was established at the 0.05.

Results

Table2 presents and compares the activity of the selected muscles (%MVC). There were significant differences in the muscle activity between the two groups ($p=0.002$, Partial Eta Square=0.844). The post hoc analysis for pairwise comparisons revealed a higher level of activity for UT ($p=0.002$, $F=13.36$), SA ($p=0.023$, $F=6.33$) and LD ($p=0.002$, $F=13.09$) in the elite swimmers with shoulder pain compared to the healthy control group. There was no significant difference in the activation of MT, LT, MD, and SCM muscles. Partial Eta square value showed a large effect of shoulder pain on the muscle activity.

Discussion and Implications

The main purpose of this study was to investigate the UT, MT, LT, MD, SCM, SA, and LD muscle activity during a functional upper limb task between swimmers with and without shoulder pain. The majority of studies in elite swimmers reported data during swimming motions. The reliability and generalisability of such data are potentially affected by pain experience during recordings as well as technical challenges associated with dynamic (EMG) recordings including high day-to-day variability, normalisation process, and complexity of multiphase movement analysis (Halaki & Ginn, 2012; Martens, Daly, Deschamps, Staes, Fernandes, 2016; Clarys, Scafoglieri, Tresignie, Reilly & Van Roy, 2010). To the authors' best knowledge, there has been only one previous study investigating muscle activation during a low load task in elite swimmers (Hidalgo-Lozano et al., 2012). The use of a low-load pain free functional task has been suggested as a feasible alternative method for assessing muscle activation patterns in painful shoulder conditions (Hidalgo-Lozano et al., 2012; Hawkes et al., 2012).

The results showed significantly higher muscle activity for UT, SA, and LD in swimmers with shoulder pain during the functional task. An increased activity of the UT observed in swimmers with shoulder pain is in line with previous reports of abnormal activation patterns in painful conditions such as subacromial impingement syndrome (Kamkar et al., 1993; Fu et al., 1991). In a study of swimmers with shoulder pain Scovazzo et al., (1991) reported significantly higher activity of UT in swimmers with painful shoulders compared to those with normal shoulders during freestyle swimming. Contradictory to this, Pink et al., (1993) reported significantly less activity in swimmers with shoulder pain during butterfly stroke. Hidalgo-Lozano et al., (2012) examined the activation of UT in elite swimmers during a low load functional upper limb task and reported no difference between those with and without shoulder pain. According to Janda, (1985), some muscles such as UT are known as tonic muscles because of their inherent tendency to increase tone and consequent tightening. Furthermore, UT needs to maintain a higher level of activity and contraction as an upward rotator and anti-gravity muscle (Janda, 1985). Elite swimmers usually practice 4 to 5 days a week, 2 times a day, swim between 8,000 and 12,000 m, and 9900 strokes per week for each shoulder that places a huge physical load on the shoulder complex (Hidalgo- Lozano et al., 2012). This high volume of repetitive movements associated with frequent scapula elevation and rotation would potentially lead to an overactive UT.

In the present study, altered SA activity in swimmers with shoulder pain is consistent with that in other studies in patients with shoulder pain (Wadsworth & Bullock-Saxton, 1997). SA is the prime mover during upward rotation phase of active arm elevation; during upper limb activities, it posteriorly tilts and externally rotates the scapula in order to stabilise it against the thoracic cage (Sahrmann, Azevedo, & Van Dillen, 2017; Ludewig et al., 2009; Kibler & McMullen, 2003). Lack of sufficient shoulder girdle stability is one of the key risk factors associated with shoulder disorders. Since the location of the humeral head in the centre of glenoid cavity is important to maintain stability in the shoulder joint, any disruption of these mechanisms would lead to abnormal displacement of the humeral head during active movements. In this scenario, one of the important factors in maintaining the shoulder joint stability is the scapulothoracic joint force couple including UT and SA muscles (Inman & Abbott, 1996). Alterations in the synergistic muscle activity of UT and SA and consequent disruption of the normal force couple can lead to dysfunctional scapulothoracic joint in front crawl in elite swimmers and cause shoulder pain (Scovazzo et al.,1991; Wadsworth & Bullock-Saxton, 1997).

Among contradictory studies, Ludewig & Cook, (2000) investigated shoulder muscle activity during humeral elevation in the scapular plane in 3 different load conditions in participants with symptoms of shoulder impingement and reported increased activity of UT and LT and decreased activity of SA muscle. This partial contradiction with the present study may be explained by several factors such as the difference in the type of disorder in both studies and the low demand of muscles activity in task performed in the present study (Hidalgo-Lozano et al., 2012). The increase observed in LD muscle activity during the functional task in swimmers with painful shoulder is consistent with the result of the previous studies (Ruwe et al., 1994; Pink et al., 1993; Scovazzo et al.,1991) that reported an increased activation of LD as the hand turned in and up during the terminal pull-through phase of the breaststroke, which acted to depress the humeral head in an attempt to relieve sub-acromial impingement. It is important to note that as a strong functional muscle in swimming, LD may fully develop in professional swimmers. Stiffness and overactivation of this muscle can limit the range of flexion, lateral rotation, and shoulder abduction. Furthermore, the stiffness of this muscle may contribute to the flexion of the dorsal spine and cause hyperkyphosis (Oatis, 2004).

As stated earlier, there was no difference between the activity of MT and LT, MD, and SCM muscles among swimmers with and without shoulder pain. Cools, Declercq, Cambier, Mahieu & Witvrouw, (2007) studied trapezius muscle activity and intramuscular balance in overhead athletes with impingement syndrome and reported no difference between groups or sides in the activity of MT during the isokinetic abduction. However, they observed decreased quality of temporal MT muscle recruitment in overhead athletes with impingement symptoms when compared with non-injured athletes, which suggested impaired MT neuromuscular performance in athletes with shoulder pain. In agreement with the present study, Naef, Grace, Crowley-McHattan, Hardy & McLeod, (2015) reported no difference in MD activity in participants with and without unilateral chronic shoulder pain during maximal isometric force at 30 º arm abduction. They attributed this finding to the identically used abduction motor strategy and similar muscle strength in the two groups. In the present study, it is possible that participants in both groups used the same task strategy, although the strength of the main muscles was not assessed. Even though there is a lack of scientifically proven literature, it is theoretically proposed that one of the main causes of muscle pain is muscle hyperactivity accompanied with ischemia and its consequent vicious cycle. Circumventing the weakness of the aforementioned theory, the relationship between muscle pain and motor strategy can be explained using pain adaptation model. Following this model, decreased agonist and increased antagonist muscle activity as well as less power and slower movements occurred. Also, there is another physiological model which suggests that groups III and IV afferents activate the γ-system and lead to muscular hyperactivity (Hidalgo-Lozano et al., 2012).

There were some limitations associated with the present study. EMG signals were recorded during a low-load functional upper limb task instead of swimming motions for following reasons: 1) the reliability and generalisability of EMG recordings may be affected by pain experience during forceful motions (Halaki & Ginn, 2012; Martens et al., 2016). 2) EMG recording during dynamic motions is associated with technical challenges such as high variability of EMG signals and normalisation methods particularly during multiphase movements (Clarys et al., 2010). Hence, applying a low-load pain-free functional task may eliminate these limitations as suggested by other researchers when assessing muscle activation patterns in painful shoulder conditions (Hidalgo-Lozano et al., 2012; Hawkes et al., 2012). The present Study used surface electrodes which may have caused an alternation and contamination of signals as a result of movements of the muscles below the electrodes and the nearby muscles cross-talks. Consequently, electrode placement followed well-established criteria in order to minimise crosstalk from muscles. While relatively small sample size of the study is comparable with that of previous studies, using a larger sample size could have increased the power of the test.

Conclusion

Swimmers with shoulder pain showed greater activation of UT, SA, LD muscles during the low load task, as compared to swimmers without shoulder pain. The findings of the present study support the presence of altered muscular activity in elite swimmers with shoulder pain during a low load task. While increased SA activity may occur to counterbalance increased UT activity in swimmers with shoulder pain, it may not be sufficient as activity of MT and LT remain unchanged.

Although the using a low-load functional task rather than swimming motions did not permit direct evaluation of the relationship between increased activation of muscles and shoulder pain, findings have implications for the rehabilitation of elite swimmers suffering from shoulder pain by means of appropriate exercise prescription to restore normal muscle activations.

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Table 1. Descriptive results of demographics (mean±SD) in pain and control group

Group / Variable	Pain group N=12	Control group N=12	*P*-Value
Age (years)	18.55±3.16	18.11±1.61	0.713
Body mass (Kg)	74.33±2.91	73.33±6.06	0.662
Height (Cm)	179±5.29	178.33±5.07	0.788
BMI (kg/m^2)	23.22±0.98	23.02±0.95	0.674

Abbreviation= BMI: Body Mass Index

Table 2. Results of MANOVA to compare the activity of the selected muscles (%MVC), between the pain and control groups.

Variable	Muscle	Group	Mean±SD	F	Sig.	Partial η2
Muscle activity (RMS %)	UT	Pain	28.04±10.37	13.361	0.002*	0.455
		Control	13.40±06.04			
	SA	Pain	30.78±20.09	6.330	0.023*	0.283
		Control	13.30±5.52			
	LD	Pain	27.05±17.87	13.093	0.002*	0.450
		Control	4.99±3.90			
	MT	Pain	12.72±6.81	1.358	0.261	0.078
		Control	9.06±6.50			
	LT	Pain	10.92±8.12	0.272	0.609	0.017
		Control	9.26±4.95			
	MD	Pain	15.53±12.74	1.728	0.207	0.097
		Control	9.57±4.76			
	SCM	Pain	4.64±3.75	0.462	0.507	0.028
		Control	3.63±2.45			

(*Significance Level $p<0.05$)

Abbreviation= UT: Upper Trapezius; SA: Serratus Anterior; LD: Latissimus Dorsi;

MT: Middle Trapezius, LT: Lower Trapezius, MD: Middle Deltoid, SCM: Sternocleidomastoid

Figure 1. UT, MD, MT, LT, LD, SCM, SA electrode placement

Figure 2. Functional upper limb task