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The effect of Delayed Onset of Muscle Soreness on trapezius activity

BEV3900 Master Thesis
Human Movement Science Programme
Norwegian University of Science and Technology (NTNU)
Trondheim, 2009

Acknowledgments

First, I will give a special thank my supervisor Paul Jarle Mork, for help and guidance throughout the project. I will also thank Andreas Holtermann for discussions about the use of the Biodex apparatus. I would like to thank my parents for backing me up morally and for the economic contribution. Further, thanks to my fellow master students for a good working environment, particularly Ellen Wakefield for good cooperation before and during the data acquisition process. I would also like to thank the participants in the project. Finally, I would like to thank Wenche Larsen for all her support during the process.

Abstract

The aim of the study was to investigate the effect of Delayed Onset of Muscle Soreness (DOMS) on trapezius surface electromyographic (sEMG) activity during different controlled activation levels. The study sample included 12 right-handed females (age 20 to 24 years) with no record of recent symptoms or signs of neck or shoulder pain. Pressure pain thresholds (PPT) and sEMG were recorded bilaterally from the trapezius muscle. The experimental conditions included nominal rest, arm coordination movements and sustained shoulder flexion, before and after the introduction of DOMS. The recordings were executed on two consecutive days, i.e. recordings on day 1 were performed while the trapezius was 'pain-free' while recordings on day 2 were performed with DOMS present in the trapezius muscle. DOMS was induced after recordings on day 1 by intensive eccentric exercise of the left upper trapezius.

The results of the PPT test demonstrated a significant lower pain threshold of the exercised upper left trapezius muscle at day 2. Except for an increased sEMG activity during the coordination test, the muscle activity of the painful left upper trapezius remained unchanged from day 1 to day 2. In conclusion, the findings of similar sEMG activity during the 'pain-free- and 'pain-afflicted state' resulting in a non support of the pain adaptation model.

Keywords: Pain adaptation model, DOMS, Trapezius

Introduction

Work related musculoskeletal disorders is a significant problem in the working population of the western world (Buckle, et al., 2002), and is a common cause of persistent disability (Lawrence, et al., 1998). For unknown reasons, the prevalence of shoulder and neck pain (SNP) is nearly twofold higher in the female population compared to the male population, and SNP is documented to increase with age (Ihlebæk, et al., 2002). It is well established that heavy physical workload is a risk factor for musculoskeletal pain, but prevalence rates are also shown to be high for workers with low physical loading (Bernard, 1997). Risk factors during low level physical loading include high repetitiveness of movement, long duration of workload, hand-arm vibration, static posture and insufficient rest (Sommerich, et al., 1993).

Human experimental muscle pain models can be used to investigate how muscle pain influences muscle activity during various conditions. There are some conflicting results in the literature, particularly the influence of muscle pain on muscle activation patterns. An often cited hypothesis is the pain adaptation model, proposed by Lund and co-workers (1991), which states that muscle pain, whether chronic or acute, inhibit muscle pain in order to avoid injured tissue from further damage. This has been supported mainly from studies with induced experimental muscle pain by injections of hypertonic saline, which is limited to a short duration of effect. In particular, muscle activity during various conditions in the presence of experimental muscle pain has been investigated to find a link to chronic pain. However, few studies have investigated low activation levels and the relation to muscle pain.

The pain adaptation model has achieved much support from studies investigating the effect of experimentally muscle pain on muscle activity under various conditions. In these studies hypertonic saline is injected into the muscle of interest. Muscle pain induced this way are often associated with lower surface electromyographic (sEMG) activity in the painful muscle, compared to a non painful condition at the same force level, both in isometric and dynamic tasks. This is documented in maximal voluntary contraction (MVC) and sub-maximal contractions. Ervilha and co-workers (2005) recognized a decrease in sEMG in cyclic arm movements, and Madeleine and co-workers (1999) observed this in working rhythm, and Ge and co-workers (2005) observed this during sustained contractions. Previous studies with hypertonic saline have proven to influence the dynamic motor function and coordination of the muscle, especially in moderate to maximal force levels. These effects have been observed in chewing muscles (Stohler, et al., 1988; Svensson, et al., 1995) and postural muscles during walking (Arendt-Nielsen, et al., 1996; Graven-Nielsen, et al., 1997).

The underlying mechanism of the pain adaptation model is hypothesized to be a decrease in motoneuron output when the painful muscle acts as agonist with an accompanying increase of antagonist activity. Kniffki and co-workers (1981) suggested that these adaptations may originate from altered motoneuron firing pattern, from segmental interneurons in the spinal cord, or in the brain stem. Therefore, the pain adaptation hypothesis assume that muscle nociception leads to changes in muscle coordination of the painful region, resulting in either decreased velocity and amplitude of movement, or decreased muscle activity as a product of muscle pain. Lund and co-workers (1991) demonstrate that the effect of pain on muscle function may depend on the action of the muscle or the amount of force in a task, although in some situations it is difficult to determine when the muscles act as an agonist or antagonist. This indicates that it limits movement and probably reduces further injury and pain.

Concerning upper extremity disorders, special attention should be given to the shoulder, which allows a large range of movements and the stability of the shoulder complex is particularly dependent upon its surrounding musculature (Hess, 2000). The trapezius and serratus anterior muscles are of great relevance as they help stabilizing the scapula, thereby ensuring the stability of the arm (Alexander, 2007). Moreover, the upper trapezius is of particular interest because pain location frequently includes this muscle (Toomingas, 1999), and have often been investigated in studies involving both acute- and chronic muscle pain (e.g. Madeleine, et al., 2006a; Madeleine, et al., 2003; Madeleine, et al., 2008), which have investigated the effect of trapezius muscle pain on muscle activation patterns. Such studies contribute in a wider understanding of muscle activity in SNP.

When studying the effect of acute pain, on muscle activity, specific pain intervention is necessary. Delayed Onset of Muscle Soreness (DOMS) is a result of eccentric contraction, where muscles are forcibly lengthened and the muscle act as a brake to control motion of the body (Proske, et al., 2004). DOMS lead to sensation described as dull and tender (Armstrong, 1984), and is developed within the first 24 hours after eccentric exercise (Prasartwuth, et al., 2005). The sensation usually expire within five to seven days (Ebbeling, et al., 1989). Brockett and co-workers (1997) observed that in a DOMS state, force and position matching errors occurred. Eccentric contractions performed at maximal force level is shown to result in microscopic damage of the exercised muscle fibres (Bajaj, et al., 2002; Proske, et al., 2001), such as sarcomere disruption and membrane damage (Weerakkody, et al., 2001). This damage triggers a local inflammatory response (Smith, 1991), and then lead to breakdown of the muscle tissue. This response involves a release of substances (e.g. bradykinin, prostaglandin),

which may sensitise group III and IV muscle nociceptors (Mense, 1981), that lowers the threshold to mechanical stimuli (Nie, et al., 2006), such as stretch, palpation or contraction (Weerakkody, et al., 2001). Further, it has been suggested that DOMS leads to a disturbance of proprioception, e.g. sense of force and limb position (Proske, et al., 2004). DOMS may therefore act as a useful paradigm example to study the relation between muscle pain and muscle activity.

This study aims to investigate the pain adaptation model by inducing DOMS to the upper left trapezius muscle. It is hypothesized that the presence of acute upper trapezius pain will lead to reduced trapezius activation. Since muscle pain may infer differently with muscle activity dependent on activity level, a range of tasks with different activation levels where included in the experimental protocol.

Materials and methods

Subjects

Twelve right-handed female subjects, without signs or symptoms of shoulder or neck pain during the past 6 months or no prior serious injuries to the neck area, were recruited to the study. Subject characteristics are presented in Table 1. All subjects were students at the Norwegian University of Science and Technology (NTNU). Subjects that carried out resisted strength exercise more than once a week, on a regular basis, were excluded from the study. Each subject gave an informed and written consent prior to participation in the study.

The study protocol was approved by the Regional Ethics Committee and the Norwegian Social Science Data Services. The study was carried out according to the Declaration of Helsinki.

Table 1. Subject characteristics (N=12).

	Mean	SD	Range
Age (yrs)	21.6	1.5	20-24
Height (cm)	165	6.1	151-172
Weight (kg)	61.7	7.7	50-75
BMI (kg/cm^2)	22.6	2.42	19.6-26.9

Experimental set-up

All subjects were tested on two consecutive weekdays with a series of laboratory tests (Figure 1). Information about the experimental procedures was given to each subject before the testing started at day 1. Subjects also filled in a short questionnaire on anthropometric data and history of exercising, injuries, and shoulder and neck pain. An eccentric trapezius exercise intervention consisting of unilateral eccentric contractions of the left upper trapezius muscle was performed at the end of the first day. All tests were administrated by the same person. The sequence of the procedure was 1) measurement of pressure pain threshold (PPT), 2) sEMG electrode placement, 3) maximal voluntary contractions (MVCs) and reference contractions, 4) uninformed rest, 5) coordination test, and 6) sustained contraction test.

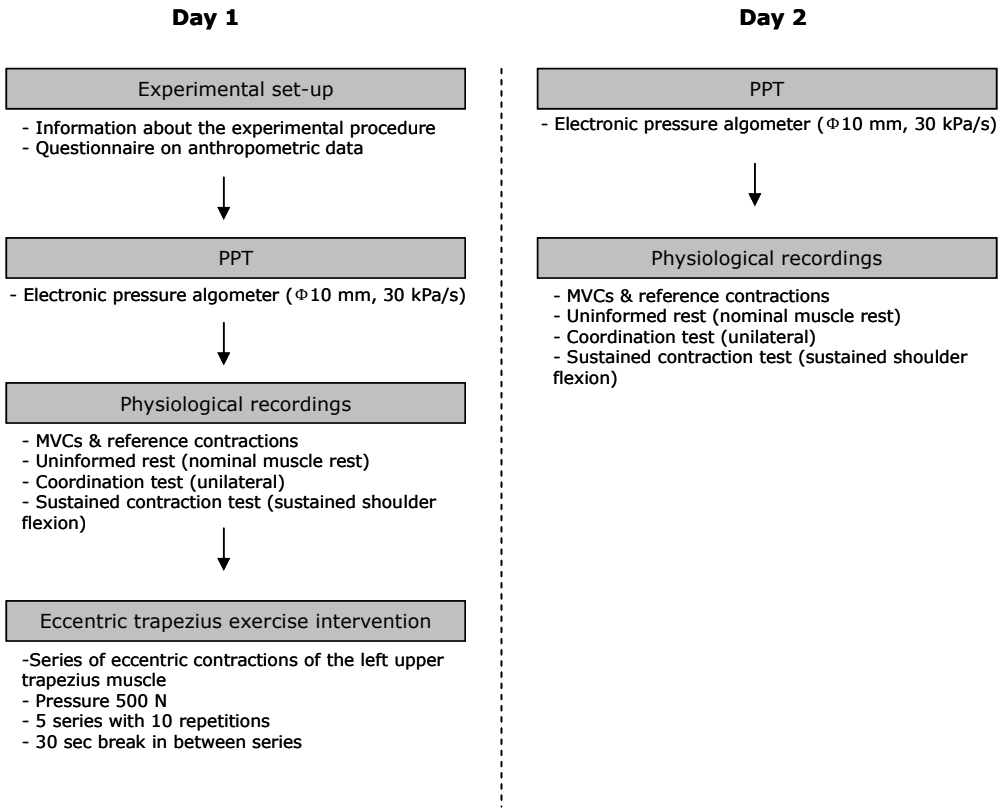

Figure 1. Experimental procedure in the present study consisted of two consecutive days. On the first day the subjects where informed about the experimental set-up, a PPT test was carried out before physiological recordings where documented. The last procedure of day 1 was a series of eccentric exercise. The second day was perform the same way as the first day, except for the information on the experiment and the eccentric exercise

Pressure pain threshold

Testing of PPT was included as a means to evaluate the effect of the exercised intervention. Tests were completed before mounting the required equipment. PPT was measured by an electronic pressure algometer (Somedic Algometer type 2, Sweden), with a probe diameter of 10 mm. The instrument was calibrated before every trial and all measurements were carried out by the same person. A standardized slope increase of 30 kPa/s was used during the pressure application. The subjects were instructed to tell when the applied pressure changed from being a perception of pressure to being slightly painful. First, PPT was tested at the lateral, centre, and medial part of the descending trapezius muscle. The centre pressure point was midway between the acromion and C7. The two other sites were 2 cm laterally and 2 cm medially to the centre point on a line between acromion and C7. Second, PPT was tested at the transverse fibres of trapezius (at the level of T4, centre between margo medialis scapulae and the vertebral column). Third, reference PPT was tested at the tibialis anterior (2 cm distal

and 2 cm lateral to the tuberositas tibia). All PPT measurements were carried out bilaterally, except for the tibialis anterior muscle, which was done on the left side only. All PPT measurements started on the non-dominant side.

Physiological recordings

A portable Myomonitor IV EMG system (Delsys, Boston, MA) was used to record sEMG and force signals (SM-200N Interface, Kissler, Scottsdale, AR). The data logging mode (Data logger, EMGworks, Delsys) was used during all recordings, with a sample rate of 1000 Hz. sEMG and force signals were digitalized and stored on a removable SD memory card (1 GB standard or 2 GB standard, ScanDisk). Ten bipolar surface electrodes (DE- 2.3 Single Differential Surface EMG Sensor, Delsys, Boston, MA) with an inter-electrode distance of 10 mm were used to record sEMG activity bilaterally from the trapezius muscle and the serratus anterior. sEMG signal were digitally band-pass filtered at 20-450 Hz and root-mean-square (RMS) values were calculated using a 100 ms non-overlapping time window. The force signal was digitally filtered (Butterworth Low pass filter 20 Hz, 6^{th} order) before further analyses. Both force and sEMG signals were analysed by use of AcqWin Version 2.2.0.57 (Jacobus systems Ltd.). The RMS detected sEMG signal was normalised by the highest sEMG response (EMG_{max}) obtained during the MVCs. The minimum noise level was subtracted before normalization.

For the trapezius electrodes were attached at the clavicular, descending, transverse, and ascending divisions. For serratus anterior the electrodes were placed at the 5^{th} digit. A reference electrode was placed above the spinous process of C7. Prior to attaching the sEMG electrodes, the skin was abraded with technical methylated spirit. Adhesive sensor interfaces (Delsys, Boston, MA) were attached to the electrodes, then, contact poles were applied with contact gel.

Maximal voluntary contractions and reference contractions

The sEMG responses during laboratory recordings were normalized relative to the maximal sEMG response ($sEMG_{max}$) obtained during isometric MVCs. MVCs were carried out bilateral for both the trapezius and the serratus anterior. The highest of the three $sEMG_{max}$ values was used for normalization. For recording of trapezius MVCs the subjects were seated in a chair, and instructed to abduct both shoulders to 90º, keep the elbows straight, and keep the back of the hand upwards. Straps connected to force transducers were placed just above the elbow joint (~1 cm proximal to the lateral epicondyle). Two force transducers (SM-200N

Interface, Kissler, Scottsdale, AR) were secured to a foundation on the floor, which ensured resistance to an isometric abduction of the shoulder. Force data (Newton) was collected bilaterally, synchronous to the MVCs of the trapezius muscle.
Recording of MVCs for the serratus anterior muscle was carried out with the subject lying supine on a bench with the elbows straight and both shoulders flexed to 125°. Manual resistance was applied to the ventral aspect of the upper arm. All MVC contractions lasted for ~3-4 sec and were repeated three times with 1 min rest in between. A reference contraction was carried out after the completion of the MVCs. The subject was instructed to abduct both shoulders to 90º with elbows straight and hands relaxed. The duration was 15 sec.

Tests of muscle resting level, voluntary activation, and muscle fatigue
The first test, uninformed rest, aims to assess the level of residual muscle activity during nominal (i.e. uninformed) rest. The test was carried out standing upright with approximately a hip distance between the feet. The subjects were instructed to perform three coordinative movements with the upper limbs/body with 15 sec uninformed rest intervals before and in between movements.

The second test was a unilateral coordination task of the upper limbs. The subjects were seated next to a table on an adjustable chair. The sitting height of the chair was adjusted until the subject was seated with a 90º angle in the elbow joint while resting the forearm on the table and the shoulders relaxed. A sheet with three circles (φ 4 mm) positioned in an equilateral triangle was placed in front of the subject. The distance from the edge of the table and the sheet was 10 cm with the centre circle placed at the midline in front of the subject. The subject task was to perform a cyclical arm movement and mark a dot with a pencil in each circle following the pace of a metronome set to 88 bpm. The test was performed for both arms. The right arm was moved counter clockwise and the left arm clockwise. The duration of the test was 2 min for each arm, with a 1 min rest in between.

The third test consisted of a sustained shoulder flexion with a straight elbow joint. The test was performed for both arms and with duration of 5 min for each arm. A rest break of 2 min was allowed between testing of right and left arm. The subjects were equipped with an orthosis to ensure that the elbow joint was kept in a 180º angle. During the test the subject was standing in front of a wall with the shoulder flexed to a 100º angle with the back of the hand facing the subject. The palm of the hand was held horizontal to a 90º angle against the wall with a distance of 2 cm from the wall. The feet's position on the floor, i.e. distance from the wall, where measured for each subject to ensures that the test was performed from the

same position on both days. The subjects were instructed to avoid movements of the shoulder. A rack with two poles standing up like fence pales was placed next to the subject. Distance between the poles was 10 cm. A small plastic pipe was attached to the non-active shoulder so to be positioned between the two poles. This made it possible to monitor slow creeping movements and rotation of the shoulder during the test. If a change in posture occurred during the test the subject was instructed to resume the correct the position. The subject task was to perform small cyclical flexion and extension movement of the wrist, in accordance to a zero marked point (i.e. hand in a 90° angle to the wall), and ~3 cm above and below this mark on a sheet of paper attached to the wall. The wrist movement was pace by a metronome set at 88 bpm. The subjects were instructed to remain the shoulder flexion and only move the wrist.

Eccentric trapezius exercise intervention

A multi-purpose system (Biodex System 3) developed for testing and rehabilitation of the human musculoskeletal system (Biodex Medical Systems, Shirley, NY) was used for the exercise intervention (Figure 2). The subject was seated in the chair of the machine with the feet placed on a hard cushion, and with knees and hips at ~90° flexion. The back of the seat was tilted backward at 85°. Stabilization straps were fitted; one around the hips and one across the right shoulder and left hip. The position of the chair was fitted as to make a trapeze shaped cushion be positioned above the non-dominant shoulder, the lateral edge of this cushion being fitting the shoulder edge. The cushion was fastened to a prop which moved it vertically by a dynamometer. The range of range motion for each subject was defined by a slight elevation of the shoulder girdle (i.e. top position) and maximal depression (i.e. lowest position). The cushion provided a pressure to the shoulder of 500N in both directions.

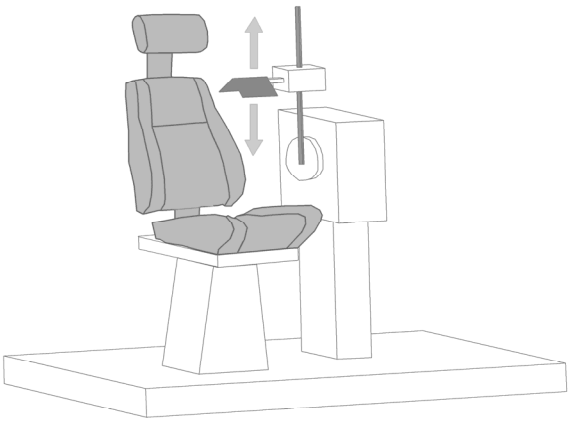

Figure 2. Illustration of the Biodex System 3. Attachment placed in the middle position, the grey arrows show the rise and drop direction of the cushion.

The exercise intervention was executed after the laboratory tests at day 1. The positions of the sEMG electrodes were draw with a marker and the electrodes removed. The exercise intervention consisted of a series of eccentric contractions of the upper trapezius muscle on the non-dominant (left) side, i.e. five series with 10 repetitions, and with a 30 sec break between the series.

During the exercise the subjects were instructed to let both hands down the side of the chair and look straight ahead and avoid any lateral flexion of the upper body. The subjects were corrected on posture and technique if necessary. The subject was instructed to make a concentric contraction of the shoulder, corresponding to the upward movement of the cushion. Further, to maximally resist the downward movement provided by the dynamometer. The speed of the dynamometer was set to 30°/sec for elevation, and 50°/sec for depression of the shoulder. A break of 2 sec was applied at the lowest point of the range of motion. After the intervention, the subject was informed to avoid any form of strenuous physical activity until the testing on the second day was completed.

Statistical analyses

Statistical analyses were performed using SPSS version 15.0 (SPSS Inc., Chicago, IL, USA) and Microsoft Excel 2002. A Shapiro-Wiilk test was carried out on all variables to test for normality. All sEMG and force variables were non-normally distributed while PPT data showed a normal distribution. For comparison of responses between day 1 and day 2 a paired sample t-test was used for the normally distributed data while a Wilcoxon signed-rank test was used for non-normally distributed data. All comparisons were performed two-tailed. The level of significance was set to $P<0.05$.

Results

Pressure pain threshold

PPT was significantly reduced from day 1 to day 2 at the medial (P=0.0003), central (P=0.0003), and lateral (P=0.0025) part of the left upper trapezius (Table 2). There was no change in PPT for the left scapular part of trapezius or in any of the parts of the right trapezius. Neither was there any change in PPT for the tibialis anterior from day 1 to day 2.

Table 2. Pressure pain threshold (kPa) measured on day 1 and day 2

	Day 1		Day 2		*P*-value*
Right side					
Medial	279	(224 – 334)	276	(211 - 342)	NS
Central	305	(242 – 368)	288	(215 - 362)	NS
Lateral	377	(294 – 459)	336	(270 - 401)	NS
Scapular	373	(312 – 433)	402	(315 - 488)	NS
Left side					
Medial	289	(229 – 348)	186	(135 - 238)	0.0003
Central	280	(236 – 324)	189	(140 - 238)	0.0003
Lateral	340	(283 – 397)	271	(214 - 327)	0.0025
Scapular	381	(314 – 448)	374	(283 - 464)	NS
Tibialis anterior	545	(421 – 668)	522	(402 - 642)	NS

Values are mean (95% CI)

* Paired sample t-test

Maximal voluntary contraction and force

Figure 3 shows scatter plots of force during isometric MVC (i.e. shoulder abduction), for right (A) and left (B) side, day 1 vs. day 2. Intra-individual consistency in force generation was high; however, there was a systematic shift toward lower force levels at day 2. This reduction was significant for left (P=0.008) but not right side (P=0.10).

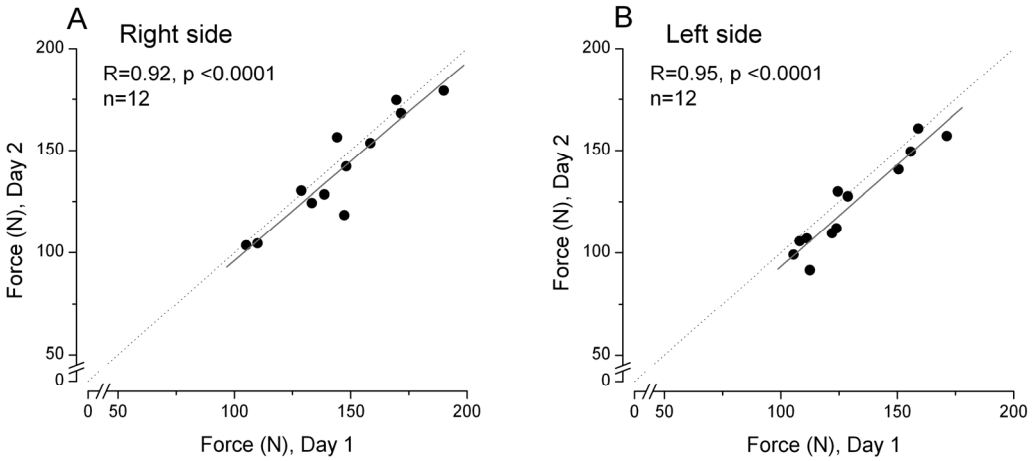

Figure 3. Scatter plot (day 1 vs. day 2) of force (N) during isometric MVC (i.e. shoulder abduction) for right (A) and left side (B). The regression line is drawn in solid and line of identity is dotted

Table 3 illustrate $sEMG_{max}$ (μV) for the different parts of trapezius and the serratus anterior during isometric MVC at day 1 and 2. Overall $sEMG_{max}$ remained unchanged from day 1 to day 2, except for a significant reduction in the right clavicular trapezius (P=0.01) and left serratus anterior (P=0.02).

Table 3. $sEMG_{max}$ (μV) for the different parts of the trapezius- and the serratus anterior muscle during MVC at day 1 and day 2.

	Day 1		Day 2		P-value*
Right side					
Clavicular	981	(682-1246)	740	(630-1231)	0.01
Descending	407	(172-578)	328	(143-157)	NS
Transverse	270	(155-454)	310	(66-411)	NS
Ascending	181	(60-327)	183	(56-304)	NS
Serratus Anterior	620	(213-817)	497	(182-844)	NS
Left side					
Clavicular	1039	(510-1205)	912	(445-1204)	NS
Descending	530	(127-746)	761	(115-910)	NS
Transverse	275	(110-488)	275	(93-430)	NS
Ascending	180	(83-328)	171	(78-345)	NS
Serratus Anterior	542	(322-782)	473	(281-864)	0.02

Values are median (95% CI)

* Wilcoxon signed rank test.

Nominal muscle rest

Table 4 illustrates median activity level (%EMG_{max}) for the different parts of trapezius and the serratus anterior during standing nominal rest at day 1 and day 2. Generally, activity level was very low, and there was no change except for a slight, but significant increase for the transverse part of right trapezius (*P*=0.017).

Table 4. Median activity level (%EMG_{max}) during standing nominal rest at day 1 and day 2.

	Day 1		Day 2		P-value*
Right side					
Clavicular	0.6	(0.1-0.8)	0.4	(0.1-1.4)	NS
Descending	1.0	(0.6-1.1)	1.1	(0.3-1.5)	NS
Transverse	0.8	(0.4-1.6)	0.9	(0.5-2.4)	0.02
Ascending	0.7	(0.5-1.1)	0.6	(0.4-1.0)	NS
Serratus Anterior	0.5	(0.2-0.7)	0.6	(0.2-0.9)	NS
Left side					
Clavicular	0.8	(0.2-2.1)	0.9	(0.2-2.3)	NS
Descending	1.1	(0.3-1.9)	1.2	(0.1-1.5)	NS
Transverse	0.6	(0.2-1.6)	1.0	(0.4-2.7)	NS
Ascending	0.6	(0.4-1.6)	1.0	(0.3-1.4)	NS
Serratus Anterior	0.5	(0.2-0.7)	0.5	(0.1-0.8)	NS

Values are median (95% CI)

* Wilcoxon signed rank test

Coordination test

Table 5 presents median activity level (%EMG_{max}) for the different parts of trapezius and the serratus anterior during the coordination test at day 1 and day 2. There was no change in muscle activity from day 1 to day 2 when the right arm was active. When the left arm was active a significant increase was present for the left descending (*P*=0.05) and the right transverse trapezius (*P*=0.03). The activity of the left clavicular trapezius showed a tendency toward an increase from day 1 to day 2 (*P*=0.09) when the left arm was active.

Table 5. Median activity level (%EMG_{max}) during coordination test at day 1 and day 2.

	Right arm active					**Left arm active**				
	Day 1		Day 2		P-value*	Day 1		Day 2		P-value*
Right side										
Clavicular	5.7	(4.0-6.9)	5.6	(4.1-7.0)	NS	2.6	(1.4-3.6)	2.7	(1.3-3.9)	NS
Descending	4.3	(2.8-6.5)	5.3	(3.7-8.1)	NS	1.9	(0.8-3.9)	2.1	(1.0-3.5)	NS
Transverse	2.7	(0.9-4.4)	3.3	(0.7-5.7)	NS	1.4	(0.7-1.6)	1.6	(0.7-2.7)	0.03
Ascending	4.7	(3.5-5.7)	4.8	(1.6-7.1)	NS	2.2	(1.2-3.3)	2.5	(1.3-3.9)	NS
Serratus Anterior	2.2	(0.9-3.7)	2.1	(0.6-3.2)	NS	0.8	(0.2-1.3)	0.8	(0.3-1.1)	NS
Left side										
Clavicular	1.9	(1.0-4.0)	2.5	(1.4-3.6)	NS	6.7	(3.4-9.7)	7.1	(5.9-9.6)	0.09
Descending	1.5	(0.6-2.7)	1.6	(0.7-2.4)	NS	4.3	(3.3-6.7)	5.5	(3.8-7.6)	0.05
Transverse	1.1	(0.4-2.9)	1.2	(0.4-3.2)	NS	2.1	(1.0-5.4)	2.7	(1.4-6.5)	NS
Ascending	2.1	(0.9-5.1)	2	(0.6-3.1)	NS	5.2	(1.3-7.3)	4	(1.6-9.9)	NS
Serratus Anterior	0.6	(0.2-0.7)	0.5	(0.3-0.7)	NS	2.3	(1.5-3.2)	2	(0.8-3.1)	NS

Values are median (95% CI)

* Wilcoxon signed rank test.

Sustained shoulder flexion

Figure 4 shows the time course of trapezius median sEMG level (%EMG_{max}) during sustained shoulder flexion on right (A and B) and left (C and D) side. Activation level varied considerably between the different parts of trapezius, i.e. from ~5-20% EMG_{max} when the muscle was 'active' (A and D) and from ~0.5-5% EMG_{max} when the muscle was 'passive' (B and C). In general there was no change in the time course (i.e. slope) or median activity level (%EMG_{max}) of the different trapezius parts from day 1 to day 2 regardless of whether the muscle was 'active' or 'passive'. For the left clavicular trapezius there was a tendency towards a steeper increase in muscle activity level (first to last min) at day 2 compared to day 1 when sustained contraction was performed on the right side; however, this increase did not reach significance (P=0.09; Figure 4B).

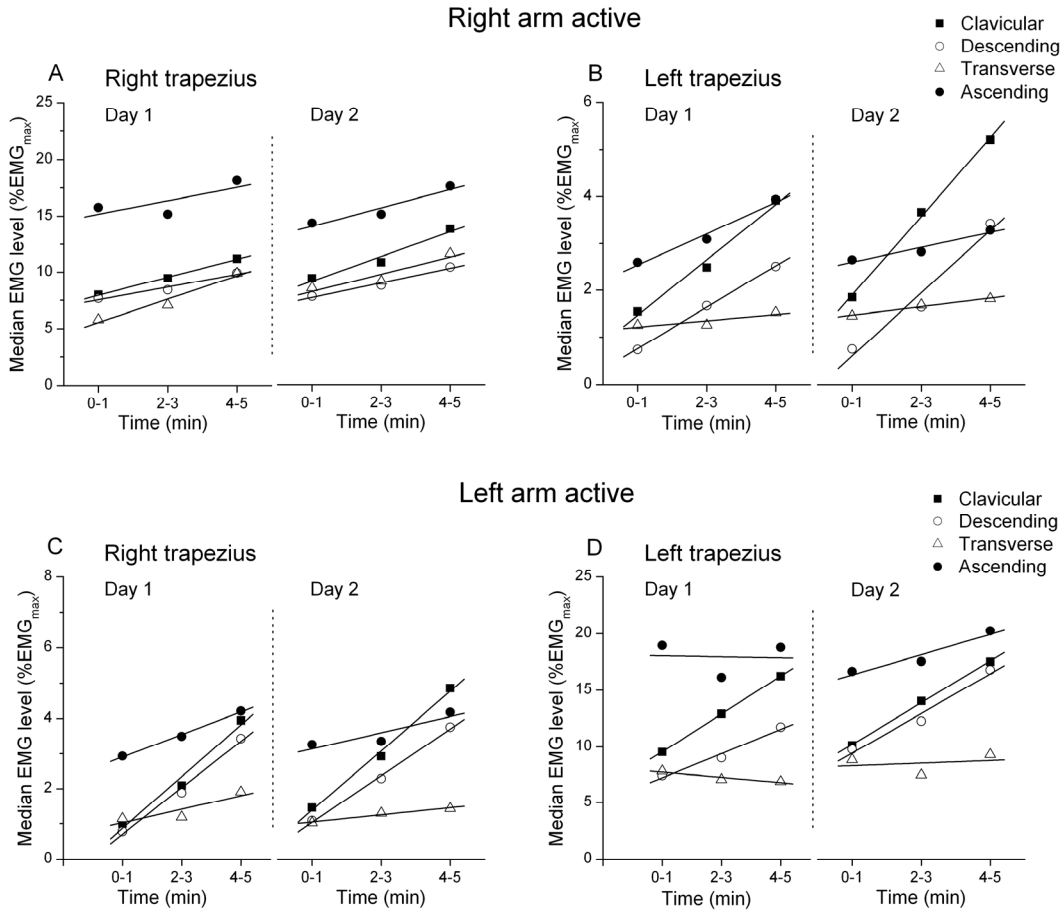

Figure 4. Time course of trapezius median sEMG level (%EMG_{max}) during sustained shoulder flexion on right (A and B) and left (C and D) side

In Figure 5 the time course of median frequency during sustained shoulder flexion on right (A and B) and left (C and D) side is illustrated. Similar to median sEMG level there was no change in the time course (i.e. slope) of the median frequency from day 1 to day 2 regardless of the arm being 'active' or 'passive'.

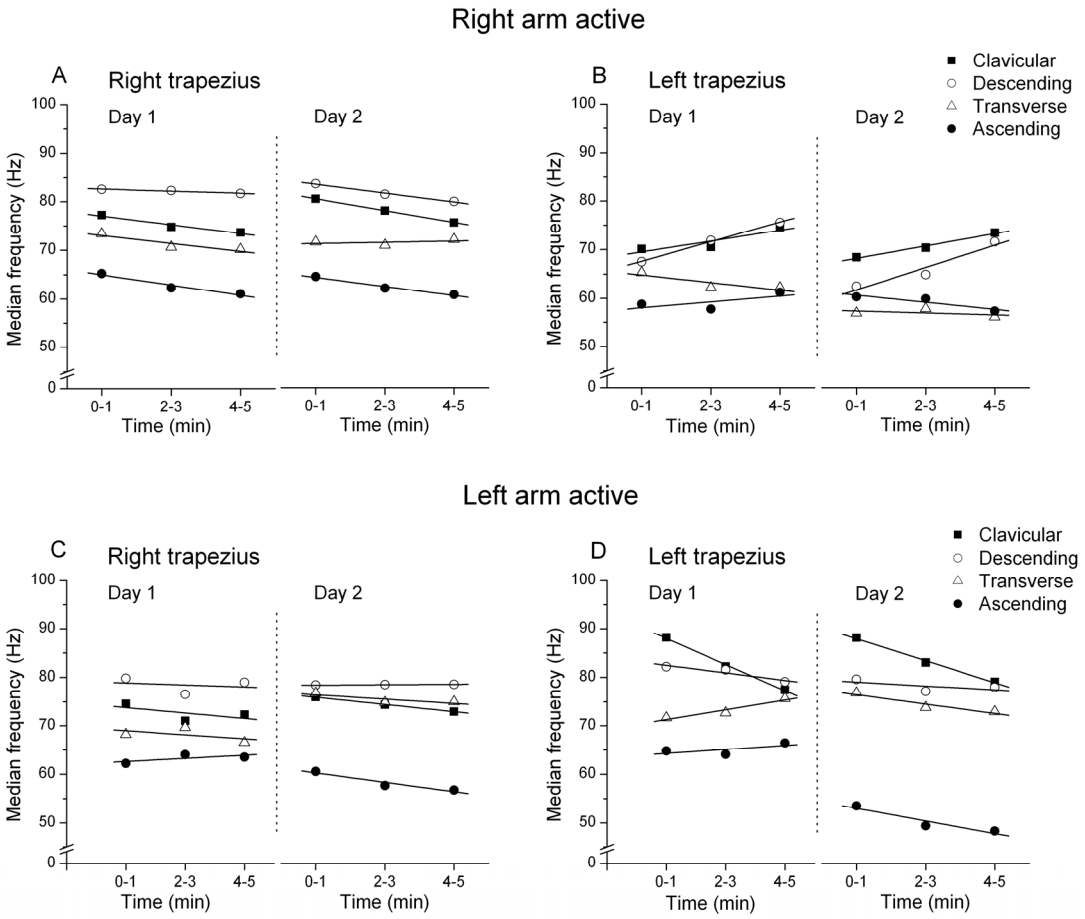

Figure 5. Time course of trapezius median frequency (Hz). during sustained shoulder flexion on right (A and B) and left (C and D) side

Discussion

The purpose of this study was to investigate the effect of acute upper trapezius pain (i.e. DOMS) during conditions with different activation levels and patterns of activation in the trapezius and serratus anterior during controlled laboratory tests. The study showed that pressure pain threshold (PPT) was reduced for all sites (i.e. medial, central, lateral) in the exercised upper left trapezius on day 2, and unchanged for the lower part of the left side, and the upper and lower part of the right side. The MVC test revealed a reduction of the force capacity on the left exercised side, but not on the non-exercised right side. In contrast there was no change in $sEMG_{max}$, from day 1 to day 2 for any of the trapezius parts on the left side. Overall, there was no change in muscle activity levels during situations with nominal rest or sustained shoulder flexion. However, during the coordination test there was a significant increase in sEMG activity in the left descending trapezius accompanied with a tendency of increased activity for the left clavicular trapezius.

The present study introduced experimental muscle pain using DOMS as a paradigm example to study the effect of pain on trapezius activity during different tasks. The pain induction in this study consisted of repeated eccentric contractions on the left shoulder. According to Madeleine and co-workers (2006b) DOMS is a well established way of introducing experimental pain to the trapezius muscle. In the present study PPT was significantly decreased on the left trapezius 24 hours after the exercise intervention, also been demonstrated in earlier studies (e.g. Madeleine, et al., 1998; Nie, et al., 2006), indicating a mechanical tenderness of the left trapezius. According to Madeleine and co-workers (1998) PPT is suggested to offer an effective indicator concerning the extent of muscle tenderness or the existence of the DOMS. Proske and co-workers (2004) observed that pain by eccentric contraction and saline induced pain resulted in the same amplitude of force matching errors. The present study showed a systematic shift towards lower force levels (MVC) on the pain afflicted side from day 1 to day 2. This finding is supported by various studies observing a reduced ability to generate force the day after eccentric exercise (e.g. Prasartwuth, et al., 2005).

The reduced MVC (i.e. force) for the left side could indicate that muscle pain affect force generation of the left trapezius muscle and the surrounding musculature (i.e. high biomechanical load). Various studies document similar results, i.e. a decrease in the force capacity after experimentally induced pain at MVC (Graven-Nielsen, et al., 1997; Sterling, et al., 2001), and this is in accordance with Lund and co-workers (1991), who suggests a

decrease in muscle activity. Ekstrøm and co-workers (2005) identified positions to obtain as high $sEMG_{max}$ values as possible, and came up with a procedure with abducted and flexed shoulder MVCs. This procedure was adopted in the present study, and the results showed no significant reduction in $sEMG_{max}$ between the two conditions. The force and $sEMG_{max}$ relationship in the MVC is in line with the findings by Prasartwuth and co-workers (2005). They reported that (after DOMS), 90% of EMG_{max} was needed to generate 50 % MVC (i.e. force). Thus, the results of unchanged $sEMG_{max}$ in the current study raise questions on the applicability of the pain adaptation model. Further, the pain adaptation model predicts a reduced muscle activity for any level of load, and that the effect of muscle pain on muscle function may depend on the action of the muscle (Lund, et al., 1991). In the present study, low-level activation was investigated (i.e. nominal rest), and the results did not show reduced muscle activity. This could indicate that the pain adaptation model may be unsuitable for studies involving low-level activation.

Falla and co-workers (2007) documented an increase in muscle activity for the lower trapezius muscle after hypertonic saline injections into the upper trapezius, hence a reorganisation within the trapezius was observed. This supports the pain adaptation model, and was not found in the present study. However, the coordination test in the present study showed that the $\%sEMG_{max}$ activity of the left descending part of the trapezius increased significantly from day 1 to day 2, while the left clavicular part showed a tendency towards increased activity. This may not be sufficient evidence of a general increase in the trapezius muscle in the coordination test (i.e. cyclical arm movements). However, these findings may contribute as evidences in rejecting the pain adaptation model. This is in line with Bottas and co-workers (2009), who document an enhanced EMG activity in rhythmic arm movements after exhausting eccentric contractions of the biceps brachii. One comprehension of increased muscle activity in the presence of pain is that muscle pain may reflect increased activity in group III and IV muscle afferents (Weerakkody, et al., 2003). These small afferents, associated with muscle damage, are recognized to be sensitive to inflammation substrates (Armstrong, 1984). This may, in particular, be due to increased γ-activation, which increases the sensitivity of the muscle spindles (Brocket, et al., 1997), which may feasible neural activation (Matre, et al., 1998). It has been suggested that increased neural adjustment result from feedback gain (Regueme, et al., 2005). In the present study the subjects were to keep up cyclical arm movement according to the metronome pace set at 88 bpm (see method). This could be a contributing factor in increasing trapezius muscle activity. Thus, the increased activity in the left trapezius muscle during pain may imply an excitatory effect of muscle pain

(Birch, et al., 2001), and not an inhibitory effect postulated in the pain adaptation model. Pedersen and co-workers (1997) found excitatory effects leading to a reduced amount of control in some movements in the neck muscles of cats. Increased activity in the muscle spindle afferents leads to enhanced activation levels in the pool of alfa-motoneurones. Furthermore, increased muscle activity can enhance muscle stiffness, resulting in higher production of metabolites, and thereby perpetuate a vicious circle (Johansson, et al., 1991). Based on this, one can assume that the increased muscle activity in DOMS-afflicted muscles can be associated with the sensitisation of nociceptors by mediators related to inflammation caused by muscle fibre damage. Since the coordination test showed significantly increased muscle activation, in contrast to nominal rest and sustained shoulder flexion, it can be considered that coordinated arm movements play an important role in understanding how muscle pain inflict muscle activation. Madeleine and co-workers (2008) found restricted movement of the arm when measuring the range of motion during experimental pain, however, the present study were unable to detect this. The present study show that muscle pain could affect muscle activation in coordinated cyclical arm movements (also seen in e.g. Bottas, et al., 2009), and muscles around the shoulder may work together at a higher level. Also, it could be assumed that the surrounding structures of shoulder muscles could act as a stabilizing factor (Sjögaard, et al., 2000), in a pain affected state.

During the sustained shoulder flexion in the present study, the muscle activation ranged between ~5–20% $sEMG_{max}$ when the arm and the trapezius muscle from the same side acted, and between ~0.5-5% $sEMG_{max}$ on the contra-lateral side (see Figure 4). There was no significant difference in sEMG during the sustained contraction test. This finding is similar to Sohn and co-workers (2000), who found no effect on muscle activity at sustained contraction levels $\leq$20%$sEMG_{max}$. Also, this concur with Birch and co-workers (2000), as they documented that during a sustained isometric contraction of 10% MVC, no effect of pain on muscle activation was found after saline injections. Studies supporting the pain adaptation model often document a decrease in EMG when experimentally pain exists (Madeleine, et al., 1999; Schulte, et al., 2004). In Figure 5 the median frequency (MF) show no significant differences between day 1 and day 2, both for the right and left arm active, and the contra-lateral trapezius. When the left arm is active a decrease in MF is observed. An interesting result is seen when the right arm is active; the left clavicular and descending have an increase (i.e. slope) in MF on both days, however no significant difference. In the present study the sustained shoulder flexion revealed no significant differences between pain-free and pain afflicted conditions. Madeleine and co-workers (1999) found higher MF in studies of chronic

and acute experimental SNP compared to the pain free controls. Ge and co-workers (2005) also documented that EMG slope increased and MF slope decreased with muscle pain, but this study had a less negative trend of MF. In the present study, MF was used as an indicator of muscle fatigue and showed the same muscle characteristics (i.e. slope) between day 1 and day 2. One significant factor of MF is the shape of the action potentials. So, it seems that the results from the present study are the same as in a pain free state; the action potentials may have decline in amplitude and increase in duration.

The measurements and number of subjects in this study is considered sufficient for the statistical procedures, i.e. the approximately same number of subjects as used in other studies (e.g. Nie, et al., 2006; Schulte, et al., 2004). However, most subjects were students of sports science, or were generally physically active, implicating that this group was well-known with the response to unaccustomed exercise. Thus, the effects may not have evoked the same affective response in this group compared to other more sedentary groups. Moreover, the small and selected test group imply that the possibility for generalizing the results is limited. Another limitation of the study design is the lack of a control group, which could have provided more opportunities in the analyses.

In conclusion, there are two contrasting findings in this study. One supporting the pain adaptation hypothesis, i.e. reduced force on the exercised side from day 1 to day 2, indicating a reduced activation in the presence of pain, and one opposing the pain adaptation hypothesis, i.e. increased sEMG activity in the painful region of the left upper trapezius during the coordination test. The current study indicates that DOMS can result in increased muscle activity in the pain afflicted muscle region during low-level activation. However, in most of the low-level conditions, sEMG activity remained unchanged. Corresponding with previous findings, DOMS lead to a reduction in maximal force output. This study questions whether the pain adaptation model is valid for low force levels as the results give an indirect support to the vicious circle theory.

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