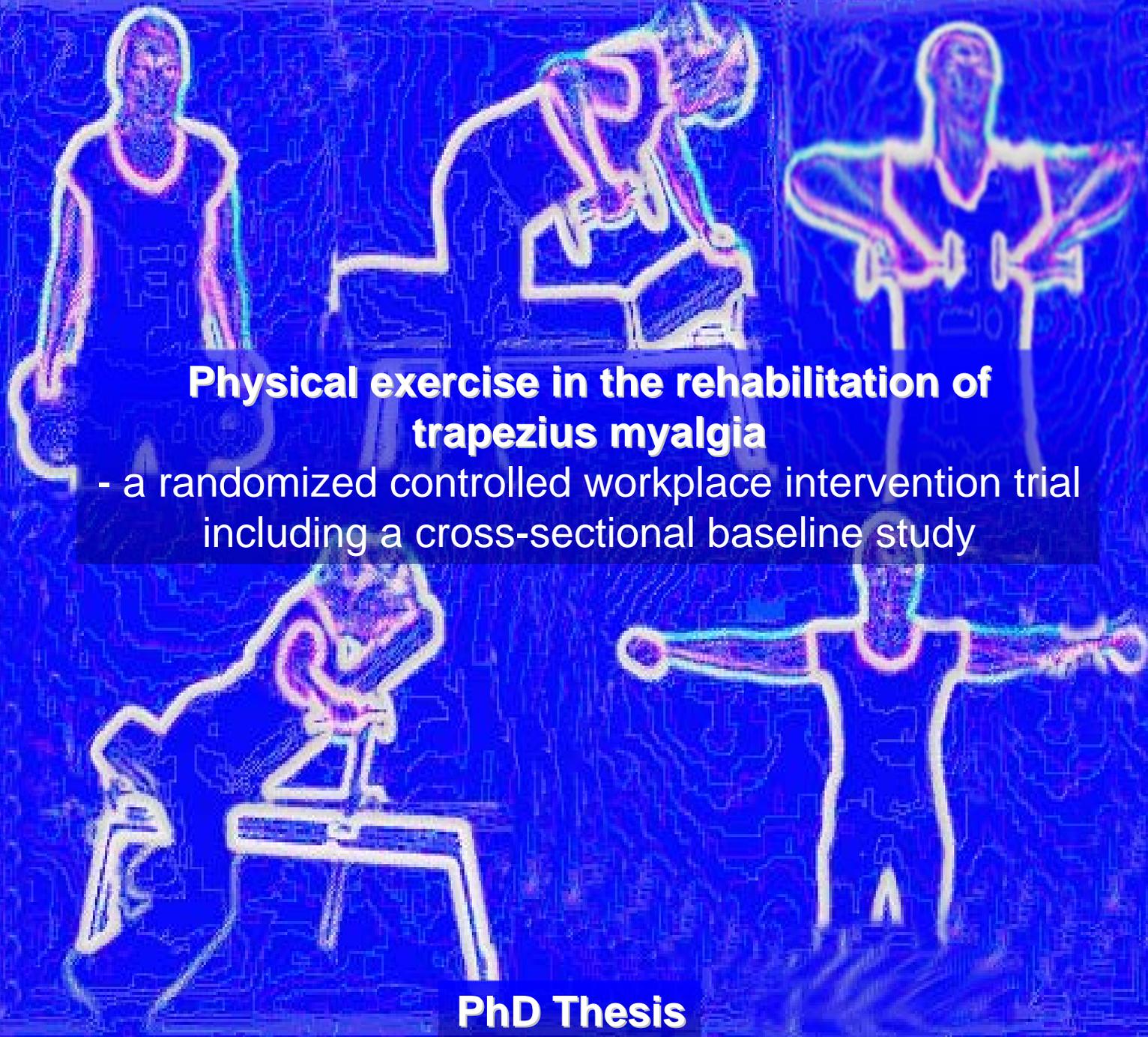




**NATIONAL RESEARCH CENTRE  
FOR THE WORKING ENVIRONMENT**



FACULTY OF HEALTH SCIENCES  
UNIVERSITY OF COPENHAGEN



## **Physical exercise in the rehabilitation of trapezius myalgia**

- a randomized controlled workplace intervention trial  
including a cross-sectional baseline study

**PhD Thesis**

**Lars L. Andersen  
National Research Centre for the Working Environment, Denmark  
2008**

**Supervisors: Gisela Sjøgaard & Michael Kjær**



PhD Thesis

**PHYSICAL EXERCISE IN THE REHABILITATION OF  
TRAPEZIUS MYALGIA**

- A RANDOMIZED CONTROLLED WORKPLACE INTERVENTION TRIAL  
INCLUDING A CROSS-SECTIONAL BASELINE STUDY

**Lars L. Andersen**

**2008**

National Research Centre for the Working Environment, Denmark



## **Preface**

The present PhD project was carried out at the National Research Centre for the Working Environment, Copenhagen, Denmark. Supervisors were Professor, DrMedSci, Gisela Sjøgaard, Institute of Sports Science and Clinical Biomechanics, University of Southern Denmark and Professor, DrMedSci, Michael Kjær, Institute for Sports Medicine, Bispebjerg Hospital, Denmark.

The studies presented in this thesis have been approved by the Local Ethical Committee (KF 01-138/04), and conforms to The Declaration of Helsinki. The intervention study qualified for registration in the International Standard Randomised Controlled Trial Number Register: ISRCTN87055459. All subjects were informed about the purpose and content of the project and gave written informed consent.

The PhD project was financed by the National Research Centre for the Working Environment and by grants received by Gisela Sjøgaard from the Danish Medical Research Council 22-03-0264 and the Danish Rheumatism Association 233-1149-02.02.04



**Lars L. Andersen,**

Copenhagen, 31 March 2008

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## List of papers

The present thesis is based on four papers. They will be referred to in the text as Study A to D (Full-length articles in Appendix).

### Study A

Andersen LL, Nielsen PK, Søgaard K, Andersen CH, Skotte J, Sjøgaard G. **Torque-EMG-velocity relationship in female workers with chronic neck muscle pain.** *J Biomech* 2008;41(9):2029-35

### Study B

Andersen LL, Suetta C, Andersen JL, Kjær M, Sjøgaard G. **Increased proportion of megafibers in chronically painful muscles.** *Pain* 2008;139:588-93

### Study C

Andersen LL, Kjær M, Søgaard K, Hansen L, Kryger AI, Sjøgaard G. **Effect of two contrasting types of physical exercise on chronic neck muscle pain.** *Arthritis & Rheumatism* 2008;59(1):84-91

### Study D

Andersen LL, Kjær M, Andersen CH, Hansen PB, Zebis MK, Hansen K, Sjøgaard G. **Muscle activation during selected strength exercises in females with chronic neck muscle pain.** *Phys Ther* 2008;88(6):703-11

## **Summary (English)**

### **Introduction**

Trapezius myalgia – chronic pain from the upper trapezius muscle – is the most frequent type of neck pain among office workers. The prevailing view is that sustained low-level activity of the upper trapezius muscle day after day leads to overload of muscle fibers of low-threshold motor units, and eventually pain develops. As a consequence, maximal muscle strength and neural activation may be impaired. Physical exercise has been suggested as treatment, however conflicting evidence exist as to which type of exercise that is most efficient.

The aim of the PhD project was, 1) in a cross-sectional study, to investigate possible differences in muscle morphology, neuromuscular activation and physical capacity between workers with and without trapezius myalgi, and 2) in an intervention study, to investigate the effect of contrasting types of physical exercise on trapezius myalgia. The overall goal was to elucidate some of the underlying mechanisms of the disorder to thereby make suggestions of potentially useful types of exercise, and finally to assess the effect of these types of exercise for treatment of trapezius myalgia.

### **Methods**

A randomised controlled intervention including a cross-sectional baseline study was performed in Copenhagen, Denmark during the years 2005 and 2006. The thesis is based on major findings from this study.

In the cross-sectional study isokinetic strength and EMG activity of the shoulder abductor muscles were measured (Study A), and muscle biopsies from the trapezius muscle were obtained and stained with traditional histochemical methods (Study B) in females with (MYA) and without (CON) trapezius myalgia.

In the intervention study (Study C) two contrasting types of physical activity were investigated: specific strength training of the neck/shoulder muscles (SST) and general fitness training performed as leg-bicycling with relaxed shoulders (GFT). All training was supervised by experienced instructors, and performed at the work place 3 x 20 min a week for 10 weeks. Training diary registrations were used to assess continuous changes in intensity of trapezius muscle pain and training load. In relation to the intervention study, validation of the strength training exercises with EMG was performed (Study D).

In both the cross-sectional and intervention study physical capacity, in terms of strength and fitness, was determined as maximal isometric muscle strength of the neck/shoulder muscles and maximal oxygen uptake estimated by a bicycle ergometer test.

### **Main findings and conclusions**

In the cross-sectional study, specific reduction of trapezius muscle activity was observed in MYA – especially during slow concentric and eccentric contraction - leading to reduced shoulder abduction torque. Further, some indications of muscle morphological differences between workers with and without myalgia were found. A higher frequency of grossly hypertrophied type I muscle fibers in female workers with myalgia – related to age and weekly working hours – suggest that prolonged exposure results in overload of these muscle fibers.

In the intervention study, SST led to marked reductions in pain intensity with a lasting effect for 10 wks after the intervention. EMG measurements showed relevant high activation of the upper trapezius in 4 out of the 5 strength exercises. GFT resulted in acute pain reduction immediately after each training session, but no prolonged effect on pain was observed. Gains in physical capacity showed specificity to the type of physical activity.

In conclusion, the most important finding is that specific strength training results in marked prolonged reductions of pain in females with trapezius myalgia.

## **Resume (Dansk)**

### **Introduktion**

Besvær i nakke/skulder regionen er vidt udbredt blandt kontorfolk, og i den forbindelse er trapezius myalgi den hyppigste form for besvær. Den mest anerkendte teori for udviklingen af myalgi er, at vedvarende muskelaktivering med lav intensitet dag efter dag kan føre til overbelastning af visse muskelfibre. Det gælder især overbelastning af de muskelfibre, der tilhører de mindste motoriske enheder, hvilket i sidste ende kan føre til smerte. Sådanne smerter kan resultere i nedsat muskelstyrke og -aktivering. Fysisk aktivitet anbefales ofte som behandling, det er dog uvist hvilken aktivitetsform der har den bedste effekt.

Formålet med nærværende ph.d. afhandling er 1) i et tværsnitsstudie, at undersøge hvilke objektive morfologiske, neuromuskulære og fysiske kapacitetsmål der adskiller arbejdstagere med og uden trapezius myalgi, og 2) dernæst i et interventionsstudie, at undersøge effekten af to forskelligartede fysiske træningsformer på trapezius myalgi. Det samlede mål med tværsnits- og interventionsundersøgelsen er at bidrage med ny viden omkring underliggende besværsmechanismer, for herigennem at begrunde hvilke træningsformer der må kunne anses at være relevante, og endelig at afprøve effekten af disse træningsformer i praksis.

### **Metoder**

Vi gennemførte i perioden 2005-2006 et randomiseret kontrolleret interventionsstudie, hvori der indgik et baseline tværsnitsstudie.

I tværsnitsstudiet sammenlignede vi kvinder med og uden trapezius myalgi. Vi målte muskelstyrke og EMG under isokinetisk skulderabduktion (Study A), samt tog muskelbiopsier fra trapezius musklen og analyserede disse med traditionelle histokemiske metoder (Study B).

I interventionsstudiet sammenlignede vi effekten af to forskellige fysiske træningsformer, nemlig specifik nakke/skulder styrketræning (SST) og generel konditionstræning, udført som cykling med afslappede skuldre på et ergometer (GFT). Træningen blev udført på arbejdspladserne 3 x 20 min per uge i 10 uger under supervision af kvalificerede instruktører. Der blev ført træningsdagbøger for at følge den tidsmæssige udvikling i smerte og træningsbelastning. I forbindelse med interventionsstudiet validerede vi styrkeøvelserne med EMG målinger. Statisk muskelstyrke og kondition blev målt i både tværsnits- og interventionsstudiet.

## **Primære fund og konklusion**

I tværsnitsstudiet fandt vi, at kvinder med myalgi har nedsat muskelstyrke, målt under isokinetisk skulderabduktion, samt reduceret muskelaktivitet specifikt for trapezius muskelen. Denne effekt var specielt udtalt ved langsom koncentrisk og excentrisk kontraktion. Endvidere fandt vi visse indikationer på muskelmorfologiske forskelle mellem kvinder med og uden myalgi. Kvinder med myalgi havde flere store type I muskelfibre – ”megafibre”. Dette fund var korreleret til alder og ugentlige arbejdstimer, hvilket indikerer at langtidseksponering resulterer i hypertrofi af enkelte muskelfibre.

I interventionsstudiet fandt vi at specifik styrketræning mindskede smerteintensiteten markant, med en varig effekt 10 uger efter træningsophør. Konditionstræning mindskede også smerteintensiteten, men kun akut og kortvarigt lige efter hvert træningspas, og i langt mindre grad end styrketræningen. Styrke- og konditionsøgningen var specifik for henholdsvis styrketrænings- og konditræningsgruppen.

Konkluderende var det vigtigste fund, at specifik styrketræning resulterede i markant smertereduktion med en blivende effekt efter interventionsophør.

## List of Abbreviations

CON	: Group of healthy controls
EMG	: Electromyography
GFT	: General fitness training
MVC	: Maximal Voluntary Contraction
MYA	: Group of females with myalgia
REF	: Reference intervention
RPE	: Rate of Perceived Exertion
SST	: Specific strength training
VAS	: Visual Analogue Scale



## **Introduction**

### **Prevalence and work relatedness of neck/shoulder disorders**

Musculoskeletal disorders comprise one of most common and costly public health problems in North America and Europe today (Punnett and Wegman, 2004), with an estimated cost between 0.5 to 2 % of the grand national product (Kilbom et al., 1996). The prevalence of neck/shoulder pain has been steadily increasing in the last decades (Hakala et al., 2002), and is now second to back pain the most common musculoskeletal disorder (Ferrari and Russell, 2003, Ihlebaek et al., 2006). More than half of all adults have experienced neck pain during the past 6 months period, and females are more likely than males to develop and suffer from persistent neck pain (Cote et al., 2004, Punnett, 2006, Jensen et al., 2002).

Epidemiologic research has provided evidence for a relationship between development of musculoskeletal disorders and physical workplace factors such as repetitive work tasks, static contractions, and tiring postures (National Research Council and Institute of medicine, 2001). Neck/shoulder pain is widespread among office workers with intensive computer use (Jensen, 2003, Juul-Kristensen et al., 2004, IJmker et al., 2006). Trapezius myalgia – chronic pain from the upper trapezius muscle – is the most frequent type of neck pain in this occupational group (Juul-Kristensen et al., 2006). The most common symptoms are sensations of localized muscle pain, tenderness at palpation, stiffness and constant muscle fatigue (Veiersted and Westgaard, 1993, Juul-Kristensen et al., 2004).

### **Strength capacity and neural activation**

Maximal muscle strength is generally impaired in many different types of neck/shoulder pain (Sjogaard et al., 2006, Brox et al., 1997, Itoi et al., 1997). Trapezius myalgia has been associated with decreased maximal muscle strength and endurance (Sjogaard et al., 2006, Larsson et al., 2000), which implies a higher relative exposure during daily work tasks. Typically, strength capacity been expressed simply as maximal static torque (Hagberg et al., 2000, Ylinen et al., 2003, Randlov et al., 1998, Sjogaard et al., 2006), while in contrast many work tasks occur in dynamic situations. Isokinetic dynamometry at various contraction modes and velocities as opposed to static contractions alone can be used to more thoroughly evaluate strength capacity. Concentric (Maas et al., 2005) and especially eccentric contractions (Kjaer,

2004, Cramer et al., 2007) have been suggested to involve high shear forces of the muscle connective tissue. Furthermore, concentric compared with static contraction involves higher cross-bridge cycling rate, energy expenditure and fatigue (Woledge et al., 1985, Vedsted et al., 2003), and eccentric contraction has been associated with ultrastructural muscle damage (Proske and Allen, 2005). Thus, concentric and eccentric contractions can be hypothesized to inhibit motor outflow in painful muscles more than static contraction. The mechanisms for decreased muscle strength in relation to neck muscle pain may be related to decreased central neural activation (Steingrimsdóttir et al., 2004) since no differences in gross muscle morphology has been observed between myalgic and healthy trapezius muscles (Larsson et al., 2001, Rosendal et al., 2004b).

It has been indicated that local pain conditions can negatively affect function of other pain free muscles when these are activated independently (Schulte et al., 2006). However, the complex nature of the shoulder joint implies that several muscles act together to provide both stability and motion (Veeger and van der Helm, 2007). For instance, during most types of shoulder joint movement the trapezius and deltoideus muscles are activated synergistically (Inman et al., 1944). Yet it is unknown whether local muscle pain negatively affects activation of pain free synergistic muscles during simultaneous activation. As a model to investigate this, maximal voluntary shoulder abduction can be performed in myalgic subjects to activate both the painful trapezius and pain free deltoideus muscle. On this background hypothesis #1 was made (see below)

### **Pathophysiological changes**

Pathophysiological changes has been observed in relation to trapezius myalgia, including increased levels of lactate and pain mediators in the interstitial space during office work task (Rosendal et al., 2004b, Larsson et al., 2007). At the cellular level abnormalities such as ragged red fibers, moth eaten fibers and COX-negative type I fibers have been reported in both healthy and myalgic trapezius muscles, albeit to a greater extent in the latter (Visser and van Dieen, 2006, Hägg, 2000). During computer work sustained low-level activity of the trapezius muscle has been reported (Blangsted et al., 2004). According to the Henneman size principle, fibers belonging to the motor units with the lowest threshold will be the first and last to be recruited and de-recruited, respectively, during a working day (Henneman and Olson, 1965). Hägg proposed that this type of prolonged exposure could lead to chronic overload of

these “Cinderella” fibers (Hagg, 1991). In support of this a positive association between a low rate of short unconscious interruptions in trapezius muscle activity during light manual work and a high risk of future trapezius myalgia has been shown (Veiersted et al., 1993).

Although muscles show a remarkable adaptability to imposed stress, muscular hypertrophy can sometimes exceed the rate of neocapillarization, thus potentially impeding oxygen delivery (Tesch, 1988). Whereas two less controlled studies have indicated that work-related myalgia are associated with hypertrophied type I muscle fibers with poor capillarization (Lindman et al., 1991, Kadi et al., 1998b), a more comprehensive study with both exposed and non-exposed healthy females as well as exposed females with myalgia found no indications of this (Larsson et al., 2001). Thus, conflicting results appears to exist.

Previous studies reported group mean values based on average type I fiber size for each individual, and therefore did not account for intra-individual variations in fiber size. However, in case of small group-differences, averaging all fibers for each subject can conceal hypertrophy of a minority of exposed muscle fibers. As a model to investigate this, intra-individual distribution of fiber size is determined in the present study. With this in mind hypothesis #2 was made (see below).

### **Strategies for combating neck/shoulder pain**

It is unlikely that occupational use of computers will decrease in the future, thus strategies for prevention for those without symptoms as well as rehabilitation for those with pain are pertinent. During the past decades, intense physical exercise has changed its reputation from being a bizarre subculture for elite athletes and bodybuilders to become a therapeutic agent for treating a vast number of chronic diseases (Pedersen and Saltin, 2006). Physical exercise has also been suggested as a treatment of musculoskeletal disorders (Haahr et al., 2005, Randlov et al., 1998, Hagberg et al., 2000). While some training studies found no effect of physical training on non-specific pain in the neck area (Viljanen et al., 2003, Takala et al., 1994) others showed that pain can to some extent be reduced by strength training (Hagberg et al., 2000, Randlov et al., 1998, Ylinen et al., 2003, Waling et al., 2000, Chiu et al., 2005, Ahlgren et al., 2001), endurance training (Ylinen et al., 2003, Waling et al., 2000, Ahlgren et al., 2001) and muscle-coordination training (Waling et al., 2000, Ahlgren et al., 2001). A dose-response relationship between the

amount of training and reduction in pain has been documented (Nikander et al., 2006), however a recent review pointed out the difficulties in attaining a high compliance in training studies (Hayden et al., 2005). Together there is moderate evidence that training intervention with neck/shoulder exercises can be beneficial upon treatment of chronic or frequent neck pain (Ylinen, 2007).

However, specific exercise of painful muscles has been shown to result in acute rise in the interstitial tissue concentrations of nociceptive substances (Rosendal et al., 2004b), and especially strength training leads to marked muscular soreness in the days following unaccustomed training (Kraemer et al., 2002). A more acceptable form of exercise for subjects with pain may be general fitness training which has been shown to induce acute transient elevations in pain threshold in non-exercised parts of the body in healthy subjects (Kemppainen et al., 1985, Droste et al., 1991), and has resulted in less use of pain medication in persons with chronic back pain (Sculco et al., 2001). It can be speculated that general fitness training without involvement of the painful muscle will result in acute pain reduction in relation to trapezius myalgia due to release of beta-endorphin (Goldfarb et al., 1990), increase in core temperature (Rakel and Barr, 2003) and increased trapezius muscle oxygenation (Hansen et al., 2006). Furthermore, it has been indicated that individuals with low back pain should refrain from local muscle training but instead focus on allround physical activity (Hurwitz et al., 2005). Thus it is suggested that muscle activity in one part of the body potentially will affect distant muscles as well (Lunde et al., 2001, Yuza et al., 2000). Supporting this, vascular adaptations in the forearm muscle beds have been found with a training regimen designed to condition the lower extremities (Silber et al., 1991), and improved endothelial vasodilatory capacity in conduit arteries of non-working limbs has been observed in response to exercise with the other limb (Tanaka et al., 2006). Thus, long-term benefits of general fitness training on trapezius myalgia can be speculated to occur. However, it remains unexplained whether specific training of the painful muscle or general fitness training without direct involvement of the painful muscle should be recommended in rehabilitation of chronic neck muscle pain. This leads to the third and fourth hypotheses of the study (see below).

## **Aim**

The aim of this PhD project was, in a cross-sectional study, to investigate possible differences in muscle morphology, neuromuscular activation and physical capacity between workers with and without myalgia, and in an intervention study, to investigate the effect of contrasting types of physical exercise interventions on pain in relation to trapezius myalgia. The specific aims were to determine

- isokinetic and static muscle strength, and EMG activity of the painful trapezius and pain-free deltoideus muscles in workers with and without myalgia (Study A)
- trapezius muscle fibre characteristics based on traditional histochemical analysis of muscle biopsies in workers with and without myalgia (Study B)
- the acute and prolonged changes in neck/shoulder pain in response to specific strength training, general fitness training performed as leg-bicycling with relaxed shoulders, and a reference intervention without physical activity in female workers with trapezius myalgia (Study C)
- the level of trapezius muscle activation during strength training exercises for the neck/shoulder muscles (Study D)



## Hypotheses

In the baseline cross-sectional study, female workers with trapezius myalgia compared with matched healthy controls have

1. lower activity of both their painful trapezius and synergistic pain free deltoideus muscle during maximal voluntary shoulder abduction, resulting in lower external torque, especially during dynamic (i.e. concentric and eccentric) compared with static contraction (Study A)
2. a higher proportion of grossly hypertrophied type I muscle fibers (Study B)

In the intervention study,

3. intensity of pain increases and decreases acutely immediately after each session of strength training and general fitness training, respectively (Study C)
4. over a 10 week period, strength training and general fitness training will be equally effective in reducing intensity of pain in females with trapezius myalgia, and both types of physical exercise will be superior to the reference intervention (Study C)

Further, we expected that several of the strength training exercises used in the present study would result in relevant high levels of EMG activity in the trapezius muscle (Study D)



## Methods

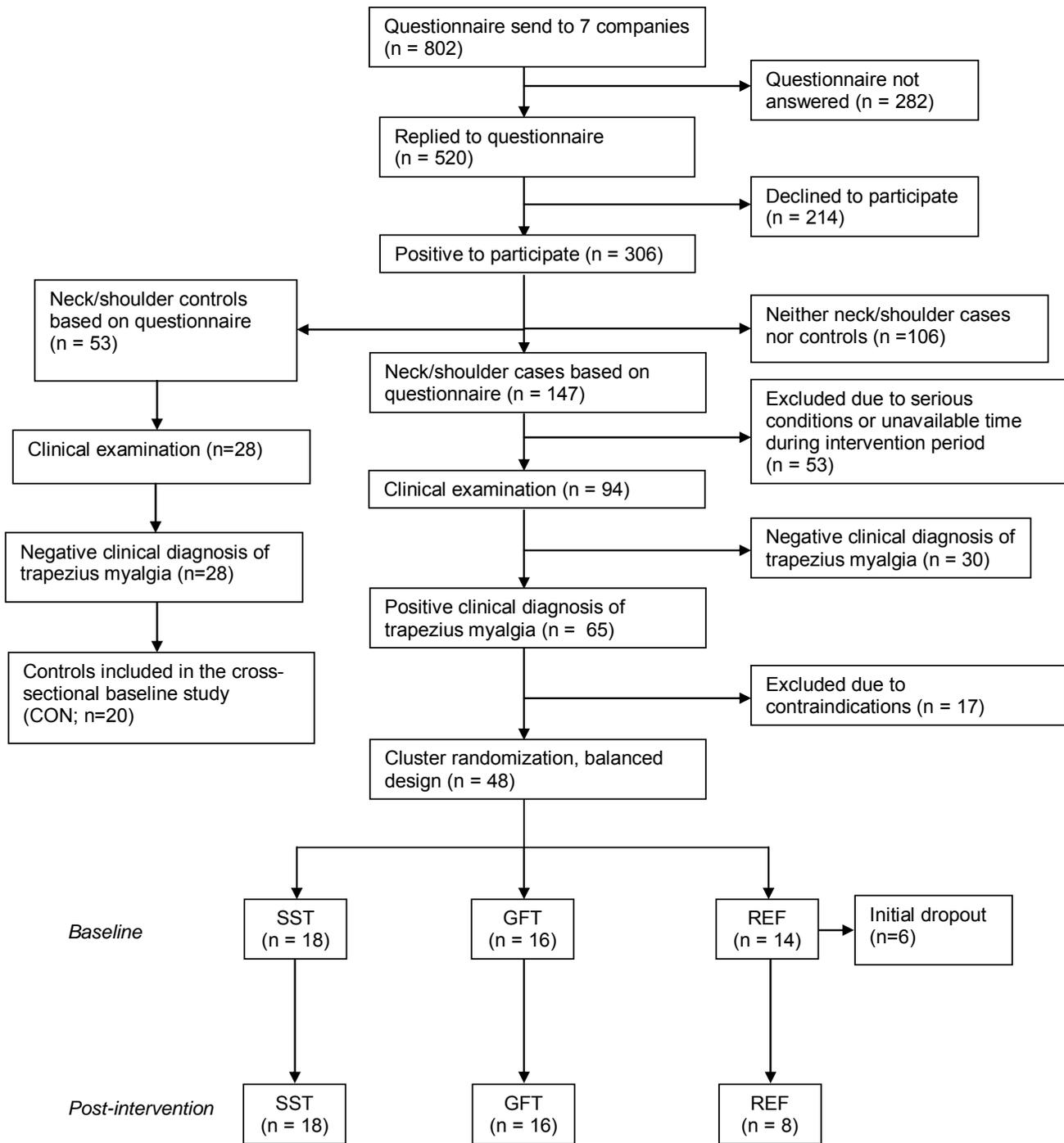
### Study Overview

A randomized controlled intervention trial (Study C) including a baseline cross-sectional study (Studies A+B) and a validation study (Study D) was performed in Copenhagen, Denmark, during the period from September 2005 until June 2006. From a questionnaire survey among 802 female employees (age 30-60 years) at 7 companies (two banks, two post office work places, two different national administrative offices and one industrial production unit), and subsequent clinical examination, 42 workers with trapezius myalgia (MYA) and 20 matched workers without (CON), were recruited for participation in the study. All females were engaged in job types with high prevalence of neck/shoulder complaints, and 82% worked at the computer and 79% used a keyboard for more than  $\frac{3}{4}$  of the working time.

The flow of participants through the study is shown in Fig. 1, and is described in more detail below. An overview of the methods used in the studies is summarized in Table 1 and described in more detail below. Baseline anthropometrical measures, age, weekly working hours, pain intensity (scale 0-9, from questionnaire) and pain duration (days during last year, from questionnaire) are given in Table 2.

<b>Study</b>	<b>A</b>	<b>B</b>	<b>C</b>	<b>D</b>
Females with myalgia (M)/controls (C)	M/C	M/C	M	M
Cross-sectional study	X	X		
Intervention study			X	
Validation study				X
Questionnaire	X	X	X	X
Clinical examination	X	X	X	X
Pain intensity	X	X	X	X
RPE	X			
Isokinetic dynamometry	X			
EMG	X			X
MVC		X	X	
Fitness		X	X	
Muscle biopsies		X		

**Table 1. Overview of the methods used in Studies A, B, C and D**



**Fig. 1. Flow chart of recruitment, clinical examination and intervention.**

	CON	MYA
Age (yrs)	44 ± 8.8	44 ± 8.4
Weight (kg)	71 ± 11	72 ± 14
Height (m)	1.67 ± 0.07	1.66 ± 0.06
BMI (kg·m <sup>-2</sup> )	25 ± 3.0	26 ± 5.0
Weekly working hours	38 ± 11	37 ± 5.2
Pain intensity (0-9)	0.9 ± 1.4	5.0 ± 1.7*
Pain duration (days)	5.4 ± 6.5	219 ± 131*

**Table 2. Baseline characteristics of females with myalgia (MYA) and the control group (CON). \*) MYA > CON, P<0.0001, Mean ± SD**

## Questionnaire

First step of recruitment included a reply to a screening questionnaire on general musculoskeletal complaints. Neck/shoulder cases were defined as: 1) Pain or discomfort for more than 30 days during the last year in the neck or shoulder region but no more than three body regions of such trouble in order to exclude generalised musculoskeletal diseases, 2) the trouble should be at least “quite a lot” on an ordinal 5-step scale of “a little”, “somewhat”, “quite a lot”, “much” and “very much”, 3) the trouble should be frequent (at least once a week on an ordinal scale of “seldom”, “once a week”, “2-3 times per week”, “almost all the time”), and 4) the intensity of the trouble should be at least 2 on a scale from 0 – 9, where 0 is no pain and 9 is the worst imaginable pain (Kryger et al., 2003, Kaergaard et al., 2000, Von Korff et al., 1992). Screening questionnaire exclusion criteria were serious conditions such as previous trauma or injuries, life threatening diseases, cardiovascular diseases or arthritis in the neck and shoulder. Finally they should respond to the questionnaire that they were interested to participate. Correspondingly, neck/shoulder controls should have pain or discomfort for less than 8 days during the last year in the neck/shoulder region at a pain intensity of 2 or less, and no more than three other body regions with more than 30 days of trouble.

## Clinical examination

In all 147 females fulfilled the neck/shoulder case inclusion criteria, and of these 53 were excluded due to the above exclusion criteria or due to unavailable time during the intervention period. In total 94 neck/shoulder cases participated in a clinical neck and upper limb examination. This examination was performed by a team of two physicians and three physiotherapists and was originally developed by Ohlsson et al.

(Ohlsson et al., 1994) and later modified as described in detail previously (Juul-Kristensen et al., 2006). Briefly, the main criteria for a positive clinical diagnosis of trapezius myalgia were 1) pain in the neck area, 2) tightness of the trapezius muscle, and 3) palpable tenderness of the trapezius muscle. Those who based on this examination qualified for trapezius myalgia and did not show contraindications corresponding to the overall exclusion criteria listed above following detailed interview were invited for the study (n=48). Unfortunately 6 participants in this group withdrew from the study after the clinical examination, leaving a total of 42 participants in MYA. Potential participants in the baseline control group went through the same clinical examination (CON; n=20).

### **Randomization of participants in MYA (Study C)**

The participants in MYA were allocated to three different intervention groups: specific strength training (SST), general fitness training performed as leg-bicycling with relaxed shoulders (GFT), and a reference group without physical activity (REF). These interventions are described in detail below. The participants were randomized at the cluster level to one of the three groups in a balanced design accounting for similar age, BMI and screening questionnaire report on neck/shoulder trouble. The time wise successive balanced recruitment resulted in a somewhat smaller REF group, e.g. due to withdrawal of participants who initially stated they would volunteer for the study. In total 42 females ( $44 \pm 8$  yrs,  $165 \pm 6$  cm,  $72 \pm 15$  kg) clinically diagnosed with trapezius myalgia participated in the intervention study.

### **Pain and perceived exertion**

In all four studies pain scores were registered, either as a VAS pain score (Study A + C), a 0-9 scale pain intensity based on questionnaire replies (Study B+D), or pain duration based on questionnaire replies (Study B). Further, the rate of perceived exertion was registered in Study A.

Study A: Intensity of pain in the trapezius muscle was rated by each subject on a 100 mm visual-analogue-scale (VAS), where 0 mm is “no pain” and 100 mm is “worst imaginable pain” (Huskisson, 1974). Perceived exertion locally in the trapezius muscle was rated on the Borg CR-10 scale where 0 is “nothing at all” and 10 is “extremely strong” (Borg, 1990). Pain and perceived exertion was registered at rest prior to and immediately after the dynamometer test.

Study B + D: Intensity and duration of pain based on the questionnaire replies was reported.

Study C: VAS pain intensity in GFT and SST was recorded in a training log in each of the 30 training sessions. Five parameters were noted, 1) pain in general since the last training session, 2) pain at worst since the last training session, 3) pain immediately before the present training session, 4) pain immediately after the present training session, 5) pain 2 hrs after the present training session. The first two parameters were used to evaluate the prolonged effect of training and the last three to assess the acute effect of training. The REF group filled in a logbook on 1) and 2) above on Mondays, Wednesdays, and Fridays at noon.

The *prolonged* effect of the interventions was determined as the continuous change over time in 2 pain parameters: General and worst pain since the last training session. Furthermore, to assess the effect of detraining, general and worst pain in the preceding week was noted once a week for 10 successive wks after the post-intervention test in all three groups.

The *acute* effect of training on pain in SST and GFT was determined as the difference between VAS pain immediately before and immediately after each training session, as well as the difference between VAS pain immediately before and 2 hrs after each training session. To evaluate the acute effect separately during the first and second half of the training period the statistical analyses were performed separately for training session 1-15 and 16-30, respectively.

### **Isokinetic Dynamometry (Study A)**

A Biodex Medical isokinetic dynamometer (System 3 Pro, Brookhaven R&D Plaza, New York, USA) was used for testing of shoulder joint function. Subjects were seated in a height adjustable chair with back support. The centre of rotation of the shoulder joint (defined as 5 cm below the acromion) was aligned to the centre of rotation of the dynamometer arm, by adjusting the height and forward-backward direction of the dynamometer. Shoulder abductions - in a plane that was 15° from the frontal plane - were performed during a range of motion of 15-135° (anatomical angle) (Fig. 2).



After warm-up and preconditioning to the dynamometer maximal muscle contractions were performed. Verbal encouragement and visual feedback on a computer screen were provided during all contractions. Four maximal attempts with rest periods of 60 s in between were performed during

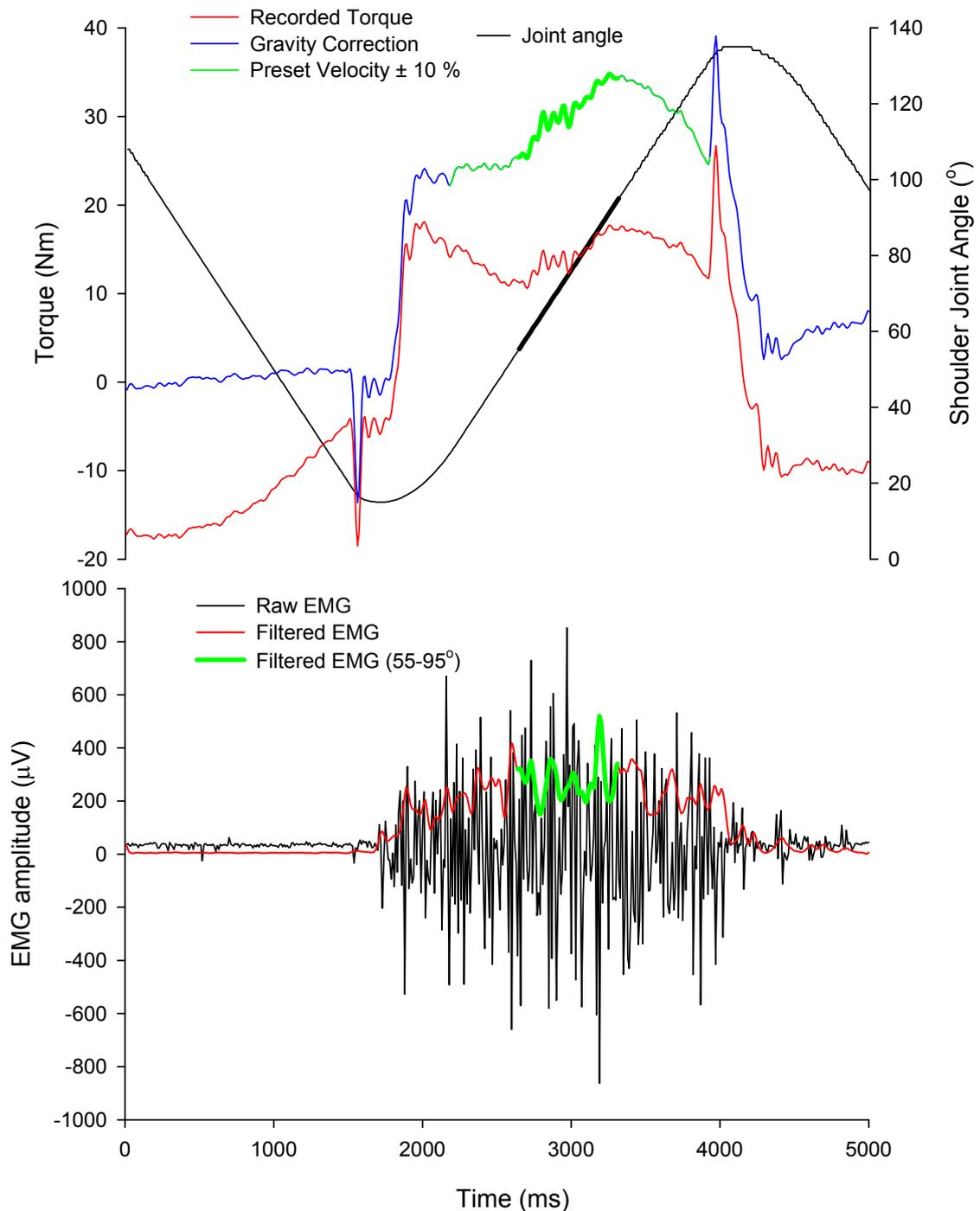
- 1) slow concentric contraction ( $60^{\circ}\cdot\text{s}^{-1}$ )
- 2) fast concentric contraction ( $180^{\circ}\cdot\text{s}^{-1}$ ),
- 3) slow eccentric contraction ( $-60^{\circ}\cdot\text{s}^{-1}$ )
- 4) static contraction (at  $75^{\circ}$ ).

**Fig. 2. Testing of isokinetic muscle strength**

All torque and position signals were sampled synchronously at 1000 Hz using a 16-bit A/D-converter (DAQ Card-AI-16XE-50, National Instruments, USA) and stored on a laptop for further analysis.

During off-line analyses all torque and position signals were filtered by a 12 and 8 Hz lowpass 4<sup>th</sup> order Butterworth filter, respectively. Subsequently, the torque signal was corrected for the effect of gravity on the subjects arm by adding the passive torque of the arm to the sampled torque signal. The passive torque of the arm for any given joint position was calculated as the passive torque measured at  $90^{\circ}$  multiplied by sine to the respective shoulder joint angle. Velocity correction was performed by excluding all data points where the angular velocity was 10 % above or below the preset velocity. Shoulder joint angular velocity was calculated by differentiation of the dynamometer position signal. For the isokinetic test the average moment in the midrange of motion (i.e.  $55\text{-}95^{\circ}$ ) was calculated and used for further analyses (Fig. 3). For the static test at  $75^{\circ}$  the highest average torque value over 500 ms was used.

### Isokinetic torque and EMG



**Fig. 3. A representative recording of torque, position and EMG during slow ( $60^\circ\text{s}^{-1}$ ) concentric contraction. The analyzed range of motion of  $55\text{-}95^\circ$  is marked in bold. *Above:* The recorded torque signal (red tracing) was corrected for the effect of gravity on the subjects arm (blue tracing). After gravity correction only values within the preset velocity  $\pm 10\%$  were included in the further analysis (green tracing). The dynamometer position signal (black tracing) was used as an estimate of shoulder joint angle. *Below:* Simultaneous recording of raw EMG (black tracing). The filtered EMG are shown as well (red tracing). Values within the range of motion of  $55\text{-}95^\circ$  (green tracing) were averaged for further analysis.**

## **Electromyography (EMG) (Study A + D)**

During the tests described above EMG signals were recorded synchronously from the upper trapezius muscle and the mid part of the deltoideus muscle with a bipolar surface EMG configuration (Neuroline 720 01-K, Medicotest A/S, Ølstykke, Denmark) and an inter-electrode distance of 2 cm. Before affixing the electrodes, the skin of the respective area was prepared with scrubbing gel (Acqua gel, Meditec, Parma, Italy) to effectively lower the impedance to less than 10 k $\Omega$ . For the trapezius muscle the electrodes were positioned 2 cm medially from the midpoint between acromion and the seventh cervical vertebrae. The medial part of the deltoid muscle was located by palpation, and the electrodes were placed at a distance  $\frac{1}{4}$  from the acromion to the olecranon (Hermens and Freriks, 1997). The EMG electrodes were connected directly to small pre-amplifiers located near the recording site. The raw EMG signals were led through shielded wires to instrumental differentiation amplifiers, with a bandwidth of 10-500 Hz and a common mode rejection ratio better than 100 dB, sampled at 1000 Hz using a 16-bit A/D-converter (DAQ Card-AI-16XE-50, National Instruments, USA) and stored on a laptop for further analysis.

During off-line analysis all raw EMG signals were digitally filtered using linear EMG envelopes, which consisted of 1) high-pass filtering at 10 Hz, 2) full-wave rectification and 3) low-pass filtering at 10 Hz. The filtering algorithms was based on a fourth-order zero phase lag Butterworth filter (Winter, 1990). For the isokinetic contractions the filtered EMG was averaged during a 55-95° range of motion (Fig. 3) (Study A). For the static contraction EMG was averaged over the 500 ms with the highest average torque (Study A + D). For each contraction of the training exercises in SST (Fig. 7) the highest value of integrated EMG over any 500 ms interval was used as peak EMG. During these exercises peak EMG for each of the 2 x 3 repetitions was determined, and the average value of these six repetitions was then normalized to the peak EMG obtained during MVC of each respective muscle (Study D).

The power spectral density of the EMG signals was calculated as the median power frequency (MPF) in epochs of 750 ms (slow and static contraction) and 500 ms (fast contraction) centred between the 55-95° range of motion. The power density spectra were estimated by Welch's averaged, modified periodogram method in which each

epoch was divided in eight Hamming windowed sections with 50% overlap (Study A).

### **MVC (Study B + C)**

Maximal voluntary contractions (MVC) were performed during shoulder-elevation (Fig. 4) and shoulder-abduction according to a standardised procedure (Essendrop et al., 2001). For shoulder elevation and abduction strength the participant was sitting upright in a height adjustable chair, and two Bofors dynamometers were placed bilaterally 1 cm medial to the lateral edge of the acromion (Jensen et al., 1993, Sogaard et al., 1996) and 1 cm proximal from the olecranon of the elbow joints (Backman et al., 1995), respectively. The lever arm length was measured as the horizontal distance from the cervical spine to the middle of the strain gauge dynamometer for shoulder elevation, and from the middle of the strain gauge dynamometer to the acromion minus 5 cm for shoulder abduction. The participant was instructed to gradually build up the force over 5 s, then to keep the maximal force for about 2 s and finally to lower the force slowly to zero. The MVC's were performed at least three times for each exercise. If the third recording was more than 5% higher than the previous two recordings, a fourth test was performed, and a maximum number of five tests were performed. Strong verbal encouragement was given during all trials. During later analyses torque was calculated as force times lever arm length. The individual adjustment of the testing equipment was registered and used during the post-intervention test. There was no statistical significant difference between left and right shoulder strength at baseline or with the intervention, therefore the average value of left and right shoulder are reported.

**Fig. 4. MVC during shoulder elevation**

### **Fitness (Study B + C)**

Åstrand's standardized method was used to estimate aerobic fitness (maximal oxygen uptake;  $\text{VO}_2\text{-max}$ ) during a submaximal workload provided by a bicycle ergometer (Monark, model Ergomedic 874E) (Åstrand, 1960). The starting workload was estimated based on age and level of activity, and was typically 30-90 watts at a cadence of 60 revolutions/min. Heart rate was measured using a heart rate monitor ("POLAR Sport tester", Polar Electro OY, Kempele, Finland). If the heart rate was less than 110 within the first min the workload was increased. It was aimed to achieve a heart rate of 60 % of maximal heart rate reserve capacity, and at least 120

beats/min. If heart rate had reached steady state (i.e. difference < 5 beats/min) between the 5<sup>th</sup> and 6<sup>th</sup> min the test was terminated and the final heart rate was registered. Otherwise the subject continued the test until steady state was reached, with a maximum duration of 10 min. Subsequently, the workload and corresponding heart rate were used to estimate maximal oxygen uptake using the Åstrand-Rhyming nomogram with correction for age (Åstrand and Rodahl, 1986). Maximal oxygen uptake was normalized to bodyweight ( $\text{ml O}_2 \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$ ).

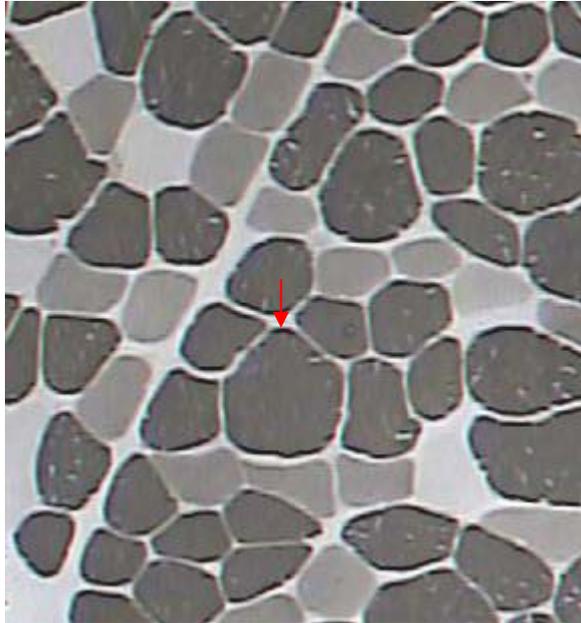
### **Muscle biopsies (Study B)**

After thorough ultrasound scanning needle muscle biopsies were obtained from the upper trapezius muscle 2 cm lateral to the midpoint between the 7<sup>th</sup> cervical vertebrae and the acromion. The tissue samples were mounted with Tissue-Tek within 2-3 min, frozen in isopentane pre-cooled with liquid nitrogen, and stored in a freezer at  $-80^\circ\text{C}$  until processed. All biopsy samples were given a unique identification number and blinded. Transverse serial sections ( $10 \mu\text{m}$ ) of the embedded muscle biopsy were cut in a cryostat (Microm, Germany) ( $22^\circ\text{C}$ ) and mounted on glass slides. Standard ATPase analysis was performed after preincubation at pH values of 4.37, 4.61 and 10.30 (Brooke and Kaiser, 1970). The biopsy sections were visualized on a computer screen using a Carl Zeiss light microscope (Zeiss Axiolab), a JVC high-resolution color digital camera (JVC, TK-C1381EG) and an 8-bit Matrox Meteor Framegrabber (Matrox Electronic Systems, Quebec, Canada). Quantitative analysis of all muscle samples for fiber type percentage, fiber cross-sectional area (CSA), capillaries per fiber (CAF), and capillaries per fiber CSA (CAFA) was performed using a digital image analysis program (TEMA 1.04, Scanbeam, Hadsund, Denmark). All values are reported for type I and II fibers separately.

For each subject the distribution of fiber CSA in intervals of 0-500, 500-100, ..., 3500-4000  $\mu\text{m}^2$  around the individual median value was determined, and calculated as a percentage of the total number of fibers for that subject. This was done separately for type I and II fibers. For each interval of 500  $\mu\text{m}^2$  the group mean percentage was then determined.

To quantify the proportion of grossly hypertrophied muscle fibers we introduce the term “megafiber”. A type I megafiber was defined as a fiber being at least twice the median CSA of all the type I fibers for that particular subject. E.g. if the median type I fiber CSA for that particular subject was 4900  $\mu\text{m}^2$  then individual fibers  $>9800$

um2 was defined as type I megafibers. The same procedure was applied for the type II fibers. The percentage of type I and II megafibers was quantified for each individual and used for further statistical analysis. A representative picture with type I megafiber is shown in Fig. 5.



**Fig. 5. ATPase staining (pH 4.61) from a trapezius muscle biopsy. The arrow points at a type I megafiber.**

### **Muscle thickness (Study A)**

The thickness of the trapezius muscle was measured during rest with an ultrasound scanner fitted with a 12 MHz linear matrix transducer (LOGIC 7, M12L, GE-Medical). Gain settings were standardized and kept constant. The subjects were sitting upright in a chair with the hands on their lap and relaxed shoulders. Contact gel was used for acoustic coupling and care was taken not to exert undue pressure on the imaged tissue. The transducer was placed perpendicular to the trapezius muscle at the midpoint between the seventh cervical vertebrae and acromion. Muscle thickness was measured as the vertical distance of the muscle at the mid-part of the image (Fig. 6).



**Fig. 6.** An ultrasound image of the trapezius muscle, showing thickness at the mid-part of the image. Above and below the muscle is the subcutaneous layer of fat and spina scapulae, respectively.

### **Interventions (Study C)**

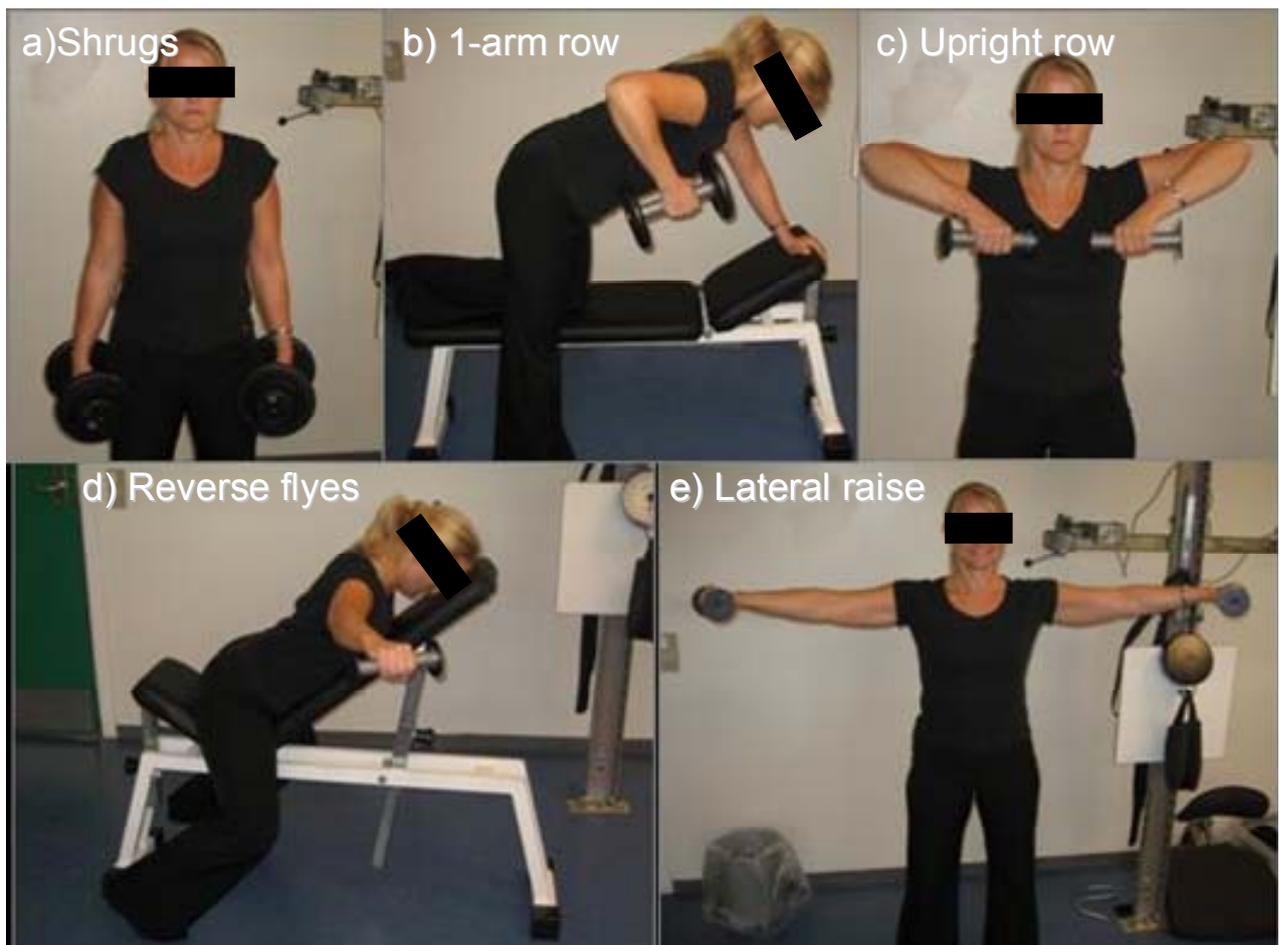
In all three intervention groups the total time allowed to spend on the project equated one hour per week. In SST and GFT supervised training was performed with a high intensity for 20 min 3 times a week (on Mondays, Wednesdays, and Fridays) for 10 wks, which has previously been shown to be a sufficient intervention period to achieve significant adaptations (Hagberg et al., 2000, Waling et al., 2000). The REF group was also allocated a total of one hour per week but met more irregular with lectures giving information on general health promoting activities.

**SST** (n=18) performed supervised high-intensity specific strength training locally for the neck and shoulder muscles with five different dumbbell exercises, one-arm row, lateral raise, shrugs, reverse flyes and upright row (Fig. 7). EMG during these exercises was measured in Study D:

- a) Shrugs. The subject is standing erect and holding the dumbbells to the side, and then elevates the shoulders while focusing on contracting the upper trapezius muscle (Fig. 7a).
- b) One-arm row. The subject is bending her torso forward to approximately 30° from horizontal with one knee on the bench and the other foot on the floor. The

subject now pulls the dumbbell towards the ipsilateral lower rib, while the contralateral arm is maintained extended and supports the body on the bench (Fig. 7b).

- c) Upright row. The subject is standing erect and holding the dumbbells while the arms are hanging relaxed in front of the body. The dumbbells are lifted towards the chest in a vertical line close to the body while flexing the elbows and abducting the shoulder. The elbows are pointing out- and upwards (Fig. 7c).
- d) Reverse flies. The subject is lying on the chest at a 45° angle from horizontal with the arms pointing towards the floor. The dumbbells are raised until the upper arm is horizontally, while the elbows are in a static slightly flexed position (~5°) during the entire range of motion (Fig. 7d).
- e) Lateral raise. The subject is standing erect and holding the dumbbells to the side, and then abducts the shoulder joint until the upper arm is horizontally. The elbows are in a static slightly flexed position (~5°) during the entire range of motion (Fig. 7e).



**Fig. 7. The strength exercises used in SST: Shrugs (a), one-arm row (b), upright row (c), reverse flies (d), and lateral raise (e)**

During the intervention period the training load was progressively increased according to the principle of periodization and progressive overload (Kraemer et al., 2002). Relative loadings were progressively increased from 12 repetitions maximum (RM) (~70% of maximal intensity) at the beginning of the training period towards 8 RM (~80% of maximal intensity) during the later phase (Table 3).

	Session (SST)						
	1-4	5-10	11-14	15-18	19-22	23-26	27-30
<b>Repetitions</b>	12,12	12,12,12	12,10,10	12,10,8	10,8,8	12,10,8	10,8,8

**Table 3. Progression table for the specific strength training group**

Absolute loads – i.e. weight of the dumbbells - were individually increased to meet the intended relative level. The strengthening exercises were performed in a conventional manner using consecutive concentric and eccentric muscle contractions, i.e. raising and lowering the pair of dumbbells in a controlled manner without pause or breaks, and each set of 8-12 repetitions typically lasted 25-35 s. Three of the five different exercises with three sets per exercise were performed during each training session in an alternating manner, with shrugs being the only exercise that was performed during each session. E.g. during the first training session 1-arm row, shrugs and shoulder abduction were performed, during the second session reverse flies, shrugs elevation and upright row were performed, and then starting over again during the third session.

**GFT** (n=16) performed high-intensity general fitness training with the legs only on a



Monark bicycle ergometer for 20 min at relative workloads of 50-70 %  $VO_2$ -max. The subjects bicycled in an upright position without holding onto the handlebars (Fig. 8). It was emphasized that the subjects in GFT should relax the shoulders during training.

**Fig. 8. Bicycling in GFT with relaxed shoulders**

A relative workload of 50 % of VO<sub>2</sub>-max was used during the initial training sessions and the intensity was progressively increased towards 70% during the following weeks and maintained at that intensity throughout the remaining training period (Table 4).

	Session (GFT)				
	1-3	4-6	7-9	10-12	13-30
<b>Intensity</b>	50%	55%	60%	65%	70%

**Table 4. Progression table for the general fitness training group**

The relative workload was estimated based on the known relationship between heart rate, HR, and oxygen uptake, i.e.  $\text{relative workload} = (\text{working HR} - \text{resting HR}) / (\text{max HR} - \text{resting HR})$ , where resting HR was set to 70 bpm and max HR was estimated as 220–age. Heart rate was recorded in each subject by a heart rate monitor (Polar Sport Tester, Kempele, Finland) during each training session to adjust the workload to meet the intended relative level.

**REF** (n=8) received an equal amount of attention as the physical training intervention groups but not offered any physical training. These females received health counselling on group level and individual level with regard to work place ergonomics, diet, health, relaxation and stress management for a total of up to one hour per week. The staff of physiotherapists and physiologists from our department gave these lectures. Some lectures lasted up to one hour and could thus not be performed regularly three times a week to keep the total allocated time equal between intervention groups.

## Statistics

In all four studies SAS version 9.1 was used for the statistical analyses. Analysis of variance was performed using the MIXED procedure, which allows both cross-sectional as well as paired longitudinal data to be analyzed. Post hoc tests with appropriate corrections for multiple comparisons were performed when a significant main effect was found. An alfa level of 5 % was considered statistically significant.

In *Study A* factors included in the model for torque and EMG were *group* (MYA and CON), *velocity* (-60, 0, 60 and 180°·s<sup>-1</sup>), and *group by velocity*. Factors included in

the model for pain and perceived exertion was *group* (MYA and CON), *time* (before and after dynamometer test), and *group by time* interaction.

In *Study B* differences in fibre size between MYA and CON were tested with two-way ANOVA. Factors included in the model were *group* (MYA, CON), *fiber type* (type I and II), and *group by fiber type*. Differences in the percentage of megafibers were tested using non-parametric Mann-Whitney test. Differences in the proportion of subjects with and without megafibers were tested using chi-square test. Multiple regression analysis was performed to determine the association between the proportion of megafibers and the other main variables (pain duration and intensity, age, working hours per week).

In *Study C* the change in VAS-pain was evaluated with a variance component model with random subject effect corresponding to repeated measures ANOVA and the assumption of compound symmetry. Variables included in the model were *group* (GFT, SST, REF; class variable) and *time* (1-30; continuous variable resulting in linear regression analyses), as well as *group by time*.

In *Study D* one-way analysis of variance was performed for each muscle to determine whether differences existed in the level of muscle activation across the five different exercises.

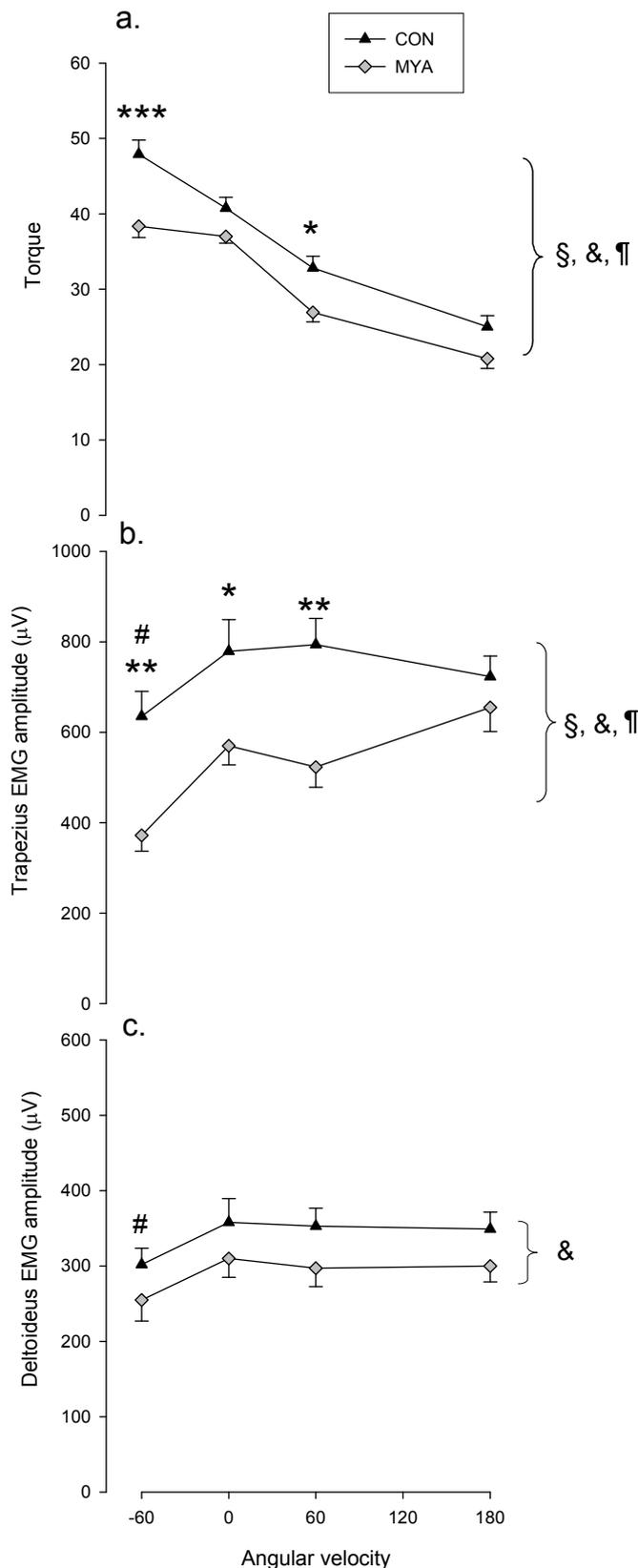
## Results

There were no significant differences in anthropometrical measures, age and weekly working hours between female workers with (MYA) and without (CON) myalgia (Table 2). However, differences between MYA and CON were observed at the muscle cellular level and during tests of maximal muscle strength. Further, in the intervention study differences were observed between the group that performed specific strength training (SST) and general fitness training (GFT) regarding acute and prolonged pain response, and for gains in physical capacity. A detailed description of these results is given below.

### Isokinetic Torque and EMG (Study A)

During isokinetic shoulder abduction there was a significant *group by velocity* effect for both torque ( $P < 0.001$ ) and trapezius EMG amplitude ( $P < 0.001$ ). Post hoc tests showed that MYA compared with CON developed significantly lower shoulder joint torque during slow concentric ( $27 \pm 1.3$  vs.  $33 \pm 1.6$  Nm,  $P < 0.05$ ) and eccentric contraction ( $38 \pm 1.5$  vs.  $48 \pm 1.9$  Nm,  $P < 0.001$ ) (Fig. 9a). EMG amplitude was significantly lower during eccentric ( $P < 0.01$ ), slow concentric ( $P < 0.01$ ) and static contraction ( $P < 0.05$ ), but not during fast concentric contraction (Fig. 9b). No significant difference in deltoideus EMG amplitude was found between MYA and CON for any of the tests (Fig. 9c).

For trapezius EMG MPF there was a significant *group by velocity* interaction ( $P < 0.001$ ). Post hoc tests showed that MPF was significantly higher in CON compared with MYA at fast concentric contraction only ( $72.6 \pm 2.1$  vs.  $61.3 \pm 1.5$  Hz,  $P < 0.01$ ) (Table 5). For deltoideus MPF there was a significant *group* effect, CON was significantly higher compared with MYA ( $P < 0.01$ ) (Table 5).



**Fig. 9. Torque-velocity (a) and EMG-velocity for the trapezius (b) and deltoideus muscles (c). Group mean  $\pm$  SE. A priori hypothesis testing of main effects: §) Significant *group x velocity* ( $P > 0.001$ ); &) Significant *velocity* ( $P < 0.001$ ); ¶: Significant *group* (CON > MYA,  $P < 0.05$ ); Post-hoc analysis of *group x velocity* effect: \*, \*\* and \*\*\* CON > MYA,  $P < 0.05$ ,  $P < 0.01$  and  $P < 0.001$ , respectively; *velocity* effect: #)  $-60 < 0, 60, 180^\circ\text{s}^{-1}$  in both MYA and CON ( $P < 0.01$ ).**

		Velocity				
		-60	0	60	180	
MPF (Hz)	Trapezius §	CON	62 ± 1.8	67 ± 1.6	66 ± 1.5	73 ± 2.1
		MYA	60 ± 1.0	63 ± 1.1	61 ± 1.2	61 ± 1.5*
	Deltoideus ¶	CON	87 ± 1.9	93 ± 1.6	85 ± 2.5	83 ± 2.8
		MYA	79 ± 1.5	86 ± 1.4	78 ± 1.5	76 ± 1.6

**Table 5. Median Power Frequency (Hz). A priori hypothesis testing of main effects: §) Significant *group x velocity* ( $P > 0.01$ ); ¶: Significant *group* (CON > MYA,  $P < 0.01$ ); Post-hoc analysis of *group x velocity* effect: \*) CON > MYA,  $P < 0.01$ ; Group mean ± SE.**

### **Muscle morphology and muscle biopsies (Study A+ B)**

Ultrasound scanning of gross muscle morphology showed that overall trapezius muscle thickness was not significantly different between MYA ( $9.8 \pm 0.3$  mm) and CON ( $9.1 \pm 0.3$  mm). Likewise, when all type I and II fibers, respectively, for each individual were averaged according to standard procedures there were no significant group mean differences for the fiber CSA, CAF, and CAFA (Table 6).

However, differences were observed when intra-individual differences in fiber size were analyzed. MYA compared with CON showed a significantly higher proportion of type I megafibers ( $0.94 \pm 1.7$  % vs.  $0.15 \pm 0.45$  %,  $P < 0.05$ ), but not of type II megafibers (Table 6). The percentage of subjects with at least one type I megafiber was significantly higher in MYA compared with CON (46 % vs. 11 %,  $P < 0.01$ ) (Table 6). CAFA was significantly lower in type I megafibers compared with the overall type I fiber pool ( $P < 0.001$ ) (Table 6). Multiple regression analysis showed that in MYA the percentage of megafibers was related to age ( $\beta = 0.44$ ,  $P < 0.01$ ) and weekly working hours ( $\beta = 0.32$ ,  $P < 0.05$ ) with a total explained variance of 29% ( $R^2 = 0.29$ ,  $P < 0.01$ ).

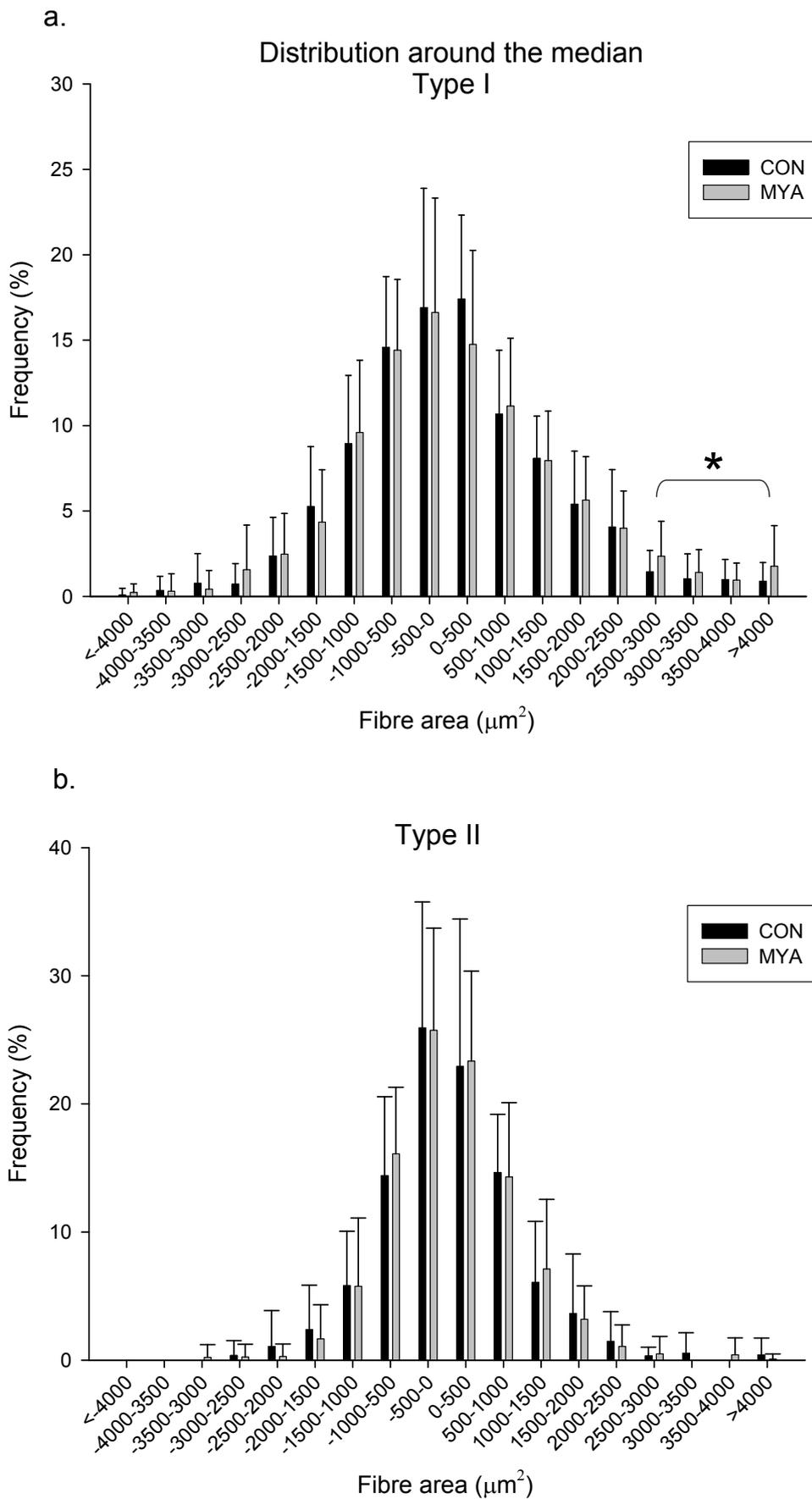
A priori hypothesis testing of main effects showed that there was a significantly different distribution of fiber size around the median for type I compared with type II fibers (pooled for MYA and CON,  $P < 0.001$ ). For type II fibers the distribution around the median was narrower compared with type I fibers (Fig. 10a vs. b). There was not a statistically significant group differences for distribution of fiber sizes around the median for either fiber type. However, MYA compared with CON had a significantly higher proportion of type I fibers larger than  $2500 \mu\text{m}^2$  above individual

median values ( $6.5 \pm 5.2$  vs  $4.4 \pm 2.9\%$ ,  $P < 0.05$ ) (Fig. 10a). No such difference was observed for type II fibers ( $1.0 \pm 2.3$  vs  $1.3 \pm 2.7\%$ , n.s.) (Fig. 10b).

In both groups type I fibers compared with type II fibers had significantly higher CSA and CAF, but not CAFA (Table 6).

		Fiber type	
		I	II
Fibertype <sup>&amp;</sup> (%)	CON	67 ± 11	33 ± 11
	MYA	69 ± 11	31 ± 11
CSA <sup>&amp;</sup> (μm <sup>2</sup> )	CON	5057 ± 1120	4000 ± 1104
	MYA	5193 ± 1110	3501 ± 977
CAF <sup>&amp;</sup>	CON	4.2 ± 0.74	3.2 ± 0.72
	MYA	4.1 ± 0.87	2.8 ± 0.70
CAFA	CON	0.89 ± 0.15	0.84 ± 0.17
	MYA	0.83 ± 0.14	0.86 ± 0.20
Megafibers (%)	CON	0.15 ± 0.45	0.16 ± 0.47
	MYA	0.94 ± 1.70*	0.34 ± 0.88
CAFA, Mega fibers		0.52 ± 0.18 <sup>§§</sup>	0.60 ± 0.32 <sup>§</sup>
Megafibers present (% of subjects)	CON	11%	11%
	MYA	46%*	17%

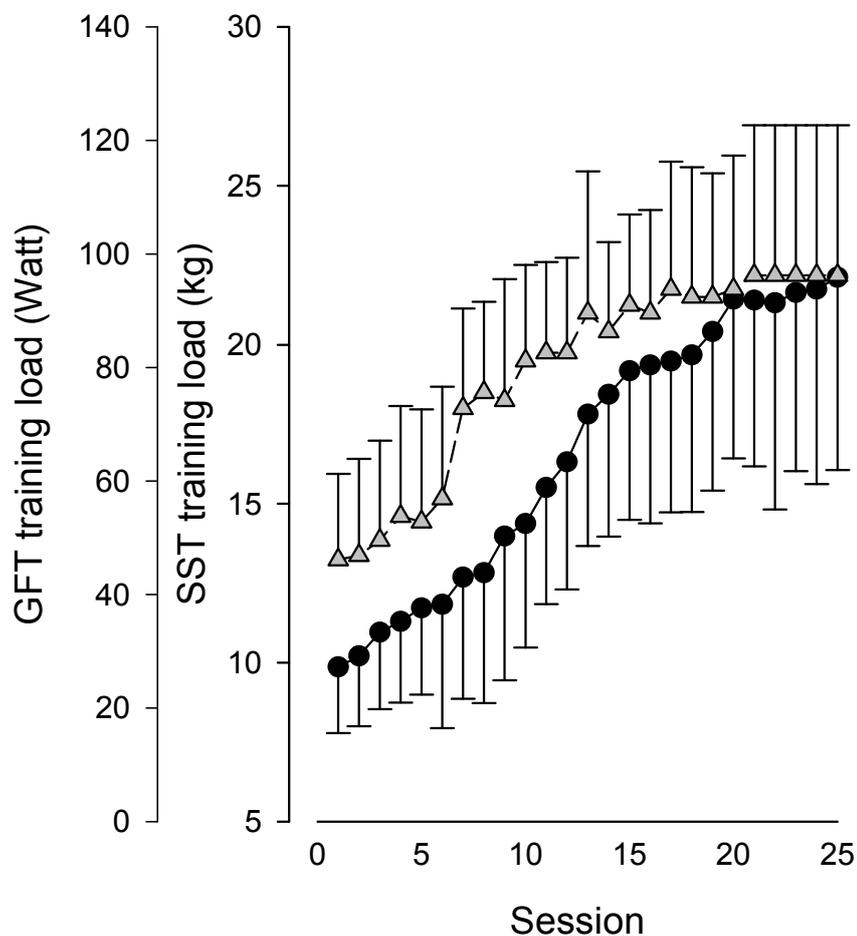
**Table 6. Fiber type percentage, fiber cross-sectional area (CSA), capillaries per fiber (CAF), capillaries per fiber cross-sectional area (CAFA), percentage of megafibers, CAFA in megafibers, and percentage of subjects with at least one megafiber in females with myalgia (MYA) and healthy controls (CON). Group mean ± SD, \*) MYA > CON ( $P < 0.05$ ), §§) CAFA type I Megafibers < CAFA type I (pooled for CON and MYA) ( $P < 0.0001$ ), §) CAFA type II Megafibers < CAFA type II (pooled for CON and MYA) ( $P < 0.05$ ), &) Type I > type II (pooled for CON and MYA) ( $P < 0.001$ )**



**Fig. 10. CSA distribution around the median for type I (a) and type II fibers (b) for females with myalgia (MYA) and controls (CON). Group mean  $\pm$  SD. \*) MYA > CON (P<0.05)**

### Training and compliance (Study C)

30 training sessions were planned during the 10 wk intervention period. The actual number of training sessions and pain registrations were  $25 \pm 4.8$ ,  $26 \pm 3.6$  and  $27 \pm 2.8$  for GFT, SST and REF, respectively. The training load in both GFT and SST increased linearly with time, and was doubled by the end of the 10 wks of training which confirmed the high compliance documented in the training logbooks of the participants for the respective training programs (Fig. 11).



**Fig. 11. Training load in SST and GFT was progressively increased throughout the training period to values that were approximately twice the initial level. Group mean  $\pm$  SD**

## MVC and fitness (Study B + C)

At baseline MVC during shoulder elevation but not shoulder abduction was significantly lower in MYA compared with CON. Fitness was also significantly lower in MYA (Table 7). In response to the 10 wk intervention VO<sub>2</sub>-max was increased 21 % in GFT from 28 ± 6 to 33 ± 7 ml O<sub>2</sub>·min<sup>-1</sup>·kg<sup>-1</sup> (P<0.001), whereas no statistical change occurred in the other groups. Isometric muscle strength increased significantly in SST during shoulder-elevation (right side: 30 %, left side: 29 %) and shoulder-abduction (right side: 28 %, left side 29 %) (Table 8).

		MYA	CON
Shoulder elevation (Nm)	L	53 ± 17	68 ± 14*
	R	54 ± 19	69 ± 17*
Shoulder abduction (Nm)	L	42 ± 13	48 ± 16
	R	40 ± 12	46 ± 14
Fitness (ml O <sub>2</sub> ·min <sup>-1</sup> ·kg <sup>-1</sup> )		30 ± 7	36 ± 8*

**Table 7. Muscle strength and fitness in females with myalgia (MYA) and healthy controls (CON). MVC peak torque was measured during shoulder elevation and abduction for the left (L) and right (R) shoulder. \*) MYA < CON (P<0.01). Group mean ± SD**

	VO <sub>2</sub> -max (ml O <sub>2</sub> ·min <sup>-1</sup> ·kg <sup>-1</sup> )	Shoulder Elevation (Nm)		Shoulder Abduction (Nm)	
		Right	Left	Right	Left
GFT Pre	28 ± 6	52 ± 18	55 ± 15	40 ± 10	41 ± 11
GFT Post	33 ± 7*	57 ± 21	55 ± 14	39 ± 15	41 ± 17
SST Pre	31 ± 7	58 ± 21	56 ± 16	42 ± 15	43 ± 16
SST Post	33 ± 8	75 ± 19*	72 ± 20*	53 ± 16*	56 ± 16*
REF Pre	33 ± 9	48 ± 22	44 ± 20	37 ± 8	37 ± 9
REF Post	35 ± 7	58 ± 18	49 ± 16	41 ± 7	42 ± 7

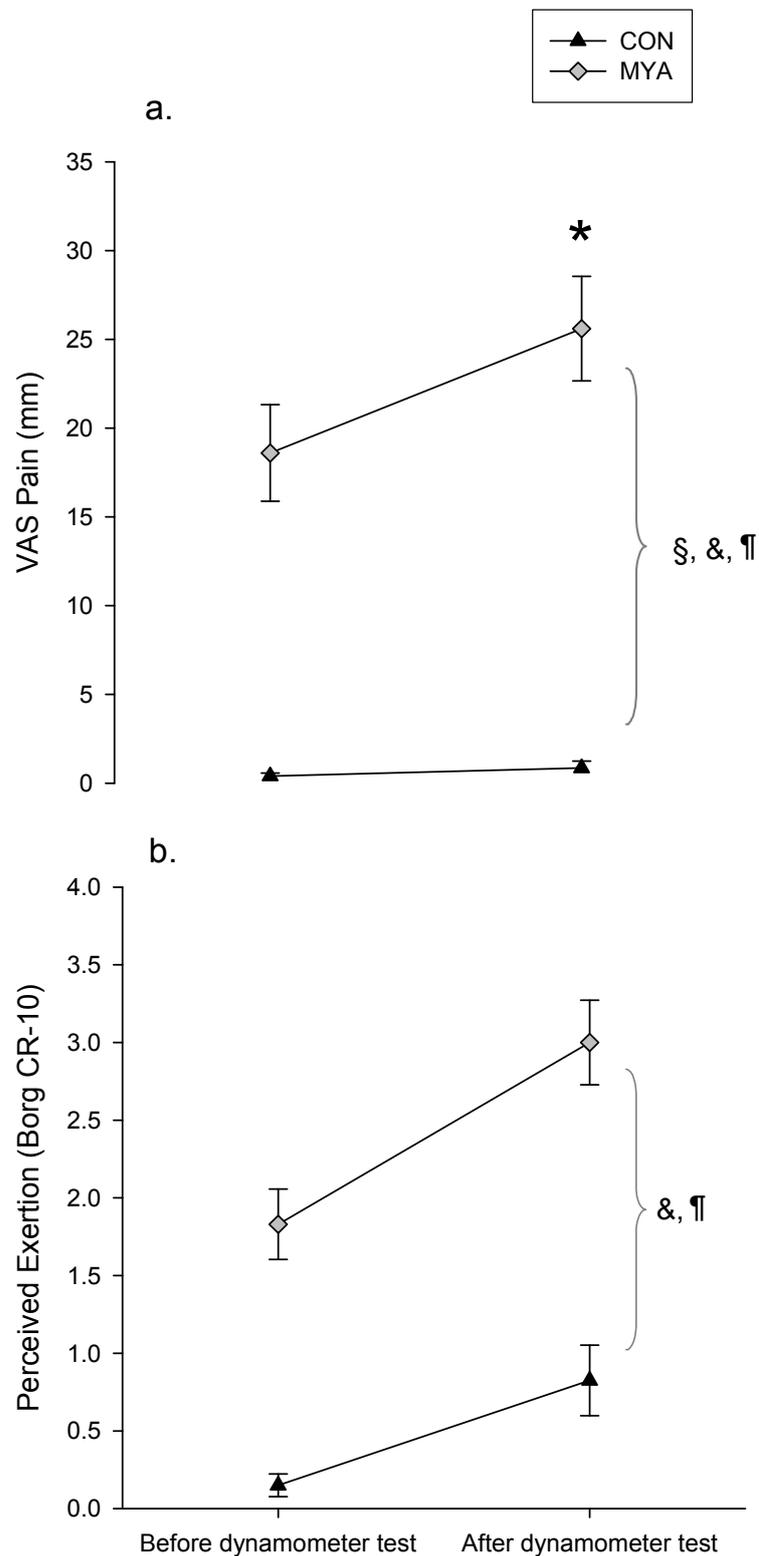
**Table 8. Fitness (VO<sub>2</sub>max) and maximal muscle strength (Shoulder elevation and abduction) pre and post the 10 wk intervention. The strength training group (SST) increased muscle strength, whereas the general fitness training group (GFT) increased fitness (VO<sub>2</sub>-max), \*) significantly different from pre-training value, P<0.001. Group mean ± SD.**

## **Pain and perceived exertion (Study A + B + C)**

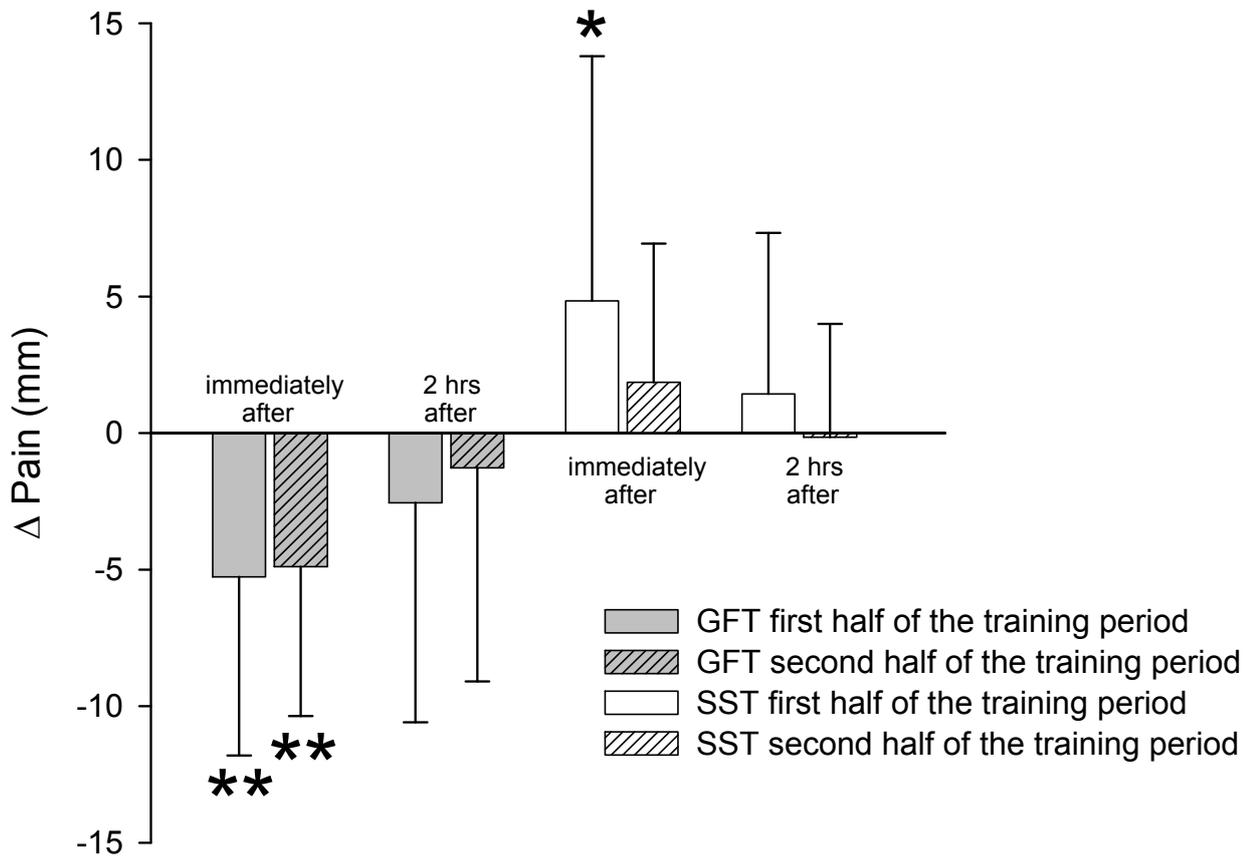
Based on the questionnaire replies pain intensity and pain duration during the last year was significantly higher in MYA compared with CON at baseline (Table 2). Likewise, pain intensity and perceived exertion at present was higher in MYA compared with CON both at rest immediately before and after the isokinetic dynamometer test ( $P < 0.0001$ ) (Fig. 12a+b). Whereas both groups increased perceived exertion in response to the dynamometer test ( $P < 0.0001$ ) (Fig. 12b), only MYA increased pain ( $P < 0.0001$ ) (Fig. 12a).

During SST an acute increase in pain in response to each training session was evident during the first half of the intervention period ( $4.8 \pm 8.9$  mm,  $P < 0.05$ ), but not during the second half. In contrast, GFT reduced intensity of pain acutely both during the first ( $-5.3 \pm 6.5$  mm,  $P < 0.01$ ) and second half ( $-4.9 \pm 5.5$  mm,  $P < 0.01$ ) of the 10 wk intervention period (Fig. 13). Two hours after the training sessions the acute effect in both groups had levelled off, i.e. the level of pain was back to levels that was not significantly different from those immediately prior to the training session (Fig. 13).

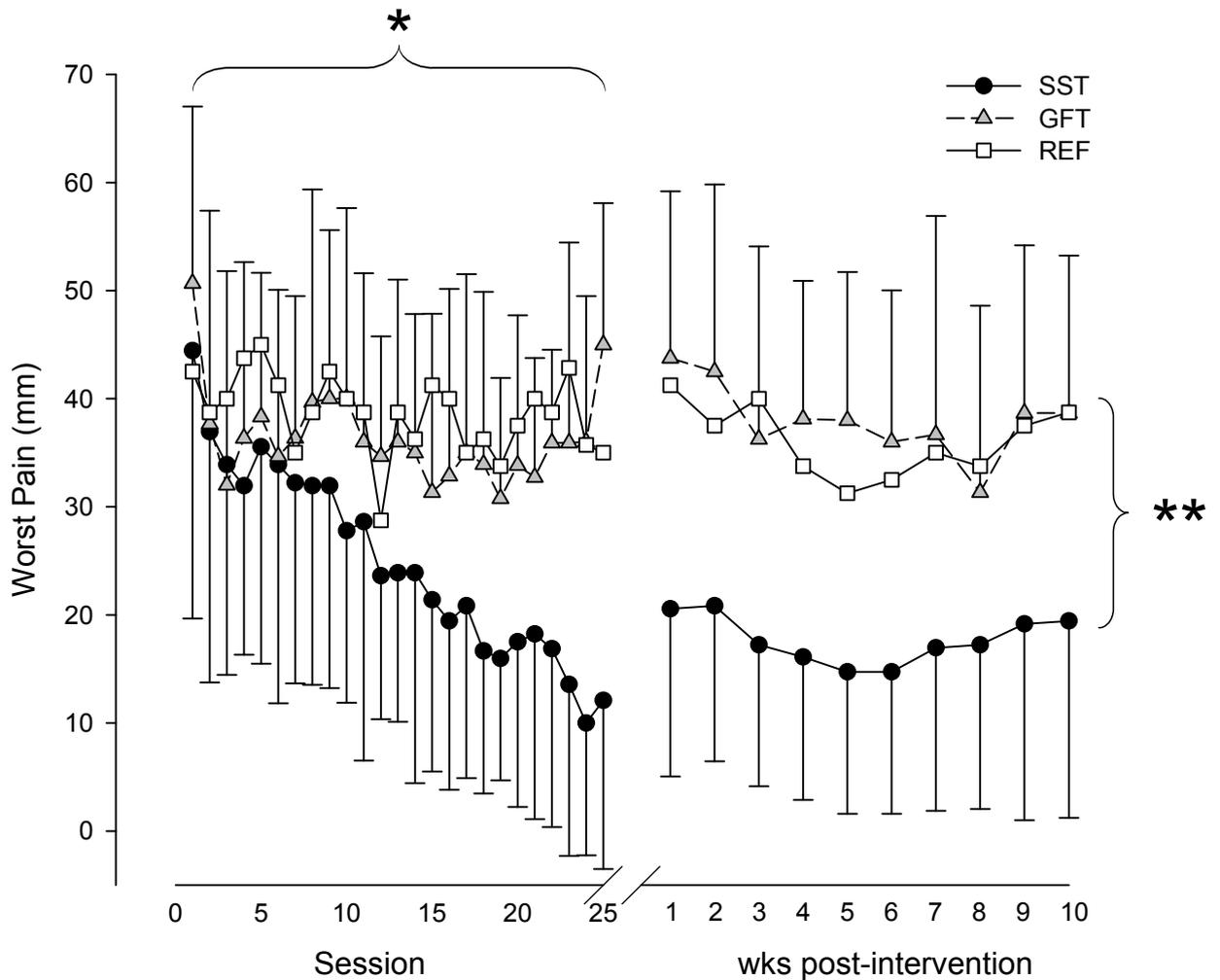
In contrast to the acute response, SST alone decreased worst and general pain 35 and 20 mm, respectively, at the VAS-scale over the 10 wk intervention period (Fig. 14). 17 of the 18 subjects in that group decreased in pain. In SST the rate of decrease of the pain was  $-1.03 \pm 0.30$  mm/session ( $P < 0.0001$ ) and  $-0.58 \pm 0.22$  mm/session ( $P < 0.0001$ ) for worst and general pain, respectively. On the contrary, no significant change over time was observed in GFT and REF. During the 10 wk post-intervention follow-up period no change in pain occurred in any of the three groups, and SST remained at a level that was significantly lower than GFT and REF ( $P < 0.001$ ) (Fig. 14).



**Fig. 12.** Neck pain and perceived exertion before and after the dynamometer test. Group mean  $\pm$  SE. A priori hypothesis testing of main effects: §) Significant *group x time*; &) Significant *time* (after dynamometer > before dynamometer test,  $P < 0.0001$ ); ¶: Significant *group* (MYA > CON,  $P < 0.0001$ ); Post-hoc analysis of *group x time* effect: \*) after Biodex > before Biodex test in MYA,  $P < 0.0001$ .



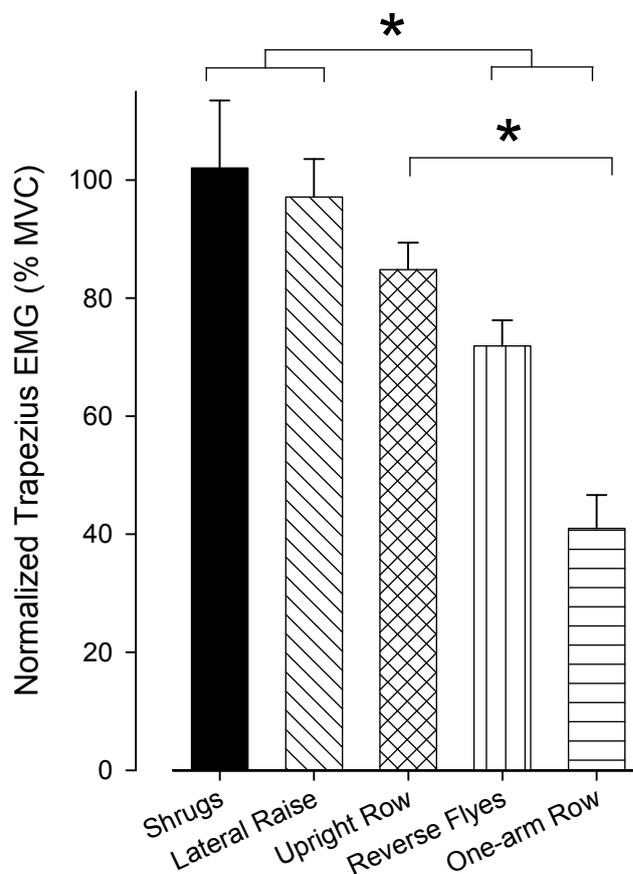
**Fig. 13. Acute pain response to training. Pain in the trapezius muscle decreased immediately after bicycling (GFT) throughout the training period (\*\*,  $P < 0.01$ ), however the effect lasted for less than 2 hrs. In contrast, pain was increased immediately after strength training (SST) during the first half of the training period (\*,  $P < 0.05$ ), but not during the second half. This acute adverse effect of SST lasted less than 2 hrs. Group mean  $\pm$  SD.**



**Fig. 14. Prolonged pain response to training.** Trapezius muscle pain (worst pain since last session, group mean  $\pm$  SD) decreased in the strength training group (SST) during the 10 wk intervention period (left), whereas no change over time occurred in the other two groups (GFT and REF). During the 10 wk post-intervention period (right) pain was unchanged in all three groups, and remained at a level that was statistically lower in SST compared with GFT and REF ( $P < 0.001$ ). \*) Significant *time by group* effect ( $P < 0.0001$ ), *Time* effect: SST ( $P < 0.0001$ ), \*\*) *Group* effect: SST < GFT, REF ( $P < 0.001$ ).

## Validation of SST exercises with EMG (Study D)

Numbers in parentheses express EMG during the respective exercises normalized to EMG during MVC, which was  $971 \pm 88$  uV for the upper trapezius muscle. The level of trapezius muscle activation was statistically higher during shrugs ( $102 \pm 11$  %) and lateral raise ( $97 \pm 6$  %) compared with reverse flyes ( $72 \pm 4$  %) and one-arm row ( $41 \pm 6$  %) ( $P < 0.01$ ), and furthermore during upright row ( $85 \pm 5$  %) compared with one-arm row ( $41 \pm 6$  %) ( $P < 0.01$ ) (Fig. 15). Although shrugs and lateral raise were numerically higher than upright row this was not statistically significant ( $P = 0.14$ ).



**Fig. 15.** The highest level of activation in the trapezius muscle was found during shrugs and lateral raise. \*) indicates significant difference in normalized EMG between exercises ( $P < 0.01$ ). Group mean  $\pm$  SE

## Discussion

The main findings of the present PhD project are: 1) females with trapezius myalgia compared with healthy controls show specific reduction of trapezius muscle activity during maximal shoulder abduction, and increased proportion of grossly hypertrophied type I muscle fibers, 2) whereas acute intensification of pain occur in response to high-intensity muscle contraction, general fitness training relieve pain immediately, 3) while general fitness training show no long-term benefit on pain, specific strength training lead to marked prolonged reductions in pain intensity. These results are discussed below.

### Muscle strength and neural activation

The first hypothesis – *“females with trapezius myalgia have lower activity of both their painful trapezius and synergistic pain free deltoideus muscle during maximal voluntary shoulder abduction, resulting in lower external torque”* - was partially confirmed. In Study B we found that muscle strength was lower during static shoulder elevation but not abduction in MYA compared with CON. Since the trapezius muscle is prime mover during shoulder elevation, this finding indicates selective inhibition of the painful trapezius muscle during maximal muscle contraction. This topic was investigated further in Study A during functional dynamic movement with simultaneous EMG sampling in the trapezius and deltoid during maximal isokinetic shoulder abduction. MYA compared with CON displayed lower shoulder abduction torque, as well as lower activation of their painful trapezius but not of their pain free deltoid muscle. The hypothesis of differences being more pronounced during concentric and eccentric than static contraction was only partially confirmed. Whereas trapezius EMG, but not torque, was significantly lower during static contraction in MYA compared to CON, no significant differences were observed during fast concentric contraction. However, the most consistent differences – in terms of both torque and EMG - were found during slow concentric and eccentric contractions. In conformity with previous findings (Rosendal et al., 2004b) the strength deficit in MYA was not related to gross muscle morphological factors.

Selective inhibition of the painful trapezius muscle is likely due to excitation of group III and IV sensory afferents. These nociceptors are normally excited by noxious chemical stimuli or excessive mechanical stress, however hypersensitivity can occur in conditions of pain (Graven-Nielsen, 2006). In Study A torque - and thus

mechanical muscle force - was lowest during fast concentric contraction, which may explain that no significant inhibition occurred. In contrast, pain inhibition of the trapezius muscle was significant during contractions with high torque, i.e. static and slow dynamic contraction. However this resulted in significantly lower torque only during the latter. High shear forces of the muscle connective tissue has been suggested to occur especially during eccentric (Kjaer, 2004) but also concentric contraction (Maas et al., 2005). In study B MYA showed higher proportions of grossly hypertrophied type I muscle fibers. Larger muscle fibers generate more power than neighbouring smaller fibers, which can be speculated to amplify the level of shear force and thus pain. Together, these factors may explain that differences between MYA and CON were more consistent during slow concentric and eccentric contraction. In contrast, no significant inhibition of the pain free deltoideus was observed in MYA compared with CON, indicating specific inhibitory feedback of painful muscles only.

The present findings confirm the basic idea of the pain adaptation model proposed by Lund, i.e. that pain inhibits agonist muscle activity as a protective mechanism (Lund et al., 1991). However, Lund also proposed that inhibition may occur even when pain is not arising from the muscle itself. In contrast, the present results showed that local trapezius pain inhibited activity specifically of this muscle, but not significantly of the synergistic pain free deltoid muscle. Of note is that the pain level in the present participants were moderate, and perhaps more severe pain conditions could affect function also of synergistic muscles as well as during other types of functional muscle activities.

In Study A EMG MPF during isokinetic contraction was generally lower in MYA compared with CON. Previous studies have shown that MPF increased (Moritani and Muro, 1987), decreased (Westbury and Shaughnessy, 1987) or remained unchanged in response to increased force levels (Petrofsky and Lind, 1980). The interpretation of the present finding is therefore not straightforward. Most studies agree that MPF decreases with fatigue (Rosendal et al., 2004a, Bigland-Ritchie et al., 1981). Thus, the present findings may be related to generally higher sensations of perceived exertion - even at rest - in females with myalgia. Differences in muscle fibre properties and levels of motor unit synchronization may also influence these findings. Whereas overall type I fiber size was not significantly different between groups, type II fiber size tended to be smaller in MYA compared with CON (Study B). This latter finding

may explain a lower MPF in MYA, since conduction velocity and thus MPF are known to be inversely related to fiber size.

### **Muscle fibre characteristics**

The second hypothesis – “*females with myalgia have a higher proportion of grossly hypertrophied type I muscle fibers*” – was confirmed. Whereas no significant differences were observed for gross muscle morphology in Study A and overall fiber type characteristics in Study B, some interesting observations were made when accounting for intra-individual differences in fibre size. With this novel method we showed in Study B that females with trapezius myalgia have a higher proportion of grossly hypertrophied type I muscle fibers – “megafibers”.

In agreement with previous studies we showed that type I fibers of healthy and painful trapezius muscles were generally larger compared with type II fibers (Lindman et al., 1991, Kadi et al., 1998b, Larsson et al., 2001), whereas the opposite has been reported for male forest machine operators and power lifters (Kadi et al., 1999, Kadi et al., 1998a). This may reflect specific adaptations to the work demands imposed on the muscle. The present study further showed a wider distribution of fiber size around the median for type I compared with type II fibers. Together these findings indicate a more heterogeneous stimulation pattern of type I fibers and/or that the high threshold motor units of these females are seldom stimulated. Type I fibers covers more than two thirds of all fibers in the trapezius muscle, and during intensive computer work where this muscle work continuously at intensities below 5% of maximal capacity (Blangsted et al., 2004), only a few of many type I muscle fibers are activated (Henneman and Olson, 1965). Thus, hypertrophy of only a fraction of all fibers in response to this type of stimulus would be expected, which is compatible with the present finding. Whereas no group differences were observed based on average type I fiber size for each subject as also reported by Larsson and coworkers (Larsson et al., 2001), we showed that this traditional method of analysis – i.e. averaging of all fibers for each subject - conceal a minority of grossly hypertrophied fibers. Type I megafibers were on average larger than  $10.000 \mu\text{m}^2$ . In comparison trapezius type I fiber size of healthy and highly resistance trained males are on average less than  $6000 \mu\text{m}^2$  (Kadi et al., 1999). Clearly, the present females did not engage in heavy load strength training, and the results simply demonstrate the high intra-individual variation in fiber size – a factor that should be looked upon also in future studies. Whether the present finding reflects a pathological condition or

functional adaptation to chronic stimuli of low-threshold motor units is yet to be determined.

Capillarization of megafibers was poor indicating increased reliance on anaerobic metabolism. During repetitive low-intensity work task increased levels of lactate in females with myalgia have been reported – a finding that was associated with intensity of pain (Rosendal et al., 2004b). It can be speculated that prolonged local acidosis due to poor capillarization of megafibers causes or enhances pain conditions. Hypertrophy can exceed neocapillarization in response to training when the aim is to increase muscle mass (Tesch, 1988). In such situations hypertrophy is advantageous since it affects mainly type II fibers of motor units producing short burst of high activity followed by long rest periods. However, marked hypertrophy of type I fibers of low-threshold motor units can hamper local oxygen delivery during prolonged low-intensity work.

Although present in half of the females in MYA type I megafibers were relatively rare, constituting approximately one percentage of all fibers. In comparison other morphological abnormalities such as cytochrom oxidase negative fibers have been observed in similar proportions, whereas ragged red fibers are even more rare (Kadi et al., 1998b). The presence of type I megafibers were significantly associated with age and weekly working hours, which indicates a dose-response relationship. Although the present study does not provide direct evidence of the Cinderella hypothesis, it demonstrates a higher proportion of megafibers in females with myalgia and that long-term exposure enhances this trend. Whether pain arises from these fibers is yet to be determined.

### **Acute pain response to exercise**

The third hypothesis – *“intensity of pain increases and decreases acutely immediately after each session of strength training and general fitness training, respectively”* – was confirmed. In Studies A and C evidence was presented of acute intensification of pain in response to high intensity muscle contractions in MYA. In Study C acute intensification of pain was observed in response to unaccustomed dynamic strength training. In Study A increased perceived exertion in response to the dynamometer test was observed in both groups, whereas parallel increases in pain and perceived exertion were observed in MYA alone. Together, this indicates that females with myalgia have impaired sensation to distinguish between development

pain and perceived exertion, and that physical exertion provokes pain increase in painful muscles. Similar findings have been reported during low-force work tasks of long duration (Rosendal et al., 2004a). This argues that alternative exercise methods should be looked upon. This was the case in Study C where we introduced exercise with large muscle groups without direct involvement of the painful muscle, i.e. general fitness training performed as bicycling with relaxed shoulders. While this type of exercise decreased intensity of pain acutely, the effect was of minor clinical relevance (i.e. < 10mm) and lasted less than 2 hrs. Likely explanations for a statistical significant reduction of pain in response to general fitness training may be related to release of beta-endorphin (Goldfarb et al., 1990), increase in core temperature (Rakel and Barr, 2003) and increased trapezius muscle oxygenation (Hansen et al., 2006). Unfortunately, this type of exercise showed no long-term benefit on pain reduction, and can therefore not be recommended as effective long-term treatment of trapezius myalgia.

### **Prolonged pain response to exercise intervention**

The fourth hypothesis – *“over a 10 week period strength training and general fitness training will be equally effective in reducing intensity of pain in females with trapezius myalgia, and both types of physical exercise will be superior to the reference intervention”* – was rejected.

In the baseline cross-sectional studies it was found that muscle strength and fitness was significantly lower in MYA compared with CON. These findings led to intervention Study C where the two contrasting types of physical training were targeted to improve these physical qualities. In this study the effect of specific strength training and general fitness training on neck muscle pain in females with myalgia were investigated. Whereas general fitness training showed no long-term benefits on pain, a marked prolonged pain reduction was found in response to specific strength training.

Over the 10 wk specific strength training intervention pain intensity decreased more than 70% from baseline values. Previous strength training studies of similar duration and comparable baseline pain values found only modest pain reductions of 17-25 % in females with non-specific neck pain (Randlov et al., 1998, Hagberg et al., 2000), 25-39 % in females with trapezius myalgia (Waling et al., 2000) or no change in non-specific neck pain compared with a control group (Viljanen et al., 2003). A study of 1

yr duration found 69 % decrease in non-specific neck pain (Ylinen et al., 2003). The markedly positive and rapid response in the present study compared with previous studies is likely caused by several factors. First of all, the basic training variables were different between studies. Most studies – as in the present - used training frequencies of 3-5 times per week with durations of 8-15 wks (Waling et al., 2000, Viljanen et al., 2003, Hagberg et al., 2000). However, there are distinct differences in intensity, specificity, volume, and contraction mode. According to the American College of Sport Medicine guidelines, the most pronounced adaptations at the muscle cellular level are achieved in response to progressive and periodized dynamic strength training involving both concentric and eccentric contractions with a high intensity (8-12 RM for beginners) and a high volume (multiple sets) (Kraemer et al., 2002). In the present study these variables were optimized by letting the exercises consist of both concentric and eccentric contractions with a high intensity (8-12 RM) and in addition a high volume (9 sets/session) performed in a periodized and progressive manner. In a previous study from the Umeå group on females with trapezius myalgia, only one of four strength training exercises was specific for the upper trapezius muscle (Kadi et al., 2000, Ahlgren et al., 2001, Waling et al., 2000), and consequently the total training volume for that muscle was lower compared with the present study. A strength of the present study may be that the exercises targeted the upper trapezius muscle from slightly different angles, ensuring effective stimulation of the entire upper trapezius. Furthermore, in the study by the Umeå group only the concentric part of the muscle contraction was trained (against hydraulic resistance), whereas the present study used combined concentric-eccentric muscle contractions, i.e. lifting and lowering the dumbbells in a controlled manner. Together, these factors may explain that pain-reduction in the present study was more effective. Other studies which investigated the effect of strength training on non-specific neck pain have used only one specific exercise (Hagberg et al., 2000), a variety of non-specific exercises (Sjogren et al., 2005) or an unspecified number of shoulder/neck-exercises (Viljanen et al., 2003).

Another important variable in strength training is intensity, which is defined as the percentage of the maximal isometric muscle strength or the maximal number of repetitions that can be performed with the particular training weight (repetitions maximum; RM) for isometric and dynamic contractions, respectively (Kraemer et al., 2002). It is generally agreed that strength training intensities of at least 60 % should

be used for effective muscular adaptations to occur and that higher intensities yield proportionate greater adaptations (Kraemer et al., 2002). Strength training intensity can be roughly estimated as a percentage of the maximal EMG amplitude during MVC (Andersen et al., 2006). For the trapezius muscle a linear force-EMG relationship has been documented (Jensen et al., 1993), thus any difference in normalized EMG amplitude between exercises reflects relative differences in levels of muscle force. In study D we found that 4 out of 5 exercises induced levels of trapezius EMG amplitude that was above 60% of peak EMG during MVC, which means that a broad range of specific strengthening exercises can be used for rehabilitation of trapezius myalgia. Previous studies have used low intensity (Viljanen et al., 2003, Randlov et al., 1998), high intensity but only concentric contractions (Waling et al., 2000), high-intensity isometric training (Hagberg et al., 2000, Ylinen et al., 2003), low total training volume (Hagberg et al., 2000) and non-periodized training (Ylinen et al., 2003, Waling et al., 2000, Randlov et al., 1998, Hagberg et al., 2000). One frequently cited study concludes that strength training of high intensity is not more effective than a program with lower intensity with regard to neck-pain reduction (Randlov et al., 1998). However the group that trained with the highest intensity in that study used 20 RM loadings. Thus the intensity was low to medium, and not high, according to the definition of strength training intensity (Fleck and Kraemer, 2004). In another study it was concluded that strength training is not more effective in reducing neck pain compared with ordinary activity (Viljanen et al., 2003). In that study intensity was not reported, but based on absolute loadings of 1-3 kg dumbbells compared with up to 25 kg in the present study it is likely that the intensity was low. Thus any conclusions regarding the effect of true high-intensity strength training on neck pain can not be drawn based on those studies. Previous studies that used high-intensity strength training all found positive effects on pain reduction (Kadi et al., 2000, Ahlgren et al., 2001, Waling et al., 2000, Ylinen et al., 2003, Hagberg et al., 2000). In the present study a combination of muscle-specific exercises, a high training intensity (8-12 RM) and a relatively high total training volume could have provided an optimal stimulus to reduce trapezius muscle pain.

In Study D some practical relevant observations were made. The exercise lateral raise induced similar high levels of trapezius muscle activation compared with shrugs, in spite that the average training weight during the former exercise was only 5 kg

compared with 24 kg during the latter. This finding has important practical relevance during rehabilitation of trapezius myalgia, since grip strength and low back strength may become limiting factors during heavy-load shrugs, especially for those with symptoms also in the low back and hip/knee. During lateral raise the upper trapezius muscle upward rotates the scapula (Ebaugh et al., 2005), and together with a long external moment arm this may explain the high level of trapezius muscle activation in spite of relatively low external loadings. Furthermore, upright row induced high levels of trapezius muscle activation that was not significantly lower than during shrugs and lateral raise. Thus, lateral raise and upright row may be offered as alternatives to shrugs for females with limited grip strength and low back and hip/knee symptoms. It has to be noted that lateral raise and upright row involves abduction of the shoulder joint. This can be demanding upon rotator cuff muscles and can be associated with impingement like symptoms due to compression of the supraspinatus tendon. In such cases, shrugs may be appropriate for patients having problems abducting the arm, e.g. due to shoulder joint impingement.

The present study demonstrated that in response to specific strength training the reduction in pain occurs gradually over time. It is well known that high-intensity strength training accelerate protein synthesis as well as degradation (Biolo et al., 1995), which over a prolonged period of time may lead to turnover of painful and abnormal muscle tissue (Hagg, 2000). This suggests that adaptations at the muscle cellular level in response to strength training in females with myalgia should be looked further upon. Also, shoulder elevation strength of the trapezius muscle was increased 28% in the specific strength training group, which lowers the relative workload of the trapezius muscle during daily low-force work tasks. Pain of the trapezius muscle was gradually decreased as the dynamic muscle strength increased. Thus, increased reserve capacity of trapezius muscle strength in response to strength training could have contributed to pain reduction.

In the group that performed general fitness training, aerobic fitness increased 21% but no change in local pain occurred over a prolonged period of time. This indicates that local muscle training is necessary to significantly decrease pain. A transfer effect as seen previously from training one muscle group and to strength gains (Hansen et al., 2001) and vascular adaptations in non-trained muscle groups (Silber et al., 1991) was not found in the present study regarding pain reduction.

## **Conclusion**

In conclusion, the present PhD project demonstrated differences in muscle morphological, neuromuscular and kinematic parameters between workers with and without trapezius myalgia, and that muscle pain can be markedly reduced by specific strength training.

Having trapezius myalgia was associated with decreased strength capacity and lowered activity of the painful trapezius muscle. The most consistent differences – in terms of both torque and EMG - between those with and without myalgia were observed during slow concentric and eccentric isokinetic contraction. Activity of the synergistic pain free deltoideus muscle was not significantly different between the groups, indicating specific inhibitory feedback of the painful trapezius muscle alone. Further, females with myalgia had a significantly higher proportion of grossly hypertrophied type I muscle fibers with poor capillarization – type I megafibers. We propose that this finding is a specific adaptation to prolonged exposure of a few of many low threshold motor units.

Above all, specific strength training led to marked reductions in pain intensity with a lasting effect for 10 wks after the intervention. Several of the investigated strength exercises led to high levels of trapezius muscle activation, and can thus contribute to a positive treatment effect. General fitness training resulted in short-lasting pain reduction only immediately after each training session, and showed no long-term benefits.



## **Perspective**

The present PhD project demonstrated noticeable benefits of specific strength training performed with high intensity for treatment of trapezius myalgia. However, new results always raise new questions. Taking it a step further, future studies should elucidate the specific mechanisms of pain relief. Based on the cross-sectional study of this thesis, it can be speculated that pain may arise from only a few of many fibers, indicating that overall differences between healthy and painful muscles are subtle. One place to start could be to scrutinize ‘megafibers’: for example, are glycogen depleted at a higher rate in these fibers during low-intensity work-task compared with ‘normal’ fibers, indicating that these fibers are actually belonging to low-threshold motor units? Secondly, inflammatory markers in these fibers should also be looked upon, e.g. by staining for macrophages. Further, the response of these fibers to training should be determined. In addition, quantification of satellite cells should be performed to determine the regenerative potential of specific fibers.

Numerous other aspects would be relevant and interesting to investigate. For example, can muscle pain in other regions of the body be relieved by specific training? What is the minimum dose of training for effective pain relief?

Altogether, the present thesis demonstrated results that are worth building upon, and it is my hope that other researchers will be inspired to work on with some of these issues.



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## References

- Ahlgren C, Waling K, Kadi F, Djupsjobacka M, Thornell L E, Sundelin G. Effects on physical performance and pain from three dynamic training programs for women with work-related trapezius myalgia. *J Rehabil Med* 2001; (33): 162-169.
- Andersen L L, Magnusson S P, Nielsen M, Haleem J, Poulsen K, Aagaard P. Neuromuscular activation in conventional therapeutic exercises and heavy resistance exercises: implications for rehabilitation. *Phys Ther* 2006; (86): 683-697.
- Åstrand I. Aerobic work capacity in men and women with special reference to age. *Acta Physiol Scand Suppl* 1960;1-92.
- Åstrand P O, Rodahl K. Textbook of work physiology: physiological bases of exercise. McGraw-Hill, New York 1986.
- Backman E, Johansson V, Hager B, Sjoblom P, Henriksson K G. Isometric muscle strength and muscular endurance in normal persons aged between 17 and 70 years. *Scand J Rehabil Med* 1995; (27): 109-117.
- Bigland-Ritchie B, Donovan E F, Roussos C S. Conduction velocity and EMG power spectrum changes in fatigue of sustained maximal efforts. *J Appl Physiol* 1981; (51): 1300-1305.
- Biolo G, Maggi S P, Williams B D, Tipton K D, Wolfe R R. Increased rates of muscle protein turnover and amino acid transport after resistance exercise in humans. *Am J Physiol* 1995; (268): E514-E520.
- Blangsted A K, Sogaard K, Christensen H, Sjogaard G. The effect of physical and psychosocial loads on the trapezius muscle activity during computer keying tasks and rest periods. *Eur J Appl Physiol* 2004; (91): 253-258.
- Borg G. Psychophysical scaling with applications in physical work and the perception of exertion. *Scand J Work Environ Health* 1990; (16(suppl 1)): 55-58.
- Brooke MH, Kaiser K K. Muscle fiber types: how many and what kind. *Arch Neurol* 1970; (23): 369-379.
- Brox J I, Røe C, Saugen E, Vøllestad N K. Isometric abduction muscle activation in patients with rotator tendinosis of the shoulder. *Arch Phys Med Rehabil* 1997; (78): 1260-1267.
- Chiu T T, Lam T H, Hedley A J. A randomized controlled trial on the efficacy of exercise for patients with chronic neck pain. *Spine* 2005; (30): E1-E7.
- Cote P, Cassidy J D, Carroll L J, Kristman V. The annual incidence and course of neck pain in the general population: a population-based cohort study. *Pain* 2004; (112): 267-273.
- Crameri R M, Aagaard P, Qvortrup K, Langberg H, Olesen J, Kjaer M. Myofibre damage in human skeletal muscle: effects of electrical stimulation versus voluntary contraction. *J Physiol* 2007; (583): 365-380.
- Droste C, Greenlee M W, Schreck M, Roskamm H. Experimental pain thresholds and plasma beta-endorphin levels during exercise. *Med Sci Sports Exerc* 1991; (23): 334-342.

- Ebaugh D D, McClure P W, Karduna A R. Three-dimensional scapulothoracic motion during active and passive arm elevation. *Clin Biomech (Bristol , Avon )* 2005; (20): 700-709.
- Essendrop M, Schibye B, Hansen K. Reliability of isometric muscle strength tests for the trunk, hands and shoulders. *Int J Ind Erg* 2001; (28): 379-387.
- Ferrari R, Russell A S. Regional musculoskeletal conditions: neck pain. *Best Pract Res Clin Rheumatol* 2003; (17): 57-70.
- Fleck S J, Kraemer W J. *Designing Resistance Training Programs*. Human Kinetics, Champaign, IL 2004.
- Goldfarb A H, Hatfield B D, Armstrong D, Potts J. Plasma beta-endorphin concentration: response to intensity and duration of exercise. *Med Sci Sports Exerc* 1990; (22): 241-244.
- Graven-Nielsen T. Fundamentals of muscle pain, referred pain, and deep tissue hyperalgesia. *Scand J Rheumatol* 2006; (35): 1-43.
- Haahr J P, Ostergaard S, Dalsgaard J, Norup K, Frost P, Lausen S, Holm E A, Andersen J H. Exercises versus arthroscopic decompression in patients with subacromial impingement: a randomised, controlled study in 90 cases with a one year follow up. *Ann Rheum Dis* 2005; (64): 760-764.
- Hagberg M, Harms-Ringdahl K, Nisell R, Hjelm E W. Rehabilitation of neck-shoulder pain in women industrial workers: a randomized trial comparing isometric shoulder endurance training with isometric shoulder strength training. *Arch Phys Med Rehabil* 2000; (81): 1051-1058.
- Hagg G M. Static work loads and occupational myalgia - a new explanation model. In: *Electromyographical Kinesiology*. (Eds. Andersen PA, Hobart DJ, Danoff J, V). Eksevier Science Publishers B.V. (Biomedical Division), 1991; 141-144.
- Hagg G M. Human muscle fibre abnormalities related to occupational load. *Eur J Appl Physiol* 2000; (83): 159-165.
- Hakala P, Rimpela A, Salminen J J, Virtanen S M, Rimpela M. Back, neck, and shoulder pain in Finnish adolescents: national cross sectional surveys. *BMJ* 2002; (325): 743.
- Hansen L, Sogaard K, Blangsted AK, Rosendal L, Nielsen PK, Andersen LL, Olsen HB, Vedsted P, Sjøgaard G. Legcycling Improves the Oxygenation in Relaxed Shoulder Muscles. *Med Sci Sports Exerc* 38(5) Supplement:S249. 2006.  
Ref Type: Abstract
- Hansen S, Kvorning T, Kjær M, Sjøgaard G. The effect of short-term strength training on human skeletal muscle: the importance of physiologically elevated hormone levels. *Scand J Med Sci Sports* 2001; (11): 347-354.
- Hayden J A, van Tulder M W, Tomlinson G. Systematic review: strategies for using exercise therapy to improve outcomes in chronic low back pain. *Ann Intern Med* 2005; (142): 776-785.
- Henneman E, Olson C B. Relations between structure and function in the design of skeletal muscles. *J Neurophysiol* 1965; (28): 581-598.

- Hermens H J, Freriks B. The state of the art on sensors and sensor placement procedures for surface electromyography: A proposal for sensor placement procedures. SENIAM Project. Roessingh Research and Development b.v., Enschede 1997.
- Hurwitz E L, Morgenstern H, Chiao C. Effects of recreational physical activity and back exercises on low back pain and psychological distress: findings from the UCLA Low Back Pain Study. *Am J Public Health* 2005; (95): 1817-1824.
- Huskisson E C. Measurement of pain. *Lancet* 1974; (2): 1127-1131.
- Ihlebaek C, Brage S, Eriksen H R. Health complaints and sickness absence in Norway, 1996-2003. *Occup Med (Lond)* 2006.
- Ijmker S, Huysmans M, Blatter B M, van der Beek A J, van Mechelen W, Bongers P M. Should office workers spend fewer hours at their computer? A systematic review of the literature. *Occup Environ Med* 2006.
- Inman V T, Saunders J B d M, Abbott L C. Observations on the Function of the Shoulder Joint. *Bone Joint Surg (Am)* 1944; (XXVI(1)): 1-30.
- Itoi E, Minagawa H, Sato T, Sato K, Tabata S. Isokinetic strength after tears of the supraspinatus tendon. *J Bone Joint Surg Br* 1997; (79): 77-82.
- Jensen C. Development of neck and hand-wrist symptoms in relation to duration of computer use at work. *Scand J Work Environ Health* 2003; (29): 197-205.
- Jensen C, Finsen L, Sogaard K, Christensen H. Musculoskeletal symptoms and duration of computer and mouse use. *International Journal of Industrial Ergonomics* 2002; (30): 265-275.
- Jensen C, Vasseljen O, Westgaard R H. The influence of electrode position on bipolar surface electromyogram recordings of the upper trapezius muscle. *Eur J Appl Physiol Occup Physiol* 1993; (67): 266-273.
- Juul-Kristensen B, Kadefors R, Hansen K, Bystrom P, Sandsjo L, Sjogaard G. Clinical signs and physical function in neck and upper extremities among elderly female computer users: the NEW study. *Eur J Appl Physiol* 2006; (96): 136-145.
- Juul-Kristensen B, Sogaard K, Stroyer J, Jensen C. Computer users' risk factors for developing shoulder, elbow and back symptoms. *Scand J Work Environ Health* 2004; (30): 390-398.
- Kadi F, Ahlgren C, Waling K, Sundelin G, Thornell L E. The effects of different training programs on the trapezius muscle of women with work-related neck and shoulder myalgia. *Acta Neuropathol (Berl)* 2000; (100): 253-258.
- Kadi F, Eriksson A, Holmner S, Butler-Browne G S, Thornell L E. Cellular adaptation of the trapezius muscle in strength-trained athletes. *Histochem Cell Biol* 1999; (111): 189-195.
- Kadi F, Hagg G, Hakansson R, Holmner S, Butler-Browne G S, Thornell L E. Structural changes in male trapezius muscle with work-related myalgia. *Acta Neuropathol (Berl)* 1998a; (95): 352-360.
- Kadi F, Waling K, Ahlgren C, Sundelin G, Holmner S, Butler-Browne G S, Thornell L E. Pathological mechanisms implicated in localized female trapezius myalgia. *Pain* 1998b; (78): 191-196.

- Kaergaard A, Andersen J H, Rasmussen K, Mikkelsen S. Identification of neck-shoulder disorders in a 1 year follow-up study. Validation Of a questionnaire-based method. *Pain* 2000; (86): 305-310.
- Kemppainen P, Pertovaara A, Huopaniemi T, Johansson G, Karonen S L. Modification of dental pain and cutaneous thermal sensitivity by physical exercise in man. *Brain Res* 1985; (360): 33-40.
- Kilbom Å, Armstrong T, Buckle P, Fine L, Hagberg M, Haring-Sweeney M, Martin B, Punnett L, Silverstein B, Sjøgaard G, Theorell T, Viikari-Juntura E. Musculoskeletal disorders: Work-related risk factors and prevention. *Int J Occup Environ Health* 1996; (2): 239-246.
- Kjaer M. Role of extracellular matrix in adaptation of tendon and skeletal muscle to mechanical loading. *Physiol Rev* 2004; (84): 649-698.
- Kraemer W J, Adams K, Cafarelli E, Dudley G A, Dooly C, Feigenbaum M S, Fleck S J, Franklin B, Fry A C, Hoffman J R, Newton R U, Pottenger J, Stone M H, Ratamess N A, Triplett-McBride T. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Med Sci Sports Exerc* 2002; (34): 364-380.
- Kryger A I, Andersen J H, Lassen C F, Brandt L P, Vilstrup I, Overgaard E, Thomsen J F, Mikkelsen S. Does computer use pose an occupational hazard for forearm pain; from the NUDATA study. *Occup Environ Med* 2003; (60): e14.
- Larsson B, Bjork J, Elert J, Gerdle B. Mechanical performance and electromyography during repeated maximal isokinetic shoulder forward flexions in female cleaners with and without myalgia of the trapezius muscle and in healthy controls. *Eur J Appl Physiol* 2000; (83): 257-267.
- Larsson B, Bjork J, Elert J, Lindman R, Gerdle B. Fibre type proportion and fibre size in trapezius muscle biopsies from cleaners with and without myalgia and its correlation with ragged red fibres, cytochrome-c-oxidase-negative fibres, biomechanical output, perception of fatigue, and surface electromyography during repetitive forward flexions. *Eur J Appl Physiol* 2001; (84): 492-502.
- Larsson B, Sogaard K, Rosendal L. Work related neck-shoulder pain: a review on magnitude, risk factors, biochemical characteristics, clinical picture and preventive interventions. *Best Pract Res Clin Rheumatol* 2007; (21): 447-463.
- Lindman R, Hagberg M, Angqvist K A, Soderlund K, Hultman E, Thornell L E. Changes in muscle morphology in chronic trapezius myalgia. *Scand J Work Environ Health* 1991; (17): 347-355.
- Lund J P, Donga R, Widmer C G, Stohler C S. The pain-adaptation model: a discussion of the relationship between chronic musculoskeletal pain and motor activity. *Can J Physiol Pharmacol* 1991; (69): 683-694.
- Lunde P K, Sjaastad I, Schiøtz Thorud H M, Sejersted O M. Skeletal muscle disorders in heart failure. *Acta Physiol Scand* 2001; (171): 277-294.
- Maas H, Lehti T M, Tiihonen V, Komulainen J, Huijing P A. Controlled intermittent shortening contractions of a muscle-tendon complex: muscle fibre damage and effects on force transmission from a single head of rat EDL. *J Muscle Res Cell Motil* 2005; (26): 259-273.
- Moritani T, Muro M. Motor unit activity and surface electromyogram power spectrum during increasing force of contraction. *Eur J Appl Physiol Occup Physiol* 1987; (56): 260-265.

- National Research Council, Institute of medicine. Musculoskeletal disorders and the workplace - Low back and upper extremities. National Research Council; Institute of medicine; ISBN-10: 0-309-07284-0, Washington D.C. 2001.
- Nikander R, Malkia E, Parkkari J, Heinonen A, Starck H, Ylinen J. Dose-response relationship of specific training to reduce chronic neck pain and disability. *Med Sci Sports Exerc* 2006; (38): 2068-2074.
- Ohlsson K, Attewell R G, Johnsson B, Ahlm A, Skerfving S. An assessment of neck and upper extremity disorders by questionnaire and clinical examination. *Ergonomics* 1994; (37): 891-897.
- Pedersen B K, Saltin B. Evidence for prescribing exercise as therapy in chronic disease. *Scand J Med Sci Sports* 2006; (16 Suppl 1): 3-63.
- Petrofsky J S, Lind A R. Frequency analysis of the surface electromyogram during sustained isometric contractions. *Eur J Appl Physiol Occup Physiol* 1980; (43): 173-182.
- Proske U, Allen T J. Damage to skeletal muscle from eccentric exercise. *Exerc Sport Sci Rev* 2005; (33): 98-104.
- Punnett L. Work-related musculoskeletal disorders: is the burden equitably distributed? *Med Lav* 2006; (97): 182-183.
- Punnett L, Wegman D H. Work-related musculoskeletal disorders: the epidemiologic evidence and the debate. *J Electromyogr Kinesiol* 2004; (14): 13-23.
- Rakel B, Barr J O. Physical modalities in chronic pain management. *Nurs Clin North Am* 2003; (38): 477-494.
- Randlov A, Ostergaard M, Manniche C, Kryger P, Jordan A, Heegaard S, Holm B. Intensive dynamic training for females with chronic neck/shoulder pain. A randomized controlled trial. *Clin Rehabil* 1998; (12): 200-210.
- Rosendal L, Blangsted A K, Kristiansen J, Sogaard K, Langberg H, Sjogaard G, Kjaer M. Interstitial muscle lactate, pyruvate and potassium dynamics in the trapezius muscle during repetitive low-force arm movements, measured with microdialysis. *Acta Physiol Scand* 2004a; (182): 379-388.
- Rosendal L, Larsson B, Kristiansen J, Peolsson M, Sogaard K, Kjaer M, Sorensen J, Gerdle B. Increase in muscle nociceptive substances and anaerobic metabolism in patients with trapezius myalgia: microdialysis in rest and during exercise. *Pain* 2004b; (112): 324-334.
- Schulte E, Kallenberg L A C, Christensen H, Disselhorst-Klug C, Hermens H J, Rau G, Søgaard K. Comparison of the electromyographic activity in the upper trapezius and biceps brachii muscle in subjects with muscular disorders: a pilot study. *Eur J Appl Physiol* 2006; (96): 185-193.
- Sculco A D, Paup D C, Fernhall B, Sculco M J. Effects of aerobic exercise on low back pain patients in treatment. *Spine J* 2001; (1): 95-101.
- Silber D, McLaughlin D, Sinoway L. Leg exercise conditioning increases peak forearm blood flow. *J Appl Physiol* 1991; (71): 1568-1573.
- Sjogaard G, Sogaard K, Hermens H J, Sandsjo L, Laubli T, Thorn S, Vollenbroek-Hutten M M, Sell L, Christensen H, Klipstein A, Kadefors R, Merletti R. Neuromuscular assessment in elderly

- workers with and without work related shoulder/neck trouble: the NEW-study design and physiological findings. *Eur J Appl Physiol* 2006; (96): 110-121.
- Sjogren T, Nissinen K J, Jarvenpaa S K, Ojanen M T, Vanharanta H, Malkia E A. Effects of a workplace physical exercise intervention on the intensity of headache and neck and shoulder symptoms and upper extremity muscular strength of office workers: a cluster randomized controlled cross-over trial. *Pain* 2005; (116): 119-128.
- Sogaard K, Fallentin N, Nielsen J. Work load during floor cleaning. The effect of cleaning methods and work technique. *Eur J Appl Physiol Occup Physiol* 1996; (73): 73-81.
- Steingrimsdóttir O A, Knardahl S, Vøllestad N K. Prospective study of the relationship between musculoskeletal and psychological complaints and electromyographic activity during isometric muscular contractions in a working population. *Scand J Work Environ Health* 2004; (30): 410-420.
- Takala E P, Viikari-Juntura E, Tynkkynen E M. Does group gymnastics at the workplace help in neck pain? A controlled study. *Scand J Rehabil Med* 1994; (26): 17-20.
- Tanaka H, Shimizu S, Ohmori F, Muraoka Y, Kumagai M, Yoshizawa M, Kagaya A. Increases in blood flow and shear stress to nonworking limbs during incremental exercise. *Med Sci Sports Exerc* 2006; (38): 81-85.
- Tesch P A. Skeletal muscle adaptations consequent to long-term heavy resistance exercise. *Med Sci Sports Exerc* 1988; (20): S132-S134.
- Vedsted P, Larsen A H, Madsen K, Sjogaard G. Muscle performance following fatigue induced by isotonic and quasi-isometric contractions of rat extensor digitorum longus and soleus muscles in vitro. *Acta Physiol Scand* 2003; (178): 175-186.
- Veeger H E, van der Helm F C. Shoulder function: the perfect compromise between mobility and stability. *J Biomech* 2007; (40): 2119-2129.
- Veiersted K B, Westgaard R H. Development of trapezius myalgia among female workers performing light manual work. *Scand J Work Environ Health* 1993; (19): 277-283.
- Veiersted K B, Westgaard R H, Andersen P. Electromyographic evaluation of muscular work pattern as a predictor of trapezius myalgia. *Scand J Work Environ Health* 1993; (19): 284-290.
- Viljanen M, Malmivaara A, Uitti J, Rinne M, Palmroos P, Laippala P. Effectiveness of dynamic muscle training, relaxation training, or ordinary activity for chronic neck pain: randomised controlled trial. *BMJ* 2003; (327): 475.
- Visser B, van Dieen J H. Pathophysiology of upper extremity muscle disorders. *J Electromyogr Kinesiol* 2006; (16): 1-16.
- Von Korff M, Ormel J, Keefe F J, Dworkin S F. Grading the severity of chronic pain. *Pain* 1992; (50): 133-149.
- Waling K, Sundelin G, Ahlgren C, Jarvholm B. Perceived pain before and after three exercise programs--a controlled clinical trial of women with work-related trapezius myalgia. *Pain* 2000; (85): 201-207.

- Westbury J R, Shaughnessy T G. Associations between spectral representation of the surface electromyogram and fiber type distribution and size in human masseter muscle. *Electromyogr Clin Neurophysiol* 1987; (27): 427-435.
- Winter D A. Biomechanics and motor control of human movement. In: New York: John Wiley & Sons, 1990; 2nd: 11-50.
- Wolledge R C, Curtin N A, Homsher E. Energetic aspects of muscle contraction. Academic Press, London 1985.
- Ylinen J. Physical exercises and functional rehabilitation for the management of chronic neck pain. *Eura Medicophys* 2007; (43): 119-132.
- Ylinen J, Takala E P, Nykanen M, Hakkinen A, Malkia E, Pohjolainen T, Karppi S L, Kautiainen H, Airaksinen O. Active neck muscle training in the treatment of chronic neck pain in women: a randomized controlled trial. *JAMA* 2003; (289): 2509-2516.
- Yuza N, Ishida K, Miyamura M. Cross transfer effects of muscular endurance during training and detraining. *J Sports Med Phys Fitness* 2000; (40): 110-117.



# Appendix