Available online at www.sciencedirect.com

SCIENCE DIRECT®

European Journal of Pain 9 (2005) 673–681

www.EuropeanJournalPain.com

Effect of long-term neck muscle training on pressure pain threshold: A randomized controlled trial

Jari Ylinen [a,*], Esa-Pekka Takala [b], Hannu Kautiainen [c], Matti Nykänen [d], Arja Häkkinen [a], Timo Pohjolainen [e], Sirkka-Liisa Karppi [e], Olavi Airaksinen [f]

[a] *Department of Physical and Rehabilitation Medicine, Jyväskylä Central Hospital, Keskussairaalantie 19, 40620 Jyväskylä, Finland*
[b] *Finnish Institute of Occupational Health, Helsinki, Finland*
[c] *Rheumatism Foundation Hospital, Heinola, Finland*
[d] *Punkaharju Rehabilitation Centre, Punkaharju, Finland*
[e] *Social Insurance Institution, Finland*
[f] *Department of Physical and Rehabilitation Medicine, Kuopio University Hospital, Kuopio, Finland*

Received 7 June 2004; accepted 4 January 2005
Available online 3 March 2005

Abstract

Muscle tenderness has been measured in several studies to evaluate effectiveness of treatment methods, but only short-term results have been reported so far. The aim of the present study was to evaluate the long-term effects of two different muscle training methods on the pressure pain threshold of neck muscles in women with neck pain.

Altogether 180 woman with chronic, non-specific neck pain were randomized into three groups: neck muscle endurance training, neck muscle strength training and control groups.

The main outcome measures included pressure pain threshold measurement at six muscle sites and on the sternum. Neck pain was assessed by a visual analogue scale (VAS).

At the 12-month follow-up statistically significantly higher pressure pain threshold values were obtained in both training groups at all muscle sites compared to the baseline, while no significant change occurred in the controls. Significantly higher changes in pressure pain threshold were detected at all six sites in the strength training group and at four out of six sites in the endurance training group compared to the control group.

This is the first study to show an increase in pressure pain thresholds as a result of long-term muscle training. A decrease in neck pain was associated with reduced pressure pain sensitivity in neck muscles, showing that the pressure pain threshold may be a useful outcome measure of the effectiveness of neck muscle rehabilitation.

Keywords: Algometry; Cervical muscles; Rehabilitation; Training; Effectiveness

1. Introduction

Pressure algometry has been suggested as a diagnostic aid (Granges and Littlejohn, 1993; Incel et al., 2002), and as a means of evaluating the effect of different treatments on myofascial pain (Irnich et al., 2001; Hou et al., 2002; Chesterton et al., 2002; Smania et al., 2003). The rationale for using pressure pain threshold measurements is that the tenderness of soft tissues is commonly associated with painful conditions stemming from different etiologies such as repetitive trauma, inflammation, excessive strain or psychosocial stress. These conditions

* Corresponding author. Tel.: +358 40 5229230; fax: +358 14 254544/692931.
E-mail address: jari.ylinen@ksshp.fi (J. Ylinen).

1090-3801/$30
doi:10.1016/j.ejpain.2005.01.001

are believed to cause sensitization of peripheral nociceptive nerves in the affected area.

Pressure algometry has been shown to be a valid measure of tenderness in several studies. Both inter- and intra-rater reliability of the pressure pain threshold meter in measurements of myofascial trigger points have been shown to be satisfactory or good (Delaney and McKee, 1993; Antonaci et al., 1998). In myalgia, pressure pain thresholds have been found to be lower at a painful site compared to same site on contralateral side (Ohrbach and Gale, 1989).

Several studies have shown a lower pressure pain threshold in patients with neck and shoulder pain compared to healthy controls (Takala, 1990; Levoska, 1993; Hägg and Åström, 1997) and an association between neck pain and low pressure pain thresholds in the neck and shoulder muscles (Nakata et al., 1993; Andersen et al., 2002). Patients with chronic tension-type headache have also shown to have lower pressure pain thresholds in head and neck muscles compared to healthy controls (Langemark et al., 1989; Schoenen et al., 1991; Bovim, 1992). This hypersensitivity is most obvious at the referred pain site (Madeleine et al., 1998; Leffler et al., 2003). However, Bendtsen et al. (1996) also found generally decreased pain tolerance thresholds in patients with chronic tension-type headaches indicating that hypersensitivity to pain stimuli is affected by the central nervous system, which may play an important role in the pathogenesis of this disorder.

Exercising muscles has been shown to increase pressure pain thresholds in the upper and lower extremities (Kosek and Ekholm, 1995; Koltyn et al., 2001), as well as in the neck muscles after only a few weeks training (Levoska and Keinänen-Kiukaanniemi, 1993; Gam et al., 1998). However, previous studies have not evaluated the long-term effects of muscle training on pressure pain thresholds.

Recently, we reported that strength and endurance type neck and shoulder muscle training significantly increased neck strength and decreased neck pain and related disability over the long-term (Ylinen et al., 2003). The aim of the present study was to evaluate the effects of the same 12 months' training on the tenderness of neck muscles in women with chronic neck pain.

2. Materials and methods

2.1. Patients

Patients were recruited by occupational health care services, who were informed about the study and the inclusion and exclusion criteria. On the basis of clinical examination, physicians working in the occupational health care services referred suitable patients. All patients entering the study filled in a questionnaire on their current health and symptoms before the inclusion to the study. The inclusion and exclusion criteria are presented in Table 1. Altogether 180 woman with chronic neck pain were enrolled in the study and randomized to one of the two training groups or to the control group. The anthropometric and clinical parameters of the three groups were similar (Table 2).

Table 1

Inclusion criteria	Exclusion criteria
• female	• specific neck diseases
• age 25–53 years	• frequent migraine
• office worker	• peripheral nerve entrapment
• permanently employed	• fibromyalgia
• motivated to continue at work	• shoulder diseases
• motivated for rehabilitation	• inflammatory rheumatic diseases
• chronic neck pain (>6 months)	• severe psychiatric illness
	• other diseases preventing physical loading
	• pregnancy

Table 2
Demographic and clinical data of the patients at baseline

	Control group ($n = 60$)	Training groups	
		Endurance ($n = 59$)	Strength ($n = 60$)
Demographic			
Age, years, mean (SD)	46 (5)	46 (6)	45 (6)
Height, cm, mean (SD)	164 (5)	165 (6)	165 (5)
Weight, kg, mean (SD)	69 (12)	68 (10)	67 (11)
Body mass index (kg/m^2), mean (SD)	26 (4)	25 (3)	25 (3)
Clinical			
Neck pain on VAS, median (IQR)[a]	58 (42, 74)	57 (43, 74)	58 (43, 72)
Neck and shoulder pain and disability index, median (IQR)[a]	38 (26, 49)	36 (28, 46)	35 (24, 45)
Vernon's neck disability index, median (IQR)[a]	22 (16, 31)	22 (16, 28)	21 (16, 26)

[a] Scale 0–100; IQR, interquartile range.

2.2. Outcome measures

Pressure pain thresholds were assessed on the sternum, which was taken as the point of reference, and then on the trapezius and levator scapulae muscles in the same order, first on the right side and then on the left side (Fig. 1). One measurement was performed at each site in each test session. Intratester repeatability was assessed by retesting the pressure pain threshold of 20 patients on the following day. Intra-class correlation coefficients varied from 0.77 to 0.92, depending on the location. Pressure pain measurements were performed at the start and at the end of the 12-month intervention period, and they were repeated by the same experienced physiotherapist, who had been trained in the pressure algometry.

Pressure pain threshold was measured with a hand-held electronic pressure algometer with a surface area at the round tip of 1 cm^2 (Force five™, Wagner Instruments, Box 1217, Greenwich, CT 06836). Compression pressure was gradually increased at the rate of approximately 1 kg/s perpendicularly onto the muscle tissue (Fig. 2). The patient was told to state immediately when the sensation of pressure turned into a sensation of pain, at which point compression was stopped and the pressure was released. The algometer maintains the maximum applied pressure until tared. After a pause of 30 s the next measurement was taken. A single measurement was made at each site. The physiotherapist was not blinded to the groups.

The isometric neck strength measurement system (Kuntoväline Ltd., Helsinki) was used to assess maximal neck strength (Ylinen et al., 2004) and a submaximal bicycle ergometer test to assess general physical function (Lange Anderssen et al., 1971).

Subjectively perceived neck pain was assessed by the visual analogue scale (VAS, Dixon and Bird, 1981), modified neck and shoulder pain and disability index (Viikari-Juntura et al., 1988) and Vernon neck disability index (Vernon and Mior, 1991).

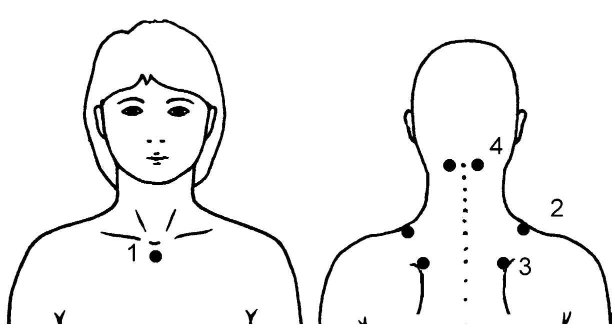

Fig. 1. Location of pain pressure threshold measurement points on the sternum in the midline (1), the upper border of the trapezius muscle halfway between the midline and the lateral border of the acromion (2), the levator scapulae muscle 2 cm above the lower insertion located in the upper medial border of the scapulae (3) and the suboccipital points 2 cm lateral to the spinous processus of the axis (4).

Fig. 2. Application of pain pressure threshold measurement.

2.3. Description of interventions

Each training group of ten patients, alternating between neck muscle endurance training and neck strength training, was started on a 12-day institutional rehabilitation program at regular intervals during the year. During rehabilitation the training regime consisted of nine muscle training sessions, each lasting from 45 to 60 min. Each patient in both training groups received four sessions of physical therapy consisting mainly of massage and mobilization in order to alleviate neck pain and to enable those with severe neck pain to perform active physical exercises. The training regime of the endurance and strength training groups was checked at 2- and 6-month follow-ups.

2.3.1. Training programs

2.3.1.1. Endurance training group. The patients exercised their neck flexor muscles by lifting the head up from the supine position in three series of 20 repetitions. After that they carried out dynamic exercises for the shoulders and upper extremities by doing shrugs, presses, curls, bent-over rows, flies and pullovers for three sets of 20 repetitions with a pair of 2 kg dumbbells.

2.3.1.2. Strength training group. The training regime consisted of pulling against elastic rubber band (Thera-band®, Hygiene Corp. Akron Ohio) to train the neck flexor muscles. The exercises were performed in the sitting position in sets of 15 repetitions: (a) directly forwards, (b) obliquely toward right and left, and (c) directly backwards (Ylinen and Ruuska, 1994). The aim was to maintain the level of resistance at 80% of the participant's maximum isometric strength recorded at the baseline and at follow-up visits. After the neck exercises the strength training group carried out the same dynamic exercise program for the shoulders and upper extremities as the endurance training group. However, they performed only one set for each exercise with the highest load possible to performing 15 repetitions with an individually adjusted single dumbbell. When they were able to manage this well the patients were advised to add 1–2 kg of weight in order to progressively increase the exercise load.

2.3.1.3. Both training groups. After exercising the neck and shoulders both training groups performed exercises for the trunk and leg muscles against their body weight by doing a single series of squats, sit-ups and back extension exercises. Training sessions finished with stretching exercises for the neck, shoulder and upper limb muscles for about 20 min. Patients were taught to keep an exercise diary throughout the training year.

2.3.1.4. Control group. The training regime consisted of the same stretching exercises as the training groups. Instruction was given during one session after the baseline tests.

2.3.1.5. All groups. Patients received written instructions about the exercises to be practised three times a week for 12 months at home. They were also told to do aerobic exercises three times a week for half an hour.

2.4. Ethics

The local ethics committee approved the study and the participants gave their informed written consent prior to inclusion in the study.

2.5. Statistics

Outcome variables were analyzed on the intention-to-treat principle. However, one patient in the endurance group was diagnosed with polymyalgia rheumatica and was released early from the study per the exclusion criteria. Thus she was not included to the analysis. The results are expressed by means and standard deviations (SD), medians and interquartile ranges (IQR). The normality of the variables was evaluated by the Shapiro-Wilk test. The effect of different treatments was evaluated by analysis of covariance (ANCOVA) with the baseline as covariant. Post-hoc testing was done with Sidak's test. The relationship between the change in neck pain and change in pressure pain threshold were analyzed with the Spearman test and a locally weighted scatter plot smoother (LOWESS). The α-level was set at 0.05 for all tests.

3. Results

After the baseline measurements there was one withdrawal from the control group due to pregnancy and one from the endurance training group due to personal reasons. These patients were included in the analysis.

At the most sensitive site the mean (SD) baseline pain pressure threshold values were 30 (15) N/cm^2, 26 (13) N/cm^2 and 21 (10) N/cm^2 for the control, endurance and strength training groups, respectively. The respective mean changes with a 95% confidence interval over 12 months were 9 (5–12) N/cm^2, 20 (16–25) N/cm^2 and 25 (20–31) N/cm^2. There was a significant difference in the change between the controls and each training group ($p < 0.001$), but not between two training groups, when the differences in each site were analyzed separately.

Table 3
Pain pressure threshold measurement results (N/cm^2) at baseline and changes at 12-month follow-up

Variables	Baseline			Change after 12 months			p value between groups[a] (post-hoc test)[b]
	Controls mean (SD)	Endurance mean (SD)	Strength mean (SD)	Controls mean (95% CI)	Endurance mean (95% CI)	Strength mean (95% CI)	
Sternum	36 (19)	35 (15)	31 (12)	2 (−2–7)	3 (−1–7)	6 (2–10)	0.83
Trapezius middle							
Right	38 (19)	33 (17)	28 (12)	5 (0–10)	15 (10–20)	19 (14–23)	0.003 (S vs C, E vs C)
Left	38 (18)	34 (17)	29 (13)	2 (−3–7)	16 (11–21)	18 (12–23)	<0.001 (S vs C, E vs C)
Levator scapulae							
Right	56 (22)	50 (21)	44 (19)	12 (6–19)	24 (19–29)	32 (25–39)	0.003 (S vs C)
Left	59 (22)	53 (21)	45 (18)	12 (6–18)	25 (20–31)	34 (27–41)	<0.001 (S vs C, S vs E, E vs C)
Trapezius upper							
Right	38 (15)	32 (15)	28 (11)	5 (1–8)	14 (10–18)	23 (17–28)	<0.001 (S vs C, S vs E)
Left	37 (15)	31 (13)	28 (13)	6 (2–10)	17 (13–22)	22 (17–26)	<0.001 (S vs C, E vs C)

Abbreviations: C, control group; CI, confidence interval; E, endurance group; S, strength group.
[a] Analysis of covariance (ANCOVA), baseline value as covariate.
[b] Statistically significant difference ($p < 0.05$) between groups located with Sidak's test.

All pressure pain thresholds were significantly higher in both training groups at the 12-month follow-up compared to the baseline values (Table 3). The changes in the values of the strength training group were significantly higher than those recorded for the control group in all the muscle test sites at the follow-up. Moreover a significant difference emerged between the change in the pressure pain threshold values of the endurance group and those of the control group in all the muscles tested except the right upper trapezius and right levator scapulae. Although the values were uniformly higher in the strength training group compared to the endurance training group, significant differences between the two training groups emerged only in the right trapezius and left levator muscles. There were no significant between-group differences in the change in the pressure pain threshold values at the control site on the sternum. Spearman's correlation coefficient between the change in pressure pain threshold at each measurement point and change in neck pain varied from −0.28 (95% CI: −0.42 to −0.14) to −0.23 (95% CI: −0.37 to −0.09). The curve on a locally weighted scatter plotter smoother fell almost linearly showing an inverse relationship between the mean change in pain and the mean change in pressure pain thresholds (Fig. 3). Greatest improvement in individual pressure pain threshold values occurred in the strength training groups as shown also in the figure.

Maximal isometric neck strength increased in average by 85% in the strength training group, by 24% in the endurance training group and by 9% in the control group compared to the baseline values. There was no statistically discrenible change in maximal oxygen uptake in any of the groups.

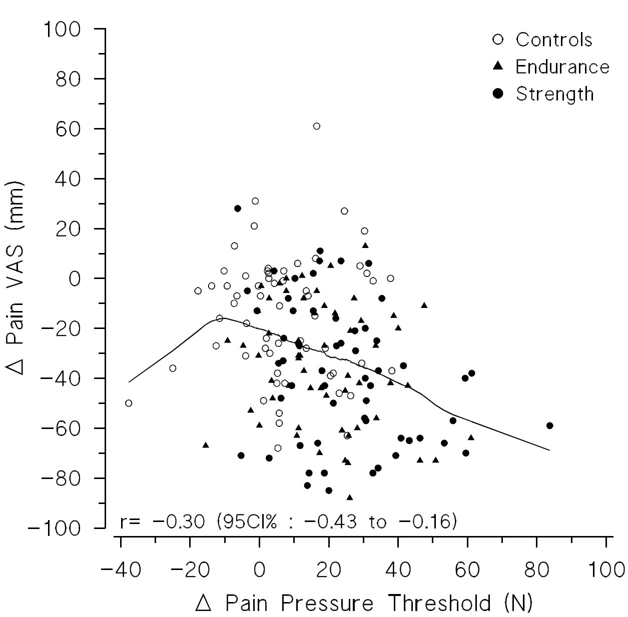

Fig. 3. Relationship between the mean change in pressure pain thresholds at six measured muscle sites and change in neck pain after training for 12 months. Line shows a locally weighted scatter plotter smoother (LOWESS).

4. Discussion

Both endurance and strength training of the neck and shoulder muscles produced higher pressure pain threshold values in both training groups compared to the control group at the 12-month follow-up, indicating decreased muscle tenderness in the long-term. This is assumed to be related to local changes in the neuromuscular system due to training of these muscles rather than to elevated general tolerance to pressure, as no significant difference was found between the training groups and controls in the pressure pain threshold values recorded at the reference site on the sternum. Thus appropriate neck and shoulder muscle training not only reduces pain, but also improves tolerance to local mechanical pressure.

Reduction in neck pain (VAS) at the 12-month follow-up was 69% in the strength training group, 61% in the endurance group and 28% in the control group compared to the baseline values (Ylinen et al., 2003). The reduction was significant between the controls and each of the training groups. Although the reduction in pain was greater in the strength training group, compared to the endurance training group, the difference was not significant. However, at the 12-month follow-up the pressure pain threshold in the strength training group was higher at two out of six sites compared to the endurance training group and at all six sites compared to the control group, while the pressure pain threshold in the endurance training group was significantly higher at only four out of six sites compared to the control group. Thus, the results suggest that more intensive neck strength training may raise pressure pain threshold in neck muscles more effectively than the neck endurance training. These changes were accompanied by increase in range of motion and maximal isometric neck strength, which were greatest in the strength training group (Ylinen et al., 2003). Neck strength gains in the endurance group were also significant compared to the control group. While maximal neck flexor muscle strength was low, many patients were doing real high intensity strength training for neck flexor muscles, although they used only the head as a training load. Thus, classifying the groups as either endurance or strength training was relative at least at the beginning of the rehabilitation.

In the present study, the mean baseline pressure pain threshold values on the trapezius muscle of the patients were on the same level as the normal values presented by Fischer (1987). This is not surprising, as wide variation in pressure tenderness in the neck muscles is found in both healthy people and patients with neck pain (Takala and Viikari-Juntura, 1991). Thus, normative pressure pain threshold values cannot be used for diagnostic purposes to differentiate patients with chronic neck pain from healthy people (Takala, 1990; Leffler et al., 2003). However, pressure pain threshold measurements may be useful in following up the effects of treatments or training, as shown in the present study. We used a single measurement protocol at each site, as previously done by several other researchers (Levoska and Keinänen-Kiukaanniemi, 1993; Waling et al., 2002). There were practical reasons for this, as it would have been too time-consuming to repeat each measurement across seven measurement sites.

The prevalence of neck pain has reported to be far higher in women than in men (Côté et al., 2000; Aromaa and Koskinen, 2002; Webb et al., 2003).

The pressure pain threshold values in soft tissues have been found to be significantly lower in women compared to men among non-symptomatic people (Hogeweg et al., 1992; Jensen et al., 1992; Isselee et al., 2001) as well as among patients with specific diseases (Takala et al., 1994; Dhondt et al., 1999). Women exhibit 50–80% of the maximal neck strength of men (Jordan et al., 1999; Chiu et al., 2002), a fact which has to be taken in account when planning loading in training programs.

In patients with conditions like fibromyalgia and rheumatoid diseases neck pain is commonly a part of symptoms and the pressure pain threshold has also been found to be lower in soft tissues in patients suffering from fibromyalgia (Mikkelsson et al., 1992; Granges and Littlejohn, 1993; Kosek et al., 1995) and rheumatoid arthritis (Dhondt et al., 1999; Incel et al., 2002) compared to healthy controls. Training may have a different effect than in the case of non-specific neck pain and thus, in the present study these conditions were controlled as far as possible by the exclusion criteria.

Persson et al. (2000) reported that unilateral loading of the shoulder in a static holding test resulted in an increased pressure pain threshold also in the muscle of the opposite non-loaded shoulder. Increases in the bilateral pressure pain threshold might be explained by central antinociceptive mechanisms activated by static muscle work. However, the present study does not support the assumption of general rise in the pressure pain threshold, as we found no significant change in the pressure pain threshold at the reference point. There may have been increased activation of the neuromuscular system on the contralateral side during the endurance test, which may explain the increase in pressure pain threshold values in the short-term (Persson et al., 2000).

Myofascial sensitivity in the cervical area has been shown to decrease in response to various physical therapeutic modalities after treatments (Jaeger and Reeves, 1986; Chesterton et al., 2002; Smania et al., 2003). However, no long-term results of these treatments have been reported. Hanten et al. (1997) found no effect on the pressure pain threshold in a single session of head retraction and retraction/extension exercise compared to controls. In a controlled study Takala et al. (1994) found that regularly performed controlled group gymnastics in the workplace over 10 weeks did not significantly affect pain or pressure pain thresholds. The training program consisted of stretching and light aerobic exercises done once a week. Our finding supports this earlier finding that stretching with light aerobic exercising does not seem to have much effect on pressure pain threshold values. Levoska and Keinänen-Kiukaanniemi (1993) compared active and passive physiotherapy in the treatment of neck and shoulder symptoms administered 1–2 times a week over 2 months. After the intervention a statistically significant decrease in neck pain and number of tender points was noticed on palpation of neck and shoulder region in both groups. Pressure pain thresholds in the trapezius and levator scapulae muscles were significantly lower in patients compared to healthy subjects at the baseline, but after the intervention there was no significant difference. Gam et al. (1998) evaluated the effects of massage and exercise over five weeks and continued training thereafter that as a treatment for neck and shoulder pain. The number of myofascial tender points was reduced and pain thresholds rose more in the treatment group compared to controls. However, the impact on neck and shoulder pain was no longer noticed after 6 months. Waling et al. (2000) used pressure algometry to evaluate the effect of three different training methods on chronic neck and shoulder pain in women. The pressure pain threshold values were contradictory in the exercise groups, as higher values were recorded after the intervention at some points and lower values at other points compared to the baseline. The training programs lasting 10 weeks also produced a much smaller change in pain compared to the present study. No long-term increase in pressure pain threshold has been reported previously in a result of active training. This may be due to low training intensity and/or too short interventions.

There may be several mechanisms which increased the pressure pain threshold in the result of muscle training. Researchers have suggested that changes reflecting decreased metabolism of the muscle tissues such as a decrease in concentration of Na+–K+-pumps and adenosine triphosphate are significant in the development of muscle fatigue and pain (Lindman et al., 1991; Booth and Criswell, 1997; Clausen, 2003). Both endurance and strength training increase Na^{+}–K^{+}-pump concentration in the neck muscles involved (Leivseth et al., 1992).

Strength training has been shown to elicit hypertrophy of muscle fibres, while both strength and endurance training induce a decrease in a proportion of cytocrome c oxidase negative fibres and an increase in the number of capillaries around the fibres (Kadi et al., 2000). Resistance exercise transforms a catabolic metabolism into an anabolic one. In women this is related to transient hormonal changes involving only a small increase in testosterone, but a greater increase in growth hormone levels (Häkkinen et al., 2000; Kraemer et al., 1998). An insulin-like growth factor also increases with muscle training (Marx et al., 2001). Thus, pain may be relieved due to modification in the environment of the peripheral nociceptors as a result of increased circulation and metabolism leading to muscle tissue healing and strengthening of other tissues as well.

The neural adaptation occur due to regular training, which is mainly due to the increased firing rates of the motor units, the recruitment of high threshold motor units and the improved control over motor units (Häkkinen and Komi, 1983). Increased motor control means increased activity in both afferent and efferent motor bathways, which may inhibit pathways mediating pain. Increased strength and better motor control may lead to improved stability (Kettler et al., 2002) and thus less strain on ligaments and joint capsules, which may cause irritation and keep on hyperestesia. According to the gate control theory of segmental pain, excitation of muscle spindles, Golgi tendon organs and mechanoreceptors around the joints due to intensive neck training cause increased activity of afferent nerves, which may inhibit the activity of small-diameter afferent fibres mediating pain in the dorsal horn (Melzack and Wall, 1965). Pain inhibitory mechanisms also occur supraspinally especially in the thalamus, basal ganglia and periaqueductal grey region, and pain perception is affected by descending pathways from the central nervous system (Bonica, 1990).

Emotions like fear may exacerbate pain (Keefe et al., 2004). Fear can be diminished or blanked out by consciously exercising structures that have been associated with pain (Klaber et al., 2004). It remains controversial which mechanisms are the most important in effecting a reduction in pain and mechanical hyperalgesia in neck muscles due to muscle training. The relevance of different factors may also vary across individuals.

5. Conclusions

Both strength and endurance training of the neck and shoulder muscles effectively diminished neck pain in the long-term and was associated with decreased pain sensitivity to mechanical pressure on local muscle points in women with chronic neck pain. The results also show that pressure pain threshold measurements may be useful in monitoring rehabilitation in cases of chronic neck pain in follow-up studies.

Acknowledgements

The authors thank physiotherapist Leena Nyrhinen for administering the pressure pain threshold measurements to the patients in the study. The research project was financed by the Social Insurance Institution, Finland.

References

Andersen JH, Kaergaard A, Frost P, Thomsen JF, Bonde JP, Fallentin N, et al. Physical, psychosocial, and individual risk factors for neck/shoulder pain with pressure tenderness in the muscles among workers performing monotonous, repetitive work. Spine 2002;27:660–7.

Antonaci F, Sand T, Lucas GA. Pressure algometry in healthy subjects: Inter-examiner variability. Scand J Rehabil Med 1998;30:3–8.

Aromaa A, Koskinen S, editors. Health and functional capacity in Finland. Baseline results of the Health 2000 health examination survey. Helsinki: Publications of the National Public Health Institute B3/2002; 2002.

Bendtsen L, Jensen R, Olesen J. Decreased pain detection and tolerance thresholds in chronic tension-type headache. Arch Neurol 1996;53:373–6.

Bonica JJ. The management of pain. Philadelphia-London: Lea & Febinger; 1990.

Booth FW, Criswell DS. Molecular events underlying skeletal muscle atrophy and the development of effective countermeasures. Int J Sports Med 1997;18(Suppl. 4):S265–9.

Bovim G. Cervicogenic headache, migraine and tension-type headache. Pressure-pain threshold measurements. Pain 1992;51:169–73.

Chesterton LS, Barlas P, Foster NE, Lundeberg T, Wright CC, Baxter GD. Sensory stimulation (TENS): Effects of parameter manipulation on mechanical pain thresholds in healthy human subjects. Pain 2002;99:253–62.

Chiu TT, Lam TH, Hedley AJ. Maximal isometric muscle strength of the cervical spine in healthy volunteers. Clin Rehabil 2002;16:772–9.

Clausen T. The sodium pump keeps us going. Ann N Y Acad Sci 2003;986:595–602.

Côté P, Cassidy JD, Carroll L. The factors associated with neck pain and its related disability in the Saskatchewan population. Spine 2000;25:1109–17.

Delaney GA, McKee AC. Inter- and intra-rater reliability of the pressure threshold meter in measurement of myofascial trigger point sensitivity. Am J Phys Med Rehabil 1993;72:136–9.

Dhondt W, Willaeys T, Verbruggen LA, Oostendorp RA, Duquet W. Pain threshold in patients with rheumatoid arthritis and effect of manual oscillations. Scand J Rheumatol 1999;28:88–93.

Dixon JS, Bird HA. Reproducibility along a 10-cm vertical visual analogue scale. Ann Rheum Dis 1981;40:87–9.

Fischer AA. Pressure algometer over normal muscles. Standard values, validity and reproducibility of pressure threshold. Pain 1987;30:115–26.

Gam AN, Warming S, Larsen LH, Jensen B, Hoydalsmo O, Allon I, et al. Treatment of myofascial trigger-points with ultrasound combined with massage and exercise – A randomised controlled trial. Pain 1998;77:73–9.

Granges G, Littlejohn G. Pressure pain threshold in pain-free subjects, in patients with chronic regional pain syndromes, and in patients with fibromyalgia syndrome. Arthritis Rheum 1993;36:642–6.

Hanten W, Barrett M, Gillespie-Plesko M, Jump KA, Olson SL. Effects of active head retraction with retraction/extension and

occipital release on the pressure pain threshold of cervical and scapular trigger points. Physiother Theory Prac 1997;13:285–91.
Hogeweg JA, Langereis MJ, Bernards AT, Faber JA, Helders PJ. Algometry. Measuring pain threshold, method and characteristics in healthy subjects. Scand J Rehabil Med 1992;24:99–103.
Hou CR, Tsai LC, Cheng KF, Chung KC, Hong CZ. Immediate effects of various physical therapeutic modalities on cervical myofascial pain and trigger-point sensitivity. Arch Phys Med Rehabil 2002;83:1406–14.
Hägg GM, Åström A. Load pattern and pressure pain threshold in the upper trapezius muscle and psychosocial factors in medical secretaries with and without shoulder/neck disorders. Int Arch Occup Environ Health 1997;69:423–32.
Häkkinen K, Komi P. Electromyographic changes during strength training and detraining. Med Sci Sports Exerc 1983;15:455–60.
Häkkinen K, Pakarinen A, Kraemer WJ, Newton RU, Alen M. Basal concentrations and acute responses of serum hormones and strength development during heavy resistance training in middle-aged and elderly men and women. J Gerontol A Biol Sci Med Sci 2000;55:B95–B105.
Incel NA, Erdem HR, Ozgocmen S, Catal SA, Yorgancioglu ZR. Pain pressure threshold values in ankylosing spondylitis. Rheumatol Int 2002;22:148–50.
Irnich D, Behrens N, Molzen H, König A, Gleditsch J, Krauss M, et al. Randomised trial of acupuncture compared with conventional massage and sham laser acupuncture for treatment of chronic neck pain. BMJ 2001;322:1–6.
Isselee H, De Laat A, Bogaerts K, Lysens R. Long-term fluctuations of pressure pain thresholds in healthy men, normally menstruating women and oral contraceptive users. Eur J Pain 2001;5:27–37.
Jaeger B, Reeves JL. Quantification of changes in myofascial trigger point sensitivity with the pressure algometer following passive stretch. Pain 1986;27:203–10.
Jensen R, Rasmussen BK, Pedersen B, Lous I, Olesen J. Cephalic muscle tenderness and pressure pain threshold in a general population. Pain 1992;48:197–203.
Jordan A, Mehlsen J, Bülow PM, Østergaard K, Danneskiold-Samsøe B. Maximal isometric strength of the cervical musculature in 100 healthy volunteers. Spine 1999;24:1343–8.
Kadi F, Ahlgren C, Waling K, Sundelin G, Thornell LE. The effects of different training programs on the trapezius muscle of women with work-related neck and shoulder myalgia. Acta Neuropathol 2000;100:253–8.
Keefe FJ, Rumble ME, Scipio CD, Giordano LA, Perri LM. Psychological aspects of persistent pain: Current state of the science. J Pain 2004;5:195–211.
Kettler A, Hartwig E, Schultheiss M, Claes L, Wilke HJ. Mechanically simulated muscle forces strongly stabilize intact and injured upper cervical spine specimens. J Biomech 2002;35:339–46.
Klaber Moffett JA, Carr J, Howarth E. High fear-avoiders of physical activity benefit from an exercise program for patients with back pain. Spine 2004;29:1167–72.
Koltyn KF, Trine MR, Stegner AJ, Tobar DA. Effect of isometric exercise on pain perception and blood pressure in men and women. Med Sci Sports Exerc 2001;33:282–90.
Kosek E, Ekholm J. Modulation of pressure pain thresholds during and following isometric contractions. Pain 1995;61:482–6.
Kosek E, Ekholm J, Hansson P. Increased pressure pain sensibility in fibromyalgia patients is located deep to the skin but not restricted to muscle tissue. Pain 1995;63:335–9.
Kraemer WJ, Staron RS, Hagerman FC, Hikida RS, Fry AC, Gordon SE, et al. The effects of short-term resistance training on endocrine function in men and women. Eur J Appl Physiol Occup Physiol 1998;78:69–76.
Lange Anderssen K, Sephard RJ, Denoling H, Varnauskas E, Masinoni R. Fundamentals of Exercising Testing. Geneva, Switzerland: World Health Organization; 1971.
Langemark M, Jensen K, Jensen TS, Olesen J. Pressure pain thresholds and thermal nociceptive thresholds in chronic tension-type headache. Pain 1989;38:203–10.
Leffler A-S, Hansson P, Kosek E. Somatosensory perception in patients suffering from long-term trapezius myalgia at the site overlying the most painful part of the muscle and in an area of pain referral. Eur J Pain 2003;7:267–76.
Leivseth G, Clausen T, Everts ME, Bjordal E. Effects of reduced joint mobility and training on Na,K-ATPase and Ca-ATPase in skeletal muscle. Muscle Nerve 1992;15:843–9.
Levoska S. Manual palpation and pain threshold in female office employees with and without neck-shoulder symptoms. Clin J Pain 1993;9:236–41.
Levoska S, Keinänen-Kiukaanniemi S. Active or passive physiotherapy for occupational cervicobrachial disorders? A comparison of two treatment methods with a 1-year follow-up. Arch Phys Med Rehabil 1993;74:425–30.
Lindman R, Hagberg M, Angqvist KA, Soderlund K, Hultman E, Thornell LE. Changes in muscle morphology in chronic trapezius myalgia. Scand J Work Environ Health 1991;17:347–55.
Madeleine P, Lundager B, Voigt M, Arendt-Nielsen L. Sensory manifestations in experimental and work-related chronic neck-shoulder pain. Eur J Pain 1998;2:251–60.
Marx JO, Ratamess NA, Nindl BC, Gotshalk LA, Volek JS, Dohi K, et al. Low-volume circuit versus high-volume periodized resistance training in women. Med Sci Sports Exerc 2001;33:635–43.
Melzack R, Wall PD. Pain mechanisms: A new theory. Science 1965;150:971–8.
Mikkelsson M, Latikka P, Kautiainen H, Isomeri R, Isomaki H. Muscle and bone pressure pain threshold and pain tolerance in fibromyalgia patients and controls. Arch Phys Med Rehabil 1992;73:814–8.
Nakata M, Hagner I-M, Jonsson B. Trapezius muscle pressure pain threshold and strain in the neck and shoulder regions during repetitive light work. Scand J Rehab Med 1993;25:131–7.
Ohrbach R, Gale EN. Pressure pain thresholds, clinical assessment, and differential diagnosis: Reliability and validity in patients with myogenic pain. Pain 1989;39:157–69.
Persson AL, Hansson GA, Kalliomäki A, Moritz U, Sjölund BH. Pressure pain thresholds and electromyographically defined muscular fatigue induced by a muscular endurance test in normal women. Clin J Pain 2000;16:155–63.
Schoenen J, Bottin D, Hardy F, Gerard P. Cephalic and extracephalic pressure pain thresholds in chronic tension-type headache. Pain 1991;47:145–9.
Smania N, Corato E, Fiaschi A, Pietropoli P, Aglioti SM, Tinazzi M. Therapeutic effects of peripheral magnetic stimulation on myofascial pain syndrome. Clin Neurophysiol 2003;114:350–8.
Takala EP. Pressure pain threshold on upper trapezius and levator scapulae muscles. Repeatability and relation to subjective symptoms in a working population. Scand J Rehabil Med 1990;22:63–8.
Takala E-P, Viikari-Juntura E. Muscle force, endurance and neck-shoulder symptoms of sedentary workers. An experimental study on bank cashiers with and without symptoms. Int J Ind Ergon 1991;7:123–32.
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.
Vernon H, Mior S. The neck disability index: A study of reliability and validity. J Manipul Physiol Ther 1991;14:409–15.
Viikari-Juntura E, Takala E-P, Alaranta H. Neck and shoulder pain and disability. Scand J Rehab Med 1988;20:167–73.
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;85:201–7.
Webb R, Brammah T, Lunt M, Urwin M, Allison T, Symmons D. Prevalence and predictors of intense, chronic, and disabling neck

and back pain in the UK general population. Spine 2003;28:1195–202.

Ylinen J, Ruuska J. Clinical use of neck isometric strength measurement in rehabilitation. Arch Phys Med Rehabil 1994;75:465–9.

Ylinen J, Salo P, Nykänen M, Kautiainen H, Häkkinen A. Decreased isometric neck muscle strength in women with chronic neck pain and the repeatability of neck strength measurements. Arch Phys Med Rehabil 2004;85:1303–8.

Ylinen J, Takala EP, Nykänen M, Häkkinen A, Mälkiä E, Pohjolainen T, et al. Active neck muscle training in the treatment of chronic neck pain in women: A randomized controlled trial. JAMA 2003;289:2509–16.