

Effect of physical training on function of chronically painful muscles: a randomized controlled trial

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Andersen LL, Andersen CH, Zebis MK, Nielsen PK, Sjøgaard K, Sjøgaard G. Effect of physical training on function of chronically painful muscles: a randomized controlled trial. *J Appl Physiol* 105: 1796–1801, 2008. First published October 23, 2008; doi:10.1152/jappphysiol.91057.2008.—Pain and tenderness of the upper trapezius muscle is frequent in several occupational groups. The objective of this study is to investigate the effect of three contrasting interventions on muscle function and pain in women with trapezius myalgia. A group of employed women ($n = 42$) with a clinical diagnosis of trapezius myalgia participated in a 10-wk randomized controlled intervention: specific strength training of the neck/shoulder muscles, general fitness training performed as leg bicycling, or a reference intervention without physical activity. Torque and electromyography (EMG) were recorded during maximal shoulder abductions in an isokinetic dynamometer at -60 , 60 , 0 , and 180° /s. Furthermore, a submaximal reference contraction with only the load of the arms was performed. Significant changes were observed only in the specific strength training group. Pain decreased by 42–49% ($P < 0.01$ – 0.05). Whereas the EMG activity of the unaffected deltoid remained unchanged during the maximal contractions, an increase in EMG amplitude (42–86%; $P < 0.001$ – 0.05) and median power frequency (19%; $P < 0.001$) were observed for the painful trapezius muscle. Correspondingly, torque increased by 18–53% ($P < 0.001$ – 0.05). EMG during the reference contraction decreased significantly for both the trapezius and deltoid muscles ($P < 0.01$). In conclusion, specific strength training relieves pain and increases maximal activity specifically of the painful trapezius muscle, leading to increased shoulder abduction strength in women with trapezius myalgia. Furthermore, decreased relative workload may indirectly augment pain reduction.

isokinetic; isometric; torque; neck pain; trapezius myalgia

WORK-RELATED NECK/SHOULDER pain is a major concern in the industrialized world because of decreased productivity and increased health care costs, and it is the most prevalent type of musculoskeletal trouble in sedentary occupational groups (16, 29). Even among adolescents, this trend is growing, posing a future challenge to society (19). Highlighting the problem, the 1-yr prevalence of neck symptoms among female office workers has been reported to be 80% (10). Trapezius myalgia (i.e., chronic pain and tenderness of the upper trapezius muscle) accounts for the vast majority of nonspecific neck pain (6, 25). Thus strategies for rehabilitation of this condition have high clinical relevance.

Neck/shoulder pain has been associated with muscle weakness (11, 23, 34), likely secondary to pain inhibition of motor

outflow (7, 28, 32, 36). In response to intensive rehabilitation with resistance training after knee injury, a relief of inhibition has been shown in the muscles of the leg (17). Although strengthening exercises has also been demonstrated to reduce neck area pain (1, 4, 6, 12, 18, 30, 41), a causal link between pain relief, increased neural activation, and strength gains has not been documented.

Whereas daily labor tasks occur during situations of both dynamic and static muscle work, training-induced gains in maximal neck/shoulder strength capacity have typically been measured solely during static contraction (1, 4, 6, 12, 18, 30, 41). In contrast, dynamic muscle strength can be assessed in a highly standardized manner by isokinetic dynamometry to more completely evaluate gains in functional muscle strength capacity (3, 13).

The complex anatomy of the shoulder necessitates coordinated activation of several muscles to provide motion and stability (38). During most types of shoulder joint movement, the trapezius and deltoid muscles are activated synergistically (22). Our laboratory has recently identified specific reduction of trapezius muscle activity, but not of the deltoid, during maximal shoulder abduction in women with trapezius myalgia (7). Thus it is relevant to investigate whether specific strength training of the neck/shoulder muscles, which is known to decrease pain, will preferentially increase activity of the painful trapezius compared with the deltoid and thereby result in a more balanced activation of these muscles. As a model to investigate this, electromyographic (EMG) activity can be measured in the trapezius and deltoid during maximal shoulder abduction before and after a period of specific strength training. In the same group of subjects, our laboratory has recently reported muscle strength, EMG, and muscle fiber-type composition compared with matched controls in a cross-sectional study design (7, 8), as well as longitudinal changes in pain in response to training intervention (6). Furthermore, our laboratory has validated the specificity of muscle activation of the strengthening exercises used in this study (5).

The aim of the present study was to investigate the effect of three different interventions on changes in isokinetic shoulder abduction strength as well as EMG activity of the painful trapezius compared with the unaffected deltoid muscle in women with trapezius myalgia. We hypothesized that specific strength training increases activation specifically of the painful trapezius, leading to increased shoulder abduction strength. Additionally, we expected muscular hypertrophy in response to the specific strength training intervention.

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MATERIALS AND METHODS

Study design. We performed a randomized controlled trial in Copenhagen, Denmark. In total, 812 workers replied to a screening questionnaire and were recruited into the study based on specified criteria on self-reported neck/shoulder pain as reported previously (6). Final inclusion was based on subsequent blinded clinical testing. In total, 42 women with clinically diagnosed trapezius myalgia participated (age 44 ± 8 yr, height 165 ± 6 cm, weight 72 ± 15 kg). Exclusion criteria's were previous trauma, life-threatening diseases, whiplash injury, cardiovascular diseases, or arthritis in the neck and shoulder. The participants were active at the labor market and recruited from workplaces with monotonous and repetitive work tasks according to criteria stated previously (26), and further including prolonged static muscle activity, insufficient variation in movements, as well as a high degree of precision, all of which have been recognized as risk factors for development of musculoskeletal disorders in the neck/shoulder area (35). All participants went through a clinical investigation of the neck and shoulder, performed by trained clinical personnel who worked together as a calibrated team as described in Juul-Kristensen et al. (25). In case of decreased range of motion in the neck, a test was conducted of neck mobility with and without passive lifting of the shoulder to reveal whether decreased range of motion was due to muscle tightness or, e.g., columnar structures such as bone on bone contact. Tenderness was determined during palpation of the muscle with a prelearned pressure of ~ 4 kg/cm² applied by the clinical personnel. Briefly, the main criteria for a clinical diagnosis of trapezius myalgia were 1) chronic or frequent pain in the neck area, 2) tightness of the upper trapezius muscle, and 3) palpable tenderness of the upper trapezius muscle (6, 8).

Combining this information resulted in a cluster randomization, regarding work site, including information on age, body mass index, seniority, self-reported pain, and clinical findings. Following the group allocations, we tested for possible group differences and confirmed no differences between groups regarding the latter variables. The cluster design was chosen to minimize contamination and maximize compliance. The first group (SST; $n = 18$) performed high-intensity strength training with five dumbbell exercises specifically for the shoulder and neck muscles (1-arm row, shoulder abduction, shoulder elevation, reverse flyes, and upright row) for 20 min three times a week. The specificity and high level of muscle activation of these exercises have been documented previously (5). During each session, three of the five different exercises were performed for three sets of each exercise with relative loadings of 8–12 repetitions maximum in a periodized and progressive manner. Such type of planned variation is generally recommended by the American College of Sports Medicine to ensure efficient gains in response to strength training (27). The second group (GFT; $n = 16$) performed general fitness training on a bicycle ergometer with relative loadings of 50–70% of the maximal oxygen uptake for 20 min three times a week. The loading was estimated based on relative workload = (working heart rate – resting heart rate)/(maximum heart rate – resting heart rate), where resting heart rate was set to 70 beats/min, and maximum heart rate was estimated as $220 - \text{age}$ (9). The subjects performed leg bicycling with in an upright position with relaxed shoulders. The third group (REF; $n = 8$) was a reference group that received information about health-promoting activities for a total of 1 h/wk but were not offered any physical training. Unfortunately, the timewise successive balanced recruitment resulted in a somewhat smaller REF group compared with the two other groups, e.g., due to withdrawal of participants who initially stated they would volunteer for the study.

All subjects were informed about the purpose and content of the project and gave written informed consent to participate in the study, which conformed to The Declaration of Helsinki, and was approved by the Local Ethical Committee (KF 01-138/04). The study qualified for registration in the International Standard Randomised Controlled Trial Number Register: ISRCTN87055459.

Intensity of pain. Intensity of pain in the trapezius muscle was rated by each subject on a 100-mm visual-analog-scale, where 0 mm is “no pain” and 100 mm is “worst imaginable pain” (21). Pain was recorded at rest as “pain at present” before and immediately after the dynamometer test, before and after the 10-wk intervention period.

Dynamometry and EMG. Shoulder abduction strength was measured in a Biodex Medical isokinetic dynamometer (System 3 Pro, Shirley, NY) according to previously described procedures (7). Only the most painful side was tested, which in most cases (70%) was the dominant side. Briefly, maximal shoulder abductions were performed in a range of 15–135° (anatomic angle) at slow and fast concentric contraction (60 and 180°/s, respectively), slow eccentric contraction (60°/s), and static contraction (at 75°). EMG signals were recorded synchronously from the upper trapezius muscle and the middle part of the deltoid muscle with a bipolar surface EMG configuration (Neuroline 720 01-K, Medicotest, Ølstykke, Denmark) and an interelectrode distance of 2 cm (20). The EMG electrodes were connected directly to small preamplifiers located near the recording site. The raw analog EMG signals were led through shielded wires to instrumental differentiation amplifiers, with a bandwidth of 10–400 Hz and a common mode rejection ratio of 0.100 dB. All torque, position, and EMG signals were sampled synchronously at 1,000 Hz using a 16-bit analog-to-digital converter (DAQ Card-AI-16XE-50, National Instruments, Austin, TX) and stored on a laptop for further analysis.

During offline analyses, all torque and position signals were digitally filtered by a 12- and 8-Hz low-pass fourth-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 (7, 40). 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. 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 (39). For the isokinetic test,

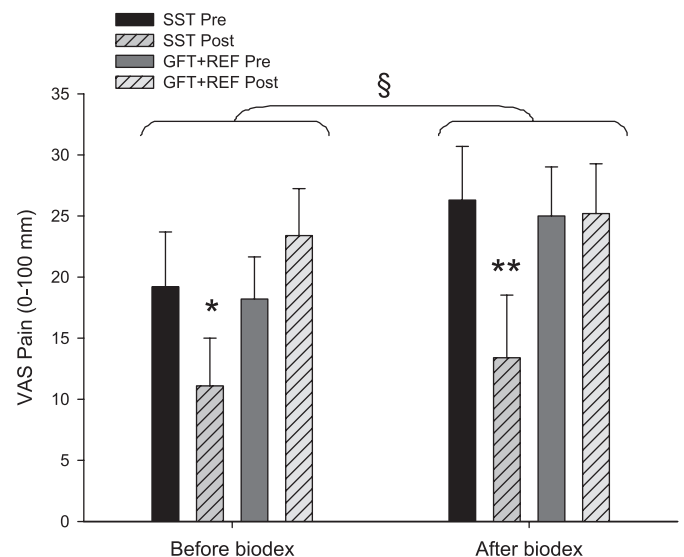


Fig. 1. Intensity of pain in the trapezius muscle rated by a visual-analog scale (VAS) for the 3 groups of subjects. SST, specific strength training of the neck/shoulder muscles; GFT, general fitness training performed as leg bicycling; REF, reference intervention without physical activity; Pre, preintervention; Post, postintervention. Pain was generally increased in response to the dynamometer test: §after Biodex > before Biodex, $P < 0.001$. Pain decreased in response to SST both before and after the dynamometer test: *postintervention < preintervention, $P < 0.05$; postintervention < preintervention, ** $P < 0.01$.

the average moment and EMG amplitude in the midrange of motion (i.e., 55–95°) was calculated and used for further analyses. For the static test at 75° the highest average torque and EMG amplitude over 500 ms was used.

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) centered 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.

Reference contraction. Before the dynamometer test, subjects performed a low-force reference contraction with straight arms maintained statically in the horizontal position in the frontal plane and palms facing down for 20 s, with no support or added weight, while the trapezius and deltoideus EMG was simultaneously measured as described above. For each muscle, EMG amplitude was expressed as a percentage of EMG amplitude measured during MVC.

Muscle thickness. 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 midpoint of the image. Determination of muscle thickness by ultrasonography has previously been shown to be highly reliable and valid (31).

Statistics. Requesting a statistical power of 80%, a priori calculations showed that 14 participants should be included in each group for allowing a 15% change with intervention to become significant at the 5% level for the variables and their SDs used in this study with paired analysis.

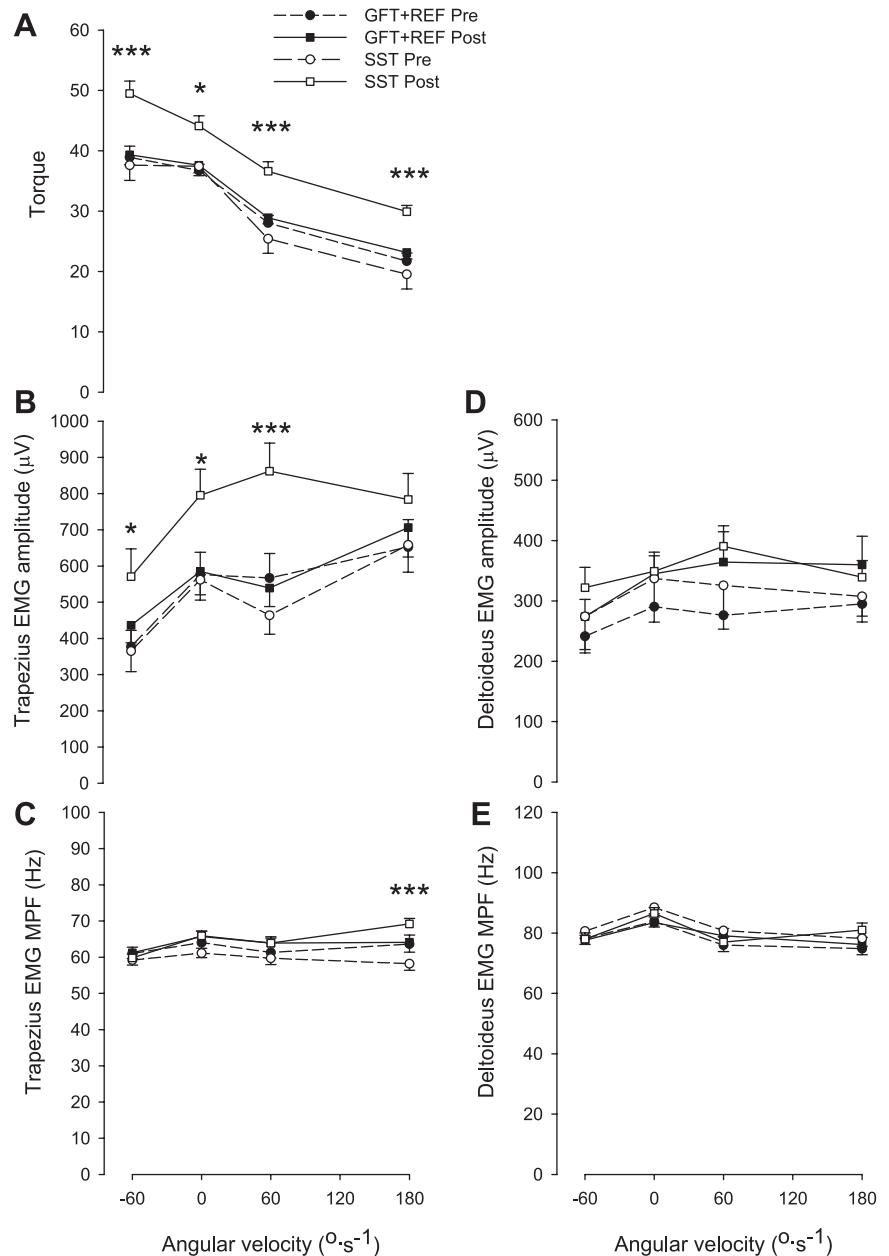


Fig. 2. Torque (A), electromyograph (EMG) amplitude (B and D), and EMG MPF (C and E) at eccentric ($-60^{\circ}/s$), static ($0^{\circ}/s$), slow concentric ($60^{\circ}/s^{-1}$), and fast concentric contraction ($180^{\circ}/s^{-1}$) for the trapezius and deltoid muscles. *Increase in SST from pre- to postintervention, $P < 0.05$. ***Increase in SST from pre- to postintervention, $P < 0.001$.

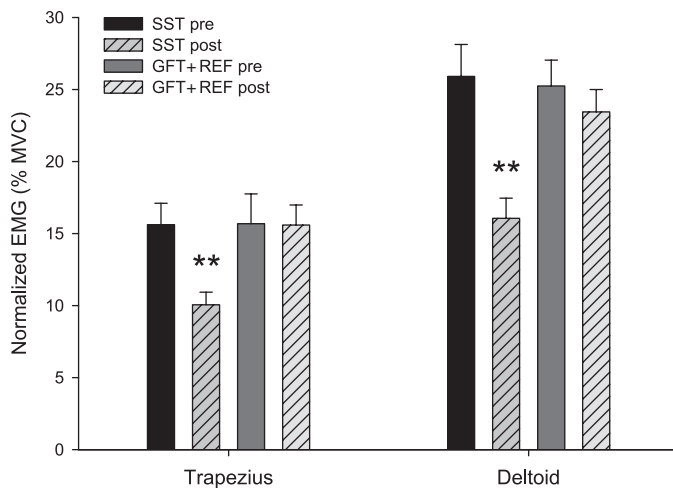


Fig. 3. EMG amplitude during the reference contraction normalized to EMG amplitude during maximal voluntary contraction (MVC). **Decrease in SST from pre- to postintervention, $P < 0.01$.

Analysis of variance with repeated measures was performed in SAS version 9 using the mixed procedure to locate differences in the main parameters. Factors included in the model for torque were group (SST, GFT, and REF), test round (pre- and postintervention) and velocity (-60 , 0 , 60 and $180^\circ/s$). For EMG variables, the factor muscle (deltoid and trapezius) was added to the model. Factors included in the model for pain was group (SST, GFT, and REF), test round (pre- and postintervention) and test time (before and after Biodex test). For the above analyses, appropriate interactions were tested as well, e.g., group \times velocity \times test round, and group \times muscle times test round. Changes in muscle thickness were evaluated with a two-way analysis of variance (group \times test round) with repeated measures. When a significant main effect was found, Bonferroni-corrected post hoc tests were performed to locate differences. Spearman's correlation coefficient was calculated between changes in torque and EMG. An alpha level of 5% was chosen as statistically significant, and results are reported as means \pm SE.

RESULTS

In response to the 10-wk intervention, significant changes were observed in SST alone. Between GFT and REF, the response was not significantly different for any of the present variables; therefore, the results of these two group were collapsed ($n = 24$) and compared with SST to yield higher statistical power.

Pain. There was a significant group \times test round effect ($P < 0.001$). Post hoc tests showed that pain decreased in SST both before (42%; $P < 0.05$) and after the dynamometer test (49%; $P < 0.01$) from pre- to postintervention (Fig. 1). Furthermore, there was a significant test time effect (i.e., pooled for all groups); pain immediately after the dynamometer test was significantly higher than before ($P < 0.01$).

Torque. There was a significant group \times test round effect for torque ($P < 0.05$). Post hoc tests showed that torque increased during all contraction modes and velocities in SST (Fig. 2A); slow eccentric torque from 37.6 ± 2.5 to 49.5 ± 2.0 N \cdot m ($P < 0.001$), isometric from 37.4 ± 1.5 to 44.1 ± 1.7 N \cdot m ($P < 0.05$), slow concentric from 25.4 ± 2.4 to 36.6 ± 1.6 N \cdot m ($P < 0.001$), and fast concentric from 19.5 ± 2.4 to 29.9 ± 1.0 N \cdot m ($P < 0.001$).

EMG amplitude. There was a significant group \times test round \times muscle effect for EMG amplitude ($P < 0.001$). Post

hoc tests showed that only trapezius EMG amplitude increased from pre- to posttraining ($P < 0.001$). To locate differences across contraction velocities, further statistical analyses were performed, showing that there was a significant group \times test-round \times velocity effect for trapezius EMG amplitude ($P < 0.05$). Post hoc tests showed an increase in trapezius EMG amplitude in SST during isometric (from 562 ± 56 to 795 ± 72 μ V; $P < 0.05$), slow concentric (from 464 ± 52 to 862 ± 78 μ V; $P < 0.001$), and slow eccentric contraction (from 365 ± 57 to 570 ± 77 μ V; $P < 0.05$; Fig. 2B). The increase in trapezius EMG amplitude was positively correlated with the increase in torque during eccentric ($R = 0.57$, $P < 0.05$) and slow concentric contraction ($R = 0.47$, $P < 0.05$). No significant change from baseline was observed for deltoideus EMG amplitude (Fig. 2D).

EMG MPF. There was a significant group \times test round \times velocity effect for trapezius EMG MPF ($P < 0.01$). Post hoc tests showed that trapezius EMG MPF increased significantly only during fast concentric contraction in SST (from 58 ± 1.8 to 69 ± 1.5 Hz; $P < 0.001$; Fig. 2C), and that this was positively correlated to the increase in torque ($R = 0.62$, $P < 0.01$). No significant changes occurred in deltoideus EMG MPF (Fig. 2E).

Reference contraction. There was a significant group \times test round effect for normalized EMG amplitude ($P < 0.05$). Post hoc tests showed a decrease in normalized EMG in SST for the trapezius and deltoid muscles from pre- to posttraining ($P < 0.01$; Fig. 3).

Muscle thickness. There was a non-significant trend for a group \times test round effect for muscle thickness ($P = 0.12$). Post hoc tests showed significant hypertrophy of 7% in SST (from 10.4 ± 0.5 to 11.3 ± 0.4 mm; $P < 0.05$), whereas GFT+REF remained unchanged (from 9.4 ± 0.4 vs. 9.6 ± 0.4 mm; not significant).

DISCUSSION

This study demonstrates that specific strength training relieves reported neck pain and increases activity specifically of

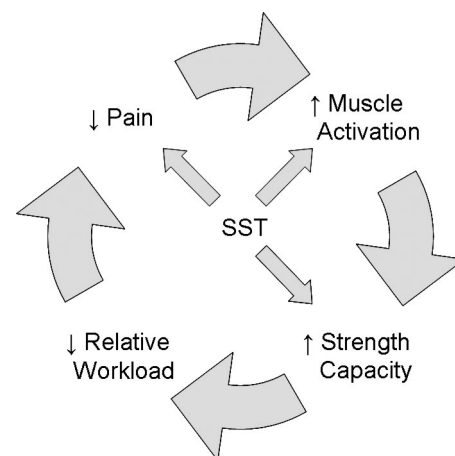


Fig. 4. The Wheel of Pain Reduction. This model proposes pain reduction as a result of training, leading to increased muscle activation and thus strength capacity. Accordingly relative exposure during low-force work tasks is lowered, contributing to further pain reduction, and thus the circle is closed. Furthermore, specific strength training per se has beneficial effects on muscle activation and strength, enhancing potency of the circle.

the painful trapezius muscle, leading to increased isokinetic as well as static shoulder abduction strength in women with trapezius myalgia syndrome diagnosis.

In the present group of subjects, our laboratory has previously shown in a cross-sectional study design specific inhibition of the painful trapezius muscle during maximal shoulder abduction (7). The present study shows that specific strength training mitigates this phenomenon, as muscle strength and trapezius EMG activity were raised to levels comparable to those previously reported in healthy matched controls (7). Whereas activity of the unaffected deltoid muscle remained unchanged, a specific increase of the painful trapezius muscle was seen along with decreased intensity of pain. Based on these results, we suggest that trapezius activity increased due to reduction of pain-related inhibition, leading to increased strength. Similarly, pain block of torn supraspinatus muscles has been shown to acutely increase shoulder abduction torque (23). The strength exercises used in the present study, i.e., lateral raise, shrugs, one-arm row, upright row, and reverse flies, involve high activation of trapezius and deltoid muscles (5). Thus parallel increased activation of the trapezius and deltoid in response to training intuitively would be expected. In sharp contrast, increased activation was seen solely in the painful trapezius, suggesting an influence of pain reduction on increased muscle activation. The demonstrated gains in isokinetic muscle strength were due to increased trapezius activation, indicating that trapezius activity is especially important during maximal dynamic shoulder abduction. This is supported by the finding that the upper trapezius guides the scapula and clavicle toward the plane of abduction and elevates the clavicle to allow upward rotation of the scapula (37).

The results suggest that slow and fast isokinetic muscle strength increased through different adaptation mechanisms. Whereas gains in slow concentric, eccentric, and static muscle strength were paralleled by increased EMG amplitude, the gain in fast concentric strength was related to increased EMG MPF. Despite the inherent variance associated with EMG measurements, the amplitude of the EMG signal is roughly related to muscle force (24), and it expresses a combination of recruitment, rate coding, and synchronization of motor units (15). Thus slow concentric, eccentric, and static muscle strength could have increased through a generally increased neural drive. Similarly, in healthy young subjects, a strong association exists between increased EMG amplitude and gains isokinetic muscle strength in response to strength training (2). It can be speculated that EMG MPF increased during fast concentric contraction due to enhanced recruitment of high-threshold motor units dominated by large fast-twitch fibers. Adaptations in muscle fibre properties and levels of motor unit synchronization may also influence these findings (14). Overall, trapezius muscle hypertrophy was minor (~7%), which would further support strength gains primarily through neural adaptation mechanisms. Another possible source of strength increase could be changes in muscle architecture, e.g., increased fascicle length and muscle fiber pennation angle, as shown in resistance training studies involving the leg muscles (33).

Importantly, muscle strength improved during the entire torque-velocity range, which documents a general increase of functional strength capacity. This is important for employees who are involved in a variety of job tasks with both dynamic and static muscle work, because increased strength capacity

lowers the relative workload during daily labor tasks. In the present study, this was reflected by lower relative EMG amplitude during the reference contraction, i.e., when statically holding the weight of the arm. Consequently, lower relative exposure during daily work can be speculated to have indirect beneficial effects on pain reduction. Based on these present findings, we propose a model of pain reduction in response to specific strength training: "The Wheel of Pain Reduction" (Fig. 4); pain reduction as a result of training leads to increased muscle activation and thus strength capacity. Accordingly, exposure during low-force work tasks is lowered, contributing to further pain reduction, and thus the circle is closed. We suggest that specific strength training per se has beneficial effects on muscle activation and strength, enhancing potency of the circle.

In conclusion, specific strength training intervention relieves pain and increases maximal activity specifically of the painful trapezius muscle, leading to increased shoulder abduction strength in women with trapezius myalgia. Furthermore, decreased relative workload may indirectly augment pain reduction.

GRANTS

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