

ORIGINAL ARTICLE

Comparing Biofeedback With Active Exercise and Passive Treatment for the Management of Work-Related Neck and Shoulder Pain: A Randomized Controlled Trial

Chao Ma, PhD, MD, Grace P. Szeto, PhD, Tiebin Yan, PhD, MD, Shaoling Wu, PhD, MD, Caina Lin, BSc, Lijuan Li, BSc

ABSTRACT. Ma C, Szeto GP, Yan T, Wu S, Lin C, Li L. Comparing biofeedback with active exercise and passive treatment for the management of work-related neck and shoulder pain: a randomized controlled trial. *Arch Phys Med Rehabil* 2011;92:849-58.

Objectives: To compare the effects of biofeedback with those of active exercise and passive treatment in treating work-related neck and shoulder pain.

Design: A randomized controlled trial with 3 intervention groups and a control group.

Setting: Participants were recruited from outpatient physiotherapy clinics and a local hospital.

Participants: All participants reported consistent neck and shoulder pain related to computer use for more than 3 months in the past year and no severe trauma or serious pathology. A total of 72 potential participants were recruited initially, of whom a smaller group of individuals (n=60) completed the randomized controlled trial.

Interventions: The 3 interventions were applied for 6 weeks. In the biofeedback group, participants were instructed to use a biofeedback machine on the bilateral upper trapezius (UT) muscles daily while performing computer work. Participants in the exercise group performed a standardized exercise program daily on their own. In the passive treatment group, interferential therapy and hot packs were applied to the participants' necks and shoulders. The control group was given an education booklet on office ergonomics.

Main Outcome Measures: Pain (visual analog scale), neck disability index (NDI), and surface electromyography were assessed preintervention and postintervention. Pain and NDI were reassessed after 6 months.

Results: Postintervention, average pain and NDI scores were reduced significantly more in the biofeedback group than in the other 3 groups, and this was maintained at 6 months. Cervical erector spinae muscle activity showed significant reductions postintervention in the biofeedback group, and there were consistent trends of reductions in the UT muscle activity.

Conclusions: Six weeks of biofeedback training produced more favorable outcomes in reducing pain and improving muscle activation of neck muscles in patients with work-related neck and shoulder pain.

Key Words: Feedback; Electrical stimulation; Exercise; Neck pain; Rehabilitation; Shoulder pain.

© 2011 by the American Congress of Rehabilitation Medicine

COMPUTER USE DOMINATES work and permeates home and school environments in modern society. It is estimated that 90% of office workers use computers daily, with 40% reporting use for at least 4 hours per day.¹ Such intensive use can greatly increase the risk of musculoskeletal disorders,^{1,2} and indeed, prevalence rates of work-related neck and shoulder disorders have increased considerably among office workers over the past few decades.² Among the factors that may influence these disorders is the sustained and increased activity of major stabilizing muscles such as the trapezius in maintaining prolonged static posture.³

Although research literature⁴⁻⁸ has supported the positive effects of exercise training and physical activity in managing musculoskeletal disorders, the underlying mechanisms are still not clear. Prolonged computer work may lead to static muscle tension, and this may contribute to fatiguing or overloading of postural muscles, resulting in pain and degenerative changes in these muscles.^{3,9,10} If this is the main cause of work-related neck and shoulder pain, then regular exercise or physical activity should help to relieve pain by alleviating static muscle tension. However, many individuals tend to have fairly fixed postural habits, and they may resume work with the same static posture and muscle tension after taking an exercise break. Work in our laboratory¹¹ has shown that high levels of trapezius muscle activity are elicited as soon as workers place their hands on the keyboard, even before any work begins. These results suggest that habitual maladaptive motor control patterns are crucial mechanisms contributing to the development of work-related musculoskeletal disorders (WMSDs).

Recent research studies have found that biofeedback can be applied to reduce muscular tension in order to treat

From the Department of Rehabilitation Medicine, Sun Yat-sen Memorial Hospital of Sun Yat-sen University, Guangzhou (Ma, Yan, Wu, Lin, Li), Department of Rehabilitation Sciences, Hong Kong Polytechnic University, Hong Kong (SAR) (Ma, Szeto), China.

Supported by a research grant from Hong Kong Polytechnic University (grant no. A-PH83).

Presented to the International Society of Electromyography and Kinesiology, June 16-19, 2010, Aalborg, Denmark.

No commercial party having a direct financial interest in the results of the research supporting this article has or will confer a benefit on the authors or on any organization with which the authors are associated.

Reprint requests to Grace P. Szeto, PhD, Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong SAR, China, e-mail: rsgszeto@inet.polyu.edu.hk.

0003-9993/11/9206-0085\$36.00/0
doi:10.1016/j.apmr.2010.12.037

List of Abbreviations

ANOVA	analysis of variance
CES	cervical erector spinae
EMG	electromyogram
NDI	Neck Disability Index
RCT	randomized controlled trial
UT	upper trapezius
VAS	visual analog scale
WMSDs	work-related musculoskeletal disorders

WMSDs. A few studies have examined the effects of biofeedback interventions to modify muscle activation in office workers and influence their symptoms.¹²⁻¹⁶ Hermens and colleagues¹²⁻¹⁵ have developed a system of myofeedback based on the Cinderella hypothesis, which proposed that pain is caused by an overuse of low-threshold motor units. They designed a biofeedback machine that provides feedback signals when upper trapezius (UT) activity is above a prefixed threshold. In their studies, myofeedback training for 4 weeks (up to 8h/d) produced significant reductions in symptoms, although the effects were not significantly better than those of conventional ergonomic training.¹³⁻¹⁵ Faucett et al¹⁶ trained computer users for 6 weeks using a biofeedback training protocol called muscle learning therapy. They reported significant reductions in trapezius and forearm muscle activity as well as significant reduction in symptoms after 18 and 32 weeks.¹⁶ This training has been proposed to enhance the patient's proprioceptive awareness and ability to regulate muscle activity in performing simple tasks at first, and subsequently in more complex work tasks.

There has been little research directly comparing the effects of biofeedback with the effects of traditional physiotherapy approaches such as active exercise and passive treatment modalities. Traditionally, passive physiotherapy involving electric stimulation and/or heat therapy has been commonly used to provide symptomatic relief in patients with neck and/or shoulder pain. Transcutaneous electric nerve stimulation has been shown to be effective in relieving musculoskeletal pain,^{17,18} but it is not clear whether habitual muscle tension during work can also be corrected through such pain-relieving treatment. When patients are satisfied with temporary symptomatic relief through passive treatment, the problem will often recur if postural or muscle activation habits do not get corrected. Hence, educating patients to correct their maladaptive posture and muscle control during actual work tasks is very important.

A few reports of randomized controlled trials (RCTs) have compared the effects of exercises with those of manual therapy,¹⁹ strength training,^{20,21} and education,^{22,23} with varying degrees of effectiveness reported for exercise therapy and electric modalities. However, in most studies, the outcome measure is pain, and there is no evaluation of the effects of different interventions on motor control mechanisms during functional tasks.²⁴ Evaluating the effects of treatment on motor control mechanisms may be a critical issue to address in designing effective therapeutic interventions, because the musculoskeletal problems may develop from the work habits.

It is important to compare the effects of biofeedback aimed at retraining muscle activation levels during realistic work situations with the effects of performing active exercises during work breaks, as well as with the effects of passive modalities in the clinic aimed at symptomatic relief. This study tested the hypothesis that by reducing muscle activity in the neck and shoulder postural stabilizing muscles, biofeedback training would be more effective than the other approaches.

METHODS

Study Design

The study was an RCT with 4 groups: a biofeedback group, an active exercise group, a passive treatment group, and a control group.

Participants

The participants were recruited from 2 universities in Hong Kong and Guangzhou, China, and from nearby outpatient clinics between January 2008 and June 2009. A full description of the study, including the randomization process, was given to each patient. The study was approved by the review boards of both participating institutions, and informed consent was obtained from all participants. The inclusion and exclusion criteria were determined with reference to those of past RCTs evaluating similar interventions.¹³⁻¹⁵ The inclusion criteria were as follows: (1) daily computer user; (2) a past and present history of computer-related neck and shoulder discomfort; (3) had worked on a computer for at least 5 years; (4) had no more than 3 months out of work, except for vacations, during the previous 5 years; (5) neck and/or shoulder pain on at least 30 days during the previous 1 year; (6) working for at least 20 hours a week; (7) less than 3 additional body regions with complaints on more than 30 days in the previous 1 year; and (8) had experienced neck and/or shoulder pain in the previous 7 days. Participants were excluded if they (1) had experienced pain in more than 3 body regions, (2) had severe arthritis or joint disorders, (3) had experienced neck and/or shoulder pain on fewer than 8 days during the previous 1 year, (4) were taking muscle relaxants, (5) had tumors or inflammatory diseases, or (6) reported other complaints in the upper extremities apparently not related to computer work.¹³⁻¹⁵

Randomization

Eligible subjects were assigned to 1 of the 4 groups on the basis of a simple, computer-based randomization strategy.

Interventions

Participants did not receive any other form of specific intervention for their neck and shoulder pain during the course of the study. Each participant was given a standard instruction booklet about the principles of office ergonomics. Those in the 3 intervention groups were also supplied with training diaries in order to monitor their compliance with the assigned intervention program. All participants were required to record their daily neck and shoulder pain scores using a numeric scale from 0 to 10 (0, no pain; 1, minimal pain; 10, extreme/intolerable pain).

Biofeedback training. Participants in the biofeedback group were instructed in how to use a portable biofeedback machine, the Prometheus system,^a on the bilateral UT and were asked to use it for 2 hours daily while performing computer work. During each session, a pair of surface electrodes was placed on each of the left and right UT muscles. The surface electromyography signals collected by the biofeedback machine during the session were stored and later downloaded to a laptop computer. A threshold amplitude was preset by the experimenter, and electromyographic signals above the threshold would trigger an auditory feedback signal warning the subject to try and reduce the UT muscle activity, which they were taught to achieve by slightly depressing the shoulders or by sitting quietly with the eyes closed and the shoulders relaxed.

The participants were instructed in how to apply the electrodes reproducibly and how to use the biofeedback machine properly while performing their regular computer work. They were instructed to apply the biofeedback machine for 2 hours a day and 2 days a week as a minimum. The actual amount of time was recorded in the training diary. During the first training session, the participants performed 10 minutes of typing work in order to set the baseline threshold amplitude. Each subject

Table 1: List of Exercises and Dosage for the Active Exercise Group

Exercise	Starting Position	Description
1	Sitting	Active movements of the neck into flexion/extension, side flexion, and rotation to each side
2	Standing	Active shoulder stretching into full flexion (stretch both arms above the head toward the ceiling)
3	Standing	Active stretching of the shoulder across the chest in horizontal adduction (do one arm first, then the other arm)
4	Standing	Holding a weight in your hand (about 1 kg), make a full circle of the whole arm (circumduction of the shoulder joint)
5	Standing	Active lumbar extension
6	Lying or sitting	Active lumbar flexion (Hug the knees and pull the knees up to the chest) to stretch the back muscles
7	Standing	Resisted shoulder elevation exercise with Thera-band
8	Sitting	Resisted shoulder elevation exercise with Thera-band
9	Sitting	Resisted shoulder elevation exercise with Thera-band
10	Sitting	Resisted shoulder elevation exercise with Thera-band

NOTE. Instructions: Each participant was given an exercise instruction booklet in which the actual number of exercises and repetitions completed were to be recorded in a table. Dosage: Each exercise was to be performed for 5 to 8 repetitions, up to 4 times per day. Each session of exercises should not last more than 20 minutes.

was required to return to the laboratory session once a week during the training period to report progress, to download the training electromyogram (EMG) data, and to perform another 10 minutes of typing in order to reset the amplitude threshold for the subsequent week. Data from participants who were out of work for longer than 1 week during the 6 weeks of the study were excluded from the analysis.

Active exercise. Those in the active exercise group were instructed to carry out a standardized exercise program daily on their own. The exercises included both stretching exercises and strengthening exercises using a Thera-band,^b focusing on the neck and shoulder muscles^{6,7,23} (table 1). They were instructed in how to perform the exercises properly at the first session, and again their progress was monitored during a weekly visit to the laboratory. The participants were instructed to perform the exercises for no longer than 20 minutes 4 times a day for the duration of the trial. The exercises were to be performed without significant provocation of neck and shoulder pain.²⁰

Passive treatment. The passive treatment group received interferential therapy (20min) and hot packs applied to their neck and shoulder regions for 15 minutes twice a week. The interferential therapy was applied using the Endomed model 582 machine^c and 4 suction cup electrodes were applied to the bilateral neck and UT region in a cross-fire pattern. The interferential current was a classic interferential current with a 4000-Hz carrier frequency and 100-Hz beat frequency, increasing intensity to the maximum tolerable current without muscle contraction.

Controls. The control group received only the standard education booklet about office ergonomics and no other intervention.

Outcome Measures

All 3 outcome measures were assessed prior to the start of the intervention and then again after 6 weeks. The measurements included pain (self-assessed using a visual analog scale [VAS]), Neck Disability Index (NDI), and surface EMG during a standardized typing task. At 6 months postintervention, the participants were contacted again and reassessed in terms of pain and NDI scores.

The neck and shoulder pain VAS was 10cm long and anchored with the words “no pain” and “worst pain imaginable” at the 2 ends. Each participant was requested to mark a point

along the scale that best represented the level of pain experienced.²⁵ The NDI is a self-rating scale that measures the impact of pain on the ability to participate in the activities of daily life.^{26,27} This tool has been used as an outcome measure for workplace interventions and has been shown to have good validity and reliability.²⁷ According to several authors who have evaluated the NDI against other established outcome measures, the minimum detectable change is 5.0 points,²⁸ and the minimum clinically important difference is in the range of 3.5 to 5.0 points.^{28,29}

The electromyographic activity of the neck and shoulder postural muscles was measured when participants performed 20 minutes of typing at an adjustable computer workstation. A Noraxon MyoSystem 1400A 16-channel fixed-cable surface EMG system^d was used to record the EMG data, with a sampling frequency of 1000Hz and a bandwidth of 10 to 500Hz. The muscles examined were the bilateral cervical erector spinae (CES) and both UT muscles. The surface electrodes were carefully positioned following accepted research protocols.^{3,11} The skin was carefully prepared by cleaning with water, shaving if necessary, and abrading with fine sandpaper and 2% alcohol. The impedance was checked to achieve an acceptable level of below 5k Ω .^{3,11}

For the preintervention and postintervention comparison, the Noraxon system was used to record more accurate surface EMG data during a sustained typing trial instead of using the Prometheus system. This was done in order to provide a more accurate set of electromyographic data, which was carefully screened for nonbiological noise using more refined signal processing procedures. The raw electromyographic data from the 20-minute typing trial were demeaned, rectified, and down-sampled to 20Hz root mean square values. The Noraxon software program was used to compute the data's amplitude probability distribution function,³⁰ and the 10th, 50th, and 90th percentiles were extracted. These values can be considered indicators of low, median, and high amplitude muscle activity, respectively.^{3,31} The results of the 10th, 50th, and 90th percentile amplitude probability distribution function of the 4 muscles preintervention and postintervention were compared.

Data Analysis

The demographic data were examined by descriptive statistics, and the differences between groups were compared

using chi-square for (men-women comparison) and 1-way analysis of variance (ANOVA) tests for the other variables. The VAS and NDI scores were modeled using a general linear model ANOVA with repeated measures, 1 within-subject factor (preintervention and postintervention), and a between-subject factor (group \times 4). This was followed by appropriate pairwise comparisons to determine which differences between groups were statistically significant. For the EMG amplitudes, the 10th, 50th, and 90th percentile amplitude probability distribution function for the 4 muscles were analyzed in 3 separate repeated-measures ANOVA analyses. Specific differences for individual variables were further analyzed within the group (baseline and 6 weeks postintervention) using paired *t* tests. The Statistical Pack-

age for the Social Sciences (SPSS 16.0)^e was used for the analysis and to test the statistical significance of all differences using a 5% confidence level.

RESULTS

Initially, 72 participants (mean age \pm SD, 33.3 \pm 9.7y) were recruited into this study, but 12 participants dropped out before or at the 6-week follow-up. Altogether 60 participants completed the intervention programs (20 men, 40 women) with 15 participants in each group. At the 6-month follow-up, an additional 22 patients dropped out. Patient recruitment, participation, and attrition during the trial are summarized in figure 1.

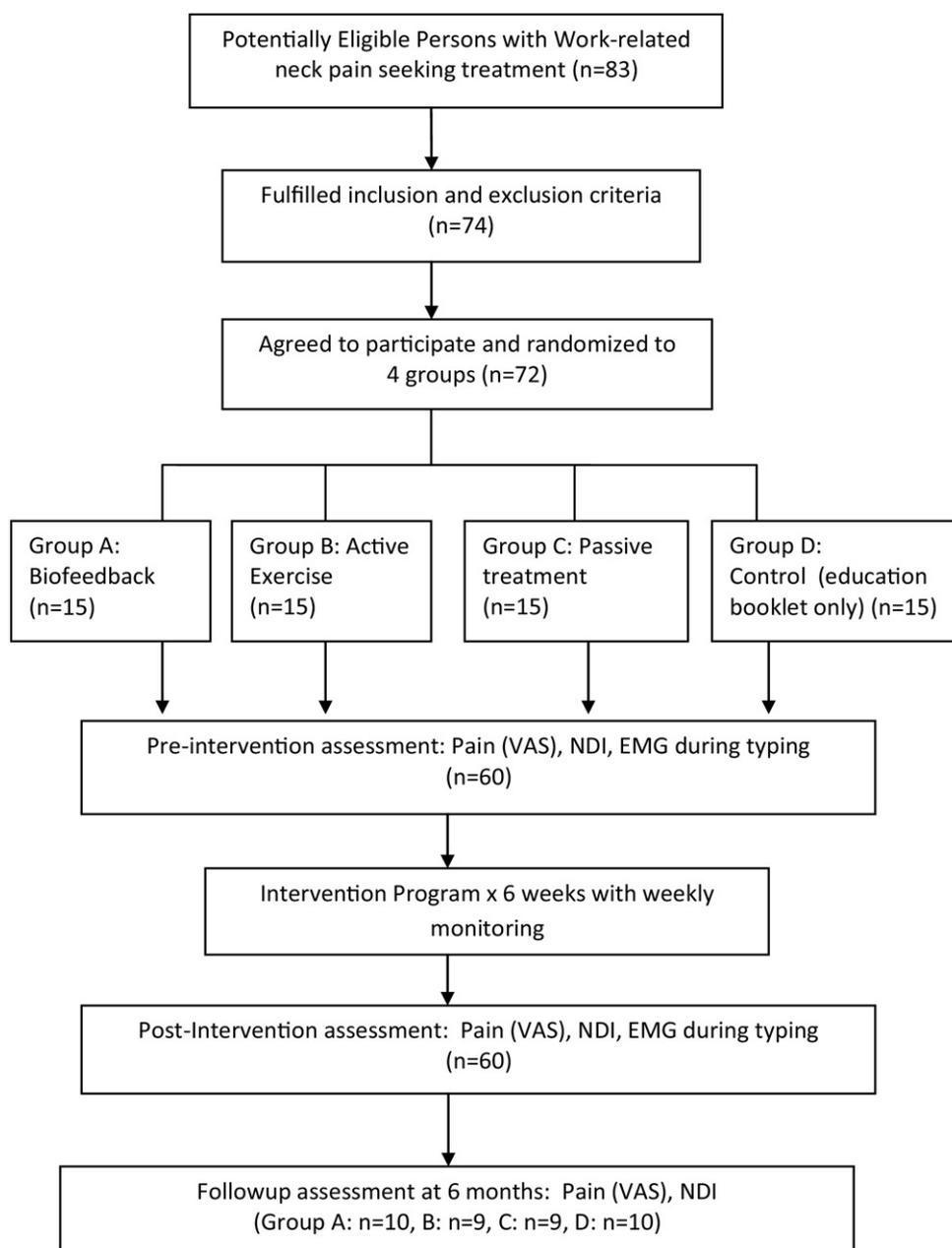


Fig 1. CONSORT flowchart showing participants' progression through the RCT.

Table 2: Demographics of the 4 Groups at Baseline

Demographic Factor	Group A: Biofeedback	Group B: Active Exercise	Group C: Passive Treatment	Group D: Control	P
Subjects (n)	15	15	15	15	
Men/women (n)	5/10	4/11	5/10	6/9	.77
Age (y)	31.3±8.6	34.2±10.3	35.3±9.4	30.0±10.3	.41
Height (cm)	162.5±7.7	161.1±5.3	162.2±8.2	165.0±7.3	.52
Weight (kg)	54.9±7.8	54.6±7.9	56.4±12.1	58.3±9.6	.70
Job experience (y)	8.5±9.0	10.3±10.3	9.7±9.3	8.2±9.4	.92
Work (h/d)	8.3±1.0	8.7±1.6	8.4±1.5	8.7±2.0	.81
Work (h/wk)	45.2±6.4	46.9±17.8	51.1±12.6	47.2±14.6	.67
Computer use (h/d)	6.4±2.5	6.3±2.7	6.3±2.8	6.1±2.4	.99
Computer use (h/wk)	40.5±16.4	37.6±13.9	39.1±20.6	38.6±10.3	.97

NOTE. Except for sex, the values are mean ± SD. There were no significant differences ($P<.05$). All variables were compared between groups using 1-way ANOVA, except men/women distribution between groups, which was compared using the χ^2 test.

The demographics of the participants at baseline are summarized in table 2, and the 4 groups are compared. No statistically significant differences were observed among the 4 groups in terms of their demographic characteristics or their computer work experience.

Changes in EMG Amplitudes During Typing

The statistical analysis using repeated-measures multivariate ANOVA revealed some significant differences in the multivariate and univariate analyses (table 3). In the multivariate analysis, both the 50th and 90th percentile amplitude probability distribution function showed a significant pre–post effect. Significant 2-way interactions between the pre–post and group effects were also found in the 10th and 90th percentile amplitude probability distribution function ($F=1.886$, $P=.039$; $F=2.104$, $P=.020$). In the univariate analysis results, the right UT showed significant pre–post effects in terms of the 50th and 90th percentile amplitude probability distribution function, although the differences in the 10th percentile were not significant ($F=3.392$; $P=.060$). The 2-way interaction for the right CES was highly significant for all 3 amplitudes of the 10th, 50th, and 90th percentile amplitude probability distribution function ($P=.001-.003$). This result indicates that the 4 groups had significantly different results in terms of their preintervention and postintervention EMG amplitudes. The rest of the results were not statistically significant.

When the group mean 10th, 50th, and 90th percentile amplitude probability distribution functions were compared between the preintervention and postintervention assessments using paired t tests, the results showed significant differences mainly in the right CES muscles in the biofeedback group (fig 2). Reductions in the EMG amplitudes in the CES and UT muscles were apparent in the biofeedback group (group A) postintervention, and these were significantly greater than those observed in the active exercise or passive treatment groups. The control group generally showed no change at all in their EMG amplitudes preintervention and postintervention. A decreasing trend was observed in the right UT muscle, but it was not significant (50th percentile amplitude probability distribution function: $t_{14}=1.843$, $P=.087$; 90th percentile amplitude probability distribution function: $t_{14}=1.809$, $P=.092$). The large variances in the EMG data (especially in the UT muscle data) made it difficult to demonstrate statistical significance with such a small sample (fig 3).

Changes in Neck Pain and Functional Scores Within and Between the Groups

After 6 weeks of treatment, the average pain scores and NDI scores of the participants in the biofeedback, active exercise, and passive treatment groups had decreased significantly, and significantly more than in the control group. The average VAS and NDI decreases in the biofeedback group were significantly

Table 3: Results of Repeated-Measures ANOVA to Examine the Pre–Post Intervention Differences in EMG Amplitudes in All 4 Groups

Factor	Univariate				
	Multivariate	Right CES	Left CES	Right UT	Left UT
APDF Percentile					
Pre–post					
10th	$F=1.715$; $P=.161$	$F=3.504$; $P=.067$	$F=0.124$; $P=.726$	$F=3.678$; $P=.060$	$F=2.638$; $P=.110$
50th	$F=2.710$; $P=.039^*$	$F=3.038$; $P=.087$	$F=0.000$; $P=.991$	$F=7.958$; $P=.007^*$	$F=2.584$; $P=.114$
90th	$F=3.171$; $P=.021^*$	$F=3.003$; $P=.089$	$F=0.035$; $P=.853$	$F=8.025$; $P=.006^*$	$F=2.243$; $P=.140$
Group					
10th	$F=0.908$; $P=.541$	$F=0.426$; $P=.735$	$F=0.443$; $P=.723$	$F=1.424$; $P=.246$	$F=1.606$; $P=.198$
50th	$F=1.017$; $P=.436$	$F=0.493$; $P=.688$	$F=1.015$; $P=.393$	$F=0.842$; $P=.477$	$F=1.246$; $P=.477$
90th	$F=0.965$; $P=.485$	$F=0.623$; $P=.603$	$F=1.381$; $P=.259$	$F=0.939$; $P=.428$	$F=0.775$; $P=.513$
Pre–post × group					
10th	$F=1.886$; $P=.039^*$	$F=6.421$; $P=.001^*$	$F=1.257$; $P=.298$	$F=1.598$; $P=.200$	$F=2.073$; $P=.114$
50th	$F=1.656$; $P=.081$	$F=5.569$; $P=.002^*$	$F=0.991$; $P=.404$	$F=1.415$; $P=.248$	$F=0.845$; $P=.475$
90th	$F=2.135$; $P=.017^*$	$F=7.397$; $P<.001^*$	$F=1.069$; $P=.370$	$F=1.380$; $P=.258$	$F=0.744$; $P=.530$

Abbreviation: APDF, amplitude probability distribution function. *Indicates significant differences ($P<.05$).

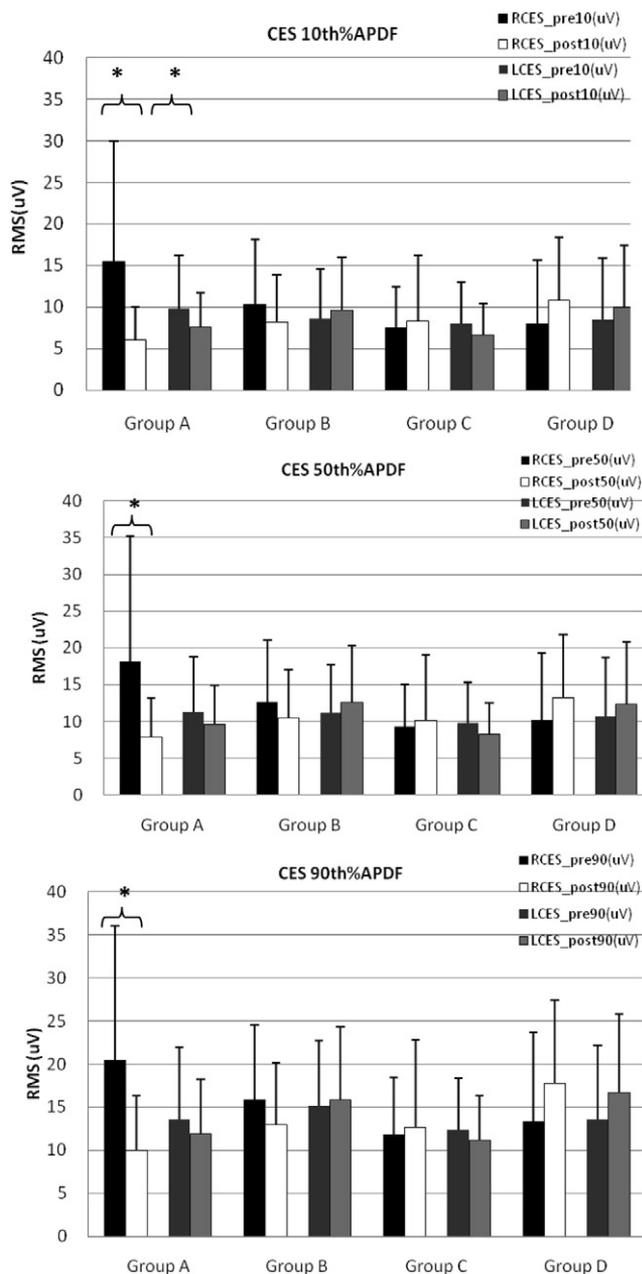


Fig 2. Comparison of CES muscle activity preintervention and postintervention. Abbreviations: APDF, amplitude probability distribution function; LCES, left CES; RCES, right CES. *Significant differences ($P < .05$) in paired t tests that compared preintervention and postintervention EMG for each muscle.

greater than in the other 3 groups after 6 weeks of intervention. There was no significant difference in the average VAS or NDI results between the active exercise and passive treatment groups. There was also no significant difference in the average VAS or NDI results in the control group comparing preintervention and postintervention (table 4).

Further post hoc analysis of least significant difference was used to evaluate the VAS and NDI results of the 4 groups 6 months after the intervention. Only 9 or 10 participants in each group could be contacted for the 6-month

follow-up. The average VAS and NDI results for the biofeedback group were still significantly lower than those for the other 3 groups. There was also a significant difference in average VAS and NDI results between the active exercise group and the passive treatment and control groups. There was no significant difference, however, between passive treatment and control groups in terms of either VAS or NDI results (table 5).

Compliance

The participants in the biofeedback and active exercise groups were asked to keep a training diary. The participants were cooperative in all 4 groups. In the biofeedback group, the average training time a day \pm SD was 121.98 ± 13.60 minutes. Within each week, the variation in daily training time ranged

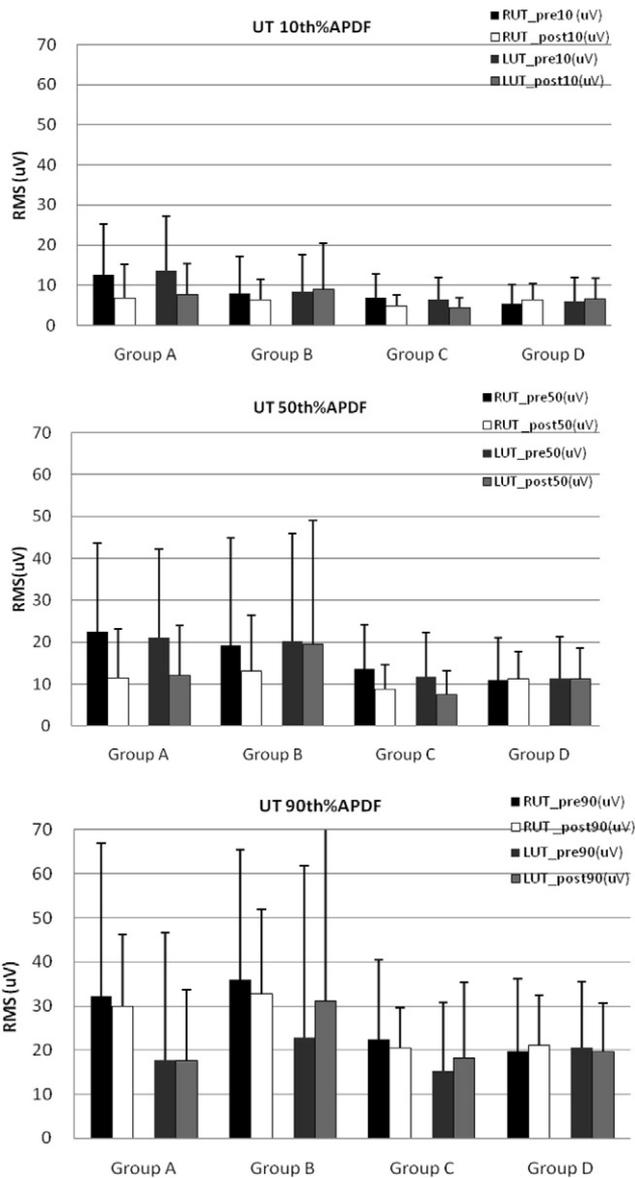


Fig 3. Comparison of UT muscle activity preintervention and postintervention. No significant differences were found in paired t tests comparing preintervention and postintervention EMG of each muscle. Abbreviations: LUT, left UT; RUT, right UT.

Table 4: Preintervention and Postintervention Comparisons of VAS and NDI Between and Within the 4 Groups

Group	Group A: Biofeedback (n=15)	Group B: Active Exercise (n=15)	Group C: Passive Treatment (n=15)	Group D: Control (n=15)
NDI-pre	16.82±6.21	16.05±5.13	15.81±4.97	16.53±5.95
NDI-post	7.00±3.05*†‡§	10.33±2.23*†	12.33±4.29*†	14.82±2.87
VAS-pre	5.12±1.65	4.75±1.59	5.69±1.54	5.27±1.27
VAS-post	1.87±0.74*†‡§	2.10±1.34*†‡	3.60±1.18*†	4.75±1.53

NOTE. Values are mean ± SD. No significant differences in NDI and VAS were found among the 4 groups before treatment. In comparison of NDI and VAS between preintervention and postintervention in each group,*significant differences in paired *t* tests (*P*<.05). After the 6-week intervention, comparison between groups A–D, B–D, C–D (independent *t* tests): †significant differences (*P*<.05); comparison between groups A–C, B–C, ‡significant differences (*P*<.05); comparison between groups A–B, §significant differences (*P*<.05).

from 4.0 to 31.0 minutes. In the active exercise group, the mean exercise time ± SD was 81.8±11.8min/wk, and most participants reported doing the exercises for 6 to 7d/wk.

DISCUSSION

This study was designed to compare the effects of different interventions on muscle activation, pain, and functional ability in office workers with chronic neck pain. Past research has mainly compared biofeedback with ergonomic training,¹⁴ relaxation training,³² or cognitive behavioral therapy,¹⁶ and frequently the outcome measures involved only pain and functional scores. To our knowledge, this is the first study that directly compared the effects of 6 weeks of biofeedback training with active exercise and passive electric therapy. Past research has demonstrated that maladaptive muscle activation

patterns are an important mechanism contributing to neck pain, especially when it is work-related.^{3,24,33} Hence, the present results provide important evidence to support the influence of altered muscle control mechanisms in contributing to musculo-skeletal disorders.

Biofeedback and Muscle Activation During Typing

The 6-week daily biofeedback training program in this study was designed with the specific aim of reducing bilateral UT muscle activity during computer work. The biofeedback machine operated by setting a feedback threshold based on EMG amplitude values. The results produced significant reductions in CES muscle activity but insignificant average reductions in the UT muscles. These results suggest that biofeedback produced a generalized

Table 5: NDI and VAS Results at 6-Month Follow-Up

Outcome Measure	Time Interval	Group A: Biofeedback (n=10)	Group B: Active Exercise (n=9)	Group C: Passive Treatment (n=9)	Group D: Control (n=10)	1-Way ANOVA <i>P</i>	Post Hoc Comparison [†]	LSD <i>P</i>	
NDI	Baseline [†]	16.20±4.56	17.00±4.38	16.88±3.98	16.60±3.71	.976			
		6 wk [†]	7.50±2.83	11.30±2.59	13.55±2.18	16.40±2.59	.000*	A vs B A vs C A vs D B vs C B vs D C vs D	.003* .000* .000* .076 .000* .012*
	6 mo	7.70±2.79	11.88±2.36	15.55±2.87	16.7±2.94	.000*	A vs B A vs C A vs D B vs C B vs D C vs D	.001* .000* .000* .008* .002* .382	
		VAS	Baseline [†]	5.40±1.50	5.61±0.85	5.70±1.39	5.59±0.96	.936	
			6 wk [†]	1.52±0.53	3.44±0.46	3.77±1.09	5.15±1.33	.000*	A vs B A vs C A vs D B vs C B vs D C vs D
		6 mo	1.70±0.63	3.70±0.90	5.05±1.23	5.70±1.16	.000*	A vs B A vs C A vs D B vs C B vs D C vs D	.000* .000* .000* .011* .000* .173

*Indicates significant differences in 1-way ANOVA and least significant difference (LSD) tests (*P*<.05).

[†]Group results are mean ± SD calculated with the actual participant number at 6-month follow-up.

[‡]Post-hoc comparisons refer to the between-group comparisons between Groups A, B, C, and D.

relaxation effect in the neck and shoulder postural muscles, which was not found in the other intervention groups.

Previous studies of biofeedback have focused on either training relaxation of the UTs only (as in the myofeedback studies¹²⁻¹⁵) or training of multiple muscles (as in the muscle learning therapy approach^{16,34}). Muscle learning therapy actually attempts to re-educate both the UT and the forearm muscles to relax at the same time. Tests have shown muscle learning therapy is more effective for reducing activity in the UT than in the forearm muscles, and the participants' symptom scores did not actually show significantly better improvements than those in other intervention groups.¹⁶ Therefore, there is a need to explore further how this approach to training multiple muscles works. In contrast, this study has shown that in training the bilateral UTs, there is some carryover effect of muscle relaxation to nearby muscles such as the CES. This may suggest that the participants learned a new muscle activation strategy for relaxing their neck and shoulder muscles in general as a result of the biofeedback training; and this was not found in the active exercise or passive therapy groups.

In designing the present study, we considered a number of different biofeedback protocols and machines. The myofeedback machine developed by Hermens and colleagues¹²⁻¹⁵ involved a fixed preset threshold at $10\mu\text{V}$ for at least 0.25 seconds. Subjects in their studies were instructed to wear the shoulder strap in the office and had continuous training for up to 8h/d.¹⁵ The feedback signals involved the processing of muscular rest periods in the trapezius muscle activity based on the Cinderella hypothesis.^{12,13} In our present study, the biofeedback threshold was simply based on the participant's average muscle activity during typing task, without computing muscular rest periods. This led to a variable feedback threshold that was adjusted every week rather than the fixed threshold of the myofeedback approach. We believe that this may have an important impact on the training outcome in the biofeedback group.

Compliance with the training protocols and variations in individual motor performance of course also contributed to the final results of the study. In the present study, the participants have demonstrated high compliance in all the intervention groups, and this factor should have contributed significantly to the outcomes. In particular, the biofeedback group reported a very high training time with about 2h/d for 5 to 6d/wk, and the training was conducted during working hours. Based on motor learning principles, this high intensity of training in the work situation would have facilitated the adoption of this new muscle activation pattern into the habitual motor control strategies of the participants.

Madeleine et al³⁵ have developed an approach to biofeedback intervention based on an individual preset threshold value for the right trapezius EMG, mechanomyography signal, and a time factor. Their results showed that biofeedback led to a significantly decreased number of errors in mouse clicks, but also fewer completed tasks. It will be interesting to compare the results of these different training approaches, and further exploration should examine the week-by-week training outcomes with different protocols.

The biofeedback group in this study consistently showed a greater reduction in average muscle activity amplitude than the other 3 groups, as is evident in figure 2. However, only some of the pre-post activity decreases were statistically significant. This is a common problem in EMG research, because there are inevitably large variations in each person's EMG signals. A sample size calculation based on 80% power and 5% type I error recommends a sample of between 144 and 325 a group, whereas the sample size calculation based on the VAS and NDI

scores showed that the sample size actually used should have been more than adequate.

Biofeedback Compared With Conventional Interventions

Past studies on biofeedback have mainly compared biofeedback with interventions such as ergonomic training but have not compared it with other types of interventions such as exercise training and passive modalities. This study monitored the compliance of the participants closely and ensured that the optimal effects were achieved with each intervention. The records of training time in the biofeedback and exercise groups showed that the participants were highly compliant with the intervention programs, and this may have contributed significantly to the positive results in these 2 groups. For the passive modality group, interferential therapy and hot packs are commonly used for treating musculoskeletal pain, and the usual practice is to provide these treatments 2 to 3 times a day. Hence, we adopted a similar approach for the passive treatment group.

Past studies have examined the effects of active exercise training and electrotherapy and found mixed results on their ability to decrease pain and improve neck and shoulder function.^{6,7,19-21} An early study by Levoska and Keinänen-Kiukaanniemi³⁶ compared active and passive physiotherapy for occupational cervicobrachial disorders with a 1-year follow-up. They mainly assessed tender points in the neck and shoulder muscles and maximum isometric extension force after physiotherapy. Chiu et al²¹ have reported that patients with chronic neck pain can benefit from a neck exercise program with significant improvements in disability, pain, and isometric neck muscle strength in different directions after 6 weeks, although the effect of exercise was less favorable at 6 months. The present study has demonstrated that active exercise and passive modalities can both decrease pain and improve neck and shoulder function, but both have limited influence on muscle activity amplitudes during typing. The improvements in muscle activation in these groups were not as great as those achieved through biofeedback. This finding supports the use of biofeedback in re-educating muscle activation patterns in a realistic work situation, which fits in with the training specificity principle; active exercises conducted in an off work situation may not have such effects. Similarly, passive treatment may relieve pain and reduce muscle tension in the clinic, but it may not have a similar effect on habitual muscle activation in a work situation.

The biofeedback group showed more favorable outcomes in terms of reduced pain and better functional scores at the 6-month follow-up, which indicates that this intervention had more long-lasting effects on the musculoskeletal system. Voerman et al¹⁴ found a similar result after 4 weeks of myofeedback training, with significant reductions in pain and disability sustained after 3 and 6 months. A future study should explore the possibility of reassessing the muscle activation during typing after 6 months or an even longer interval in order to evaluate the long-term effect of biofeedback training in correcting maladaptive muscle activation patterns.

In comparing the different interventions, cost-effectiveness is also an important consideration. If the outcomes were all the same, then active exercise should be the first choice because it involves the lowest cost and least resources compared with biofeedback and passive treatment. Biofeedback therapy can be justified only if there is strong evidence that it can influence muscle control and reduce symptoms more effectively than cheaper interventions. The successful implementation of biofeedback training also depends on the compliance and motor learning capacity of the individual, because daily training of a sufficient duration involving a realistic work situation is clearly

essential. Passive treatment involves specific costs to the client, but it can provide immediate symptomatic relief. Its effects, however, seem to be somewhat transient, as shown in the results at the 6-month follow-up.

The effects of combining various intervention strategies were not studied, but this may possibly produce even better results in terms of motor control outcomes as well as symptomatic relief. This should also be investigated in future studies.

Study Limitations

The present study might have shown more significant results if the sample size were larger. In addition, the current study involved only 1 biofeedback training group. The training protocol for biofeedback was adopted based on considerations from past studies. More research should be done to compare different training protocols in order to determine the optimal method or dosage of biofeedback training. In the follow-up assessment, only the pain score and functional outcome were reported. It would be more complete if the surface electromyography in the typing test was also compared with the preintervention data. These factors should be considered in future studies in order to provide stronger evidence for supporting the clinical effectiveness of biofeedback training compared with other forms of interventions.

CONCLUSIONS

Biofeedback, active exercise, and passive treatment all improved NDI and EMG results after 6 weeks of treatment. Biofeedback yielded the greatest average improvement in neck and shoulder muscle activation patterns during typing. These results support the importance of adopting interventions that target the underlying maladaptive motor control mechanisms rather than focusing on general muscle function or symptomatic relief. On the whole, the results indicate more favorable long-term outcomes from biofeedback training compared with conventional interventions such as active exercise or passive treatment modalities.

Acknowledgments: We thank Man Cheung, MSc for technical support and Raymond Chung, MSc for statistical advice.

References

- Gerr F, Marcus M, Monteilh C. Epidemiology of musculoskeletal disorders among computer users: lessons learned from the role of posture and keyboard use. *J Electromyogr Kinesiol* 2004;14:25-31.
- Tittiranonda P, Remple D, Armstrong T. Effect of four computer keyboards in computer users with upper extremity musculoskeletal disorders. *Am J Ind Med* 1999;35:647-61.
- Szeto GPY, Straker LM, O'Sullivan PB. A comparison of symptomatic and asymptomatic office workers performing monotonous keyboard work: 1. Neck and shoulder muscle recruitment patterns. *Man Ther* 2005;10:270-80.
- Hurwitz EL, Carragee EJ, van der Velde G, et al. Treatment of neck pain: noninvasive interventions. *Spine* 2008;33(Suppl 4):S123-52.
- Blangsted AK, Sogaard K, Hansen EA, Hannerz H, Sjogaard G. One-year randomized controlled trial with different physical-activity programs to reduce musculoskeletal symptoms in the neck and shoulders among office workers. *Scand J Work Environ Health* 2008;34:55-65.
- Verhagen Ap, Karels C, Bierma-Zeinstra SMA, et al. Exercise proves effective in a systematic review of work-related complaints of the arm, neck or shoulder. *J Clin Epidemiol* 2007;60:110-7.
- Ahlgren C, Waling K, Kadi F, Djupsjobacka M, Thornell L, Sundelin G. Effects on physical performance and pain from three dynamic training programs for women with work-related trapezius myalgia. *J Rehabil Med* 2001;33:162-9.
- Feurestein M, Shaw WS, Nicholas RA, Huang GD. From confounders to suspected risk factors: psychosocial factors and work-related upper extremity disorders. *J Electromyogr Kinesiol* 2004;14:171-8.
- Visser B, van Dieen JH. Pathophysiology of upper extremity muscle disorders. *J Electromyogr Kinesiol* 2006;16:1-16.
- Waersted M, Hanvold TN, Veiersted KB. Computer work and musculoskeletal disorders of the neck and upper extremity: a systematic review. *BMC Musculoskelet Disord* 2010;11:79-94.
- Szeto GPY, Straker LM, O'Sullivan PB. Neck-shoulder muscle activity in general and task-specific resting postures of symptomatic computer users with chronic neck pain. *Man Ther* 2009;14:338-45.
- Hermens HJ, Hutten MMR. Muscle activation in chronic pain: its treatment using a new approach of myofeedback. *Int J Ind Ergon* 2002;30:336-52.
- Voerman GE, Sandsjö L, Vollenbroek-Hutten MM, Groothuis-Oudshoorn CGM, Hermens HJ. The influence of different intermittent myofeedback training schedules on learning relaxation of the trapezius muscle while performing a gross-motor task. *Eur J Appl Physiol* 2004;93:57-64.
- Voerman GE, Sandsjö L, Vollenbroek-Hutten MMR, Groothuis-Oudshoorn CGM, Hermens HJ. Effects of ambulant myofeedback training and ergonomic counseling in female computer workers with work-related neck-shoulder complaints: a randomized controlled trial. *J Occup Rehabil* 2007;17:137-52.
- Vollenbroek-Hutten M, Hermens H, Voerman G, Sandsjö L, Kadefors R. Are changes in pain induced by myofeedback training related to changes in muscle activation patterns in patients with work-related myalgia? *Eur J Appl Physiol* 2006;96:209-15.
- Faucett J, Garry M, Nadler D, Ettare D. A test of two training interventions to prevent work-related musculoskeletal disorders of the upper extremity. *Appl Ergon* 2002;33:337-47.
- Wright A, Sluka KA. Nonpharmacological treatments for musculoskeletal pain. *Clin J Pain* 2001;17:33-46.
- Robinson AJ. Transcutaneous electrical nerve stimulation for the control of pain in musculoskeletal disorders. *J Orthop Sports Phys Ther* 1996;24:208-26.
- Jull G, Trott P, Potter H, et al. A randomized controlled trial of exercise and manipulative therapy for cervicogenic headache. *Spine* 2002;27:1835-43.
- Ylinen J, Takala EP, Nykanen M, et al. Active neck muscle training in the treatment of chronic neck pain in women: a randomized controlled trial. *JAMA* 2003;289:2509-16.
- Chiu TT, Lam TH, Hedley AJ. A randomized controlled trial on the efficacy of exercise for patients with chronic neck pain. *Spine* 2005;30:1-7.
- Hoving JL, de Vet HC, Koes BW, et al. Manual therapy, physical therapy, or continued care by a general practitioner for patients with neck pain: long-term results from a pragmatic randomised control trial. *Clin J Pain* 2006;22:370-7.
- Scholten-Peeters GG, Neeleman-van der Steen CW, van der Windt DA, Hendriks EJ, Verhagen AP, Oostendorp RA. Education by general practitioners or education and exercises by physiotherapists for patients with whiplash-associated disorders? a randomised clinical trial. *Spine* 2006;31:723-31.
- Falla D, Bilenkij G, Jull G. Patients with chronic neck pain demonstrate altered patterns of muscle activation during performance of a functional upper limb task. *Spine* 2004;29:1436-40.
- Pietrobon R, Coeytaux RR, Carey TS, Richardson WJ, DeVellis RF. Standard scales for measurement of functional outcome for cervical pain or dysfunction: a systematic review. *Spine* 2002;27:515-22.
- Vernon H, Mior S. The Neck Disability Index: a study of reliability and validity. *J Manipulative Physiol Ther* 1991;14:409-15.

27. Stratford PW, Riddle DL, Binkley JM, Spadoni G, Westaway MD, Padfield B. Using the neck disability index to make decisions concerning individual patients. *Physiother Can* 1999;51:107-12.
28. Vernon H. The Neck Disability Index: state-of-the-art, 1991–2008. *J Manipulative Physiol Ther* 2008;31:491-502.
29. Pool JJ, Ostelo RW, Hoving JL, Bouter LM, de Vet HC. Minimal clinically important change of the Neck Disability Index and the numerical rating scale for patients with neck pain. *Spine* 2007;32:3047-51.
30. Jonsson B. Measurement and evaluation of local muscular strain in the shoulder during constrained work. *J Human Ergol* 1982;11:73-88.
31. Szeto GPY, Straker LM, O'Sullivan PB. Examining the low, high and range measures of muscle activity amplitudes in symptomatic and asymptomatic computer users performing typing and mousing tasks. *Eur J Appl Physiol* 2009;106:243-51.
32. Spence SH, Sharpe L, Newton-John T, Champion D. Effect of EMG biofeedback compared to applied relaxation training with chronic, upper extremity cumulative trauma disorders. *Pain* 1995; 63:199-206.
33. Thorn S, Sjøgaard K, Kallenberg LA, et al. Trapezius muscle rest time during standardised computer work: a comparison of female computer users with and without self-reported neck/shoulder complaints. *J Electromyogr Kinesiol* 2007;17:420-7.
34. Nord S, Ettare D, Drew D, Hodge S. Muscle learning therapy: efficacy of a biofeedback based protocol in treating work-related upper extremity disorders. *J Occup Rehabil* 2001;11: 23-31.
35. Madeleine P, Vedsted P, Blangsted AK, Sjøgaard G, Sjøgaard K. Effects of electromyographic and mechanomyographic biofeedback on upper trapezius muscle activity during standardized computer work. *Ergonomics* 2006;49:921-33.
36. 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.

Suppliers

- a. The Prometheus Group, Ste 303, 1 Washington St, Dover, NH 03820.
- b. The Hygenic Corp, 1245 Home Ave, Akron, OH 44310.
- c. Enraf-Nonius B.V., 127, Vareseweg, 3047 AT Rotterdam, The Netherlands.
- d. Noraxon USA Inc, Ste 104, 13430 N Scottsdale Rd, Scottsdale, AZ 85254.
- e. SPSS Inc, 233 S Wacker Dr, 11th Fl, Chicago, IL 60606.