EMG Biofeedback and Exercise for Treatment of Cervical and Shoulder Pain in Individuals with a Spinal Cord Injury: A Pilot Study

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Background: Chronic or recurrent musculoskeletal pain in the cervical and shoulder region is a common secondary problem after spinal cord injury (SCI), reported by 30% to 70% of individuals. **Objective:** The purpose of this study was to investigate the effect of electromyographic (EMG) biofeedback training, in addition to a standard exercise program, on reducing shoulder pain in manual wheelchair users with SCI. **Methods:** Fifteen individuals with SCI, C6 or lower, who were manual wheelchair users with shoulder pain were randomly assigned to 1 of 2 interventions. The Exercise group (n = 7) received instruction on a standard home-based exercise program. The EMG Biofeedback plus Exercise group (n = 8) received identical exercise instruction plus EMG biofeedback training to improve muscle balance and muscle relaxation during wheelchair propulsion. Shoulder pain was assessed by the Wheelchair Users Shoulder Pain Index (WUSPI) at baseline, at posttest 10 weeks after the start of intervention, and at follow-up 16 weeks after posttest. **Results:** The number of participants per group allowed only within-group comparisons; however, the findings indicated a beneficial effect from EMG biofeedback training. Shoulder pain, as measured by WUSPI, decreased 64% from baseline to posttest for the EMG Biofeedback plus Exercise group ($P = .02$). Shoulder pain for the Exercise group decreased a nonsignificant 27%. At follow-up, both groups showed continued improvement, yet the benefit of EMG biofeedback training was still discernible. The EMG Biofeedback plus Exercise group had an 82% reduction in shoulder pain from baseline to follow-up ($P = .004$), while the Exercise group showed a 63% reduction ($P = .03$) over the same time period. **Conclusions:** This study provides preliminary evidence that EMG biofeedback has value when added to an exercise intervention to reduce shoulder pain in manual wheelchair users with SCI. These findings indicate that EMG biofeedback may be valuable in remediating musculoskeletal pain as a secondary condition in SCI. This preliminary conclusion will need to be studied and verified through future work. **Key Words:** biofeedback, exercise, pain, spinal cord injury

Chronic or recurrent musculoskeletal pain in the cervical and shoulder region is a common secondary problem after spinal cord injury (SCI) that interferes with daily activities and reduces quality of life (QOL).¹ Reported prevalence ranges from 30% to 70%.²⁻⁹ Both incidence and intensity increase with duration of injury and become an added concern for SCI individuals as they age.^{8,10,11} For manual wheelchair users, who rely on their upper extremities for mobility (wheelchair propulsion), 35% report shoulder pain. Shoulder pain increases to 60% for wheelchair athletes.^{12,13}

Muscle imbalance plays a role in the development of musculoskeletal pain in manual wheelchair users, as muscles used for the forceful push phase strengthen relative to muscles used for the recovery phase.^{13,14} Recent studies have reported effective use of exercise programs designed to address this problem.¹⁵⁻¹⁸ Two of these studies were randomized trials that included an untreated control group to rule out spontaneous recovery.^{17,18} As a result of this research, exercise has become a standard intervention for reducing shoulder pain in manual wheelchair users with SCI.

In addition to muscle imbalance, muscle fatigue likely plays a significant role. Research on work-related musculoskeletal pain (WRMP) has demonstrated that disruption of normal work/rest cycles can promote localized muscle fatigue and pain.¹⁹⁻²¹ Electromyographic studies have found that repetitive tasks consist of alternating periods of muscle contraction and muscle relaxation; a muscle that is slow to relax – bypassing the rest portion of work/rest cycles – is at risk of developing WRMP.²²⁻²⁴ Clinical studies have reported slow and incomplete relaxation of the upper trapezius muscle during repetitive tasks, compared to pain-free controls, in musicians with occupational upper extremity pain²⁵ and individuals with cervical pain and headache.^{19, 24} Manual wheelchair propulsion, with its highly repetitive muscle activity, puts the wheelchair user at risk of muscle fatigue and eventually pain.

This research suggests that EMG biofeedback interventions designed to improve work/rest cycling may be an effective addition to rehabilitation programs for cervical and shoulder pain in manual wheelchair users with SCI. At present, EMG biofeedback procedures are widely used for muscle training in rehabilitation, athletics, and the workplace and have been effective in training overactive muscles to relax quickly during functional activities.^{20, 26-30} In the present study, EMG biofeedback training is designed to improve both muscle balance and work/rest cycles during functional wheelchair propulsion. The purpose of this study was to determine the extent to which EMG biofeedback training is associated with a reduction in shoulder pain, above and beyond the effects of a standard exercise program.

Methods

Participants

Participants were 15 volunteers who had received care at the Medical University of South Carolina (MUSC) or the Charleston Veterans Administration Medical Center (VAMC) or participated in community recreation and advocacy groups serving wheelchair users. They were recruited by phone contact, flyers, and articles

in association newsletters. Volunteers who met preliminary criteria by phone interview attended a screening session for physician evaluation. Eligible individuals (1) were age 18 or older and living in the community, (2) had a spinal cord injury with C6 (preserved) or lower of 2 or more years duration, (3) used a manual wheelchair 30 hours per week or more, and (4) had musculoskeletal pain in the shoulder girdle region (neck, shoulder, upper back) rated as 3 to 8 (on a scale of 0 to 10) that was experienced during, or increased by, performance of daily activities. Individuals were excluded who had (1) shoulder dislocation or cervical/shoulder surgery in the previous year, (2) contraindications for moderate cervical/shoulder exercise, or (3) *DSM-IV* criteria for mood disorder. Two psychosocial pencil-and-paper tests were administered to assist with screening for depressed mood and to characterize the study sample: the Center for Epidemiologic Studies Depression Scales (CES-D)³¹ and Diener's 5-item Satisfaction With Life Scale (SWLS).³²

Eligible participants provided written informed consent. They were asked to keep medications stable during the course of the study and not start new pain-related treatment. Attendees were paid \$25 at the time of each visit to cover the cost of transportation for the participant and a companion. This study was approved by the institutional review boards of MUSC and the Charleston VAMC. All study procedures were carried out at MUSC.

Design

This study was a prospective, randomized controlled trial, with 7 participants assigned to a home-based exercise program for wheelchair users with shoulder pain and 8 participants assigned to the same exercise program plus EMG biofeedback. Participants were assessed at the beginning and end of a 2-week baseline period (baseline 1 and baseline 2), participated in an 8-week intervention period, and returned 2 weeks later for assessment of intervention outcome (10-week posttest). Baseline and posttest data were collected by an evaluator who was blind to group assignment. Participants were contacted again 16 weeks after the posttest to obtain follow-up data by phone and mail.

Table 1. Demographics of the participants

Characteristics	All participants (N=15)	Group A (n=7)	Group B (n=8)
Injury			
Cervical	2	1	1
Thoracic	12	6	6
Lumbar	1	0	1
Duration of SCI, years (range)	15.9 (2-41)	17 (2-41)	15 (7-29)
Age, years (range)	38.1 (23-56)	34.9 (23-42)	41 (23-56)
Gender, male/female	12 / 3	5 / 2	7 / 1
Education, years	14.6	15.3	14
Manual WC, hours/week	83.1	90	77
WC transfers, no./day	15.6	14.6	16.6
Athletic participation, %	47%	43 %	50 %
Pain duration, years (range)	6.6 (2-17)	6.5 (2-15)	6.6 (2.3-17)
CES-D			
Mean score	13.3	8.2	14.8
Median score	10	10	10
Satisfaction With Life Scale	22.4	22.1	22.6

Note: CES-D = Center for Epidemiologic Studies Depression Scales; WC = wheelchair.

Primary outcome measure

The Wheelchair User's Shoulder Pain Index (WUSPI) is a pencil-and-paper self-report measure of the presence and severity of shoulder pain experienced during 15 different activities including wheelchair mobility, transfers, and activities of daily living. This test has established reliability and validity¹² and has been used in previous studies of musculoskeletal pain in manual wheelchair users.¹⁵⁻¹⁸ The WUSPI uses 15 visual analog scales (VAS) consisting of 10-cm lines anchored by "no pain" and "worst pain ever experienced," with a maximum total score of 150. The total score is corrected for activities that are not performed (total score is divided by the number of activities performed and then multiplied by 15).

Baseline and randomization

All 15 individuals who qualified for the study attended 2 baseline sessions, on average 13 days apart, to obtain preintervention data and assess stability of pain report. After baseline 2, participants were randomly assigned to 1 of 2

intervention groups: 7 to group A and 8 to group B. As shown in **Table 1**, demographic characteristics were similar for both groups. The elevated mean CES-D score for group B was primarily due to a single outlier: The median for both groups was 10. The numerically lower average for hours per week in a manual wheelchair for group B was influenced by one individual who used both a manual wheelchair (33 hours per week) and an electric wheelchair (hours not included in the data).

Interventions

Group A, Exercise

Participants in this group (n = 7) attended two 90-minute sessions, scheduled 2 weeks apart, for one-on-one instruction on an exercise program to be carried out at home, in a wheelchair, using an instruction manual and elastic exercise bands. The exercise program was to be performed once a day, a minimum of 5 days a week, and noted in a daily exercise log. This exercise program was based on research on muscle function in manual wheelchair

users^{13-14, 30} and on exercises developed by Curtis et al¹⁷ to reduce cervical and shoulder pain in manual wheelchair users. Exercises were adapted for each individual to stay within a pain-free range. Exercise sessions were carried out by a research assistant with expertise in kinesiology and exercise physiology and supervised by a physical therapist. The initial exercise session included an education component with a detailed rationale for the exercises based on shoulder anatomy (with illustrations) and kinesiology. Participants were contacted weekly, by phone, to discuss problems with the exercise program and encourage compliance until the outcome assessment (posttest) at 10 weeks after the first exercise session.

Five exercises (**eAppendix**) focused on gentle stretching of the upper trapezius, biceps, and pectoral muscles. Four exercises focused on strengthening posterior scapular muscles and shoulder rotators, adductors, and extensors. These began with 1 set of 5 repetitions using moderate resistance to minimize initial muscle soreness and progressed by increasing the number of sets and elastic band resistance.

Group B, EMG Biofeedback plus Exercise

Participants randomized to group B ($n = 8$) first attended two 90-minute sessions, scheduled 2 weeks apart, for home exercise instruction and education identical to group A. This was followed by 3 to 4 additional sessions over 6 weeks for EMG biofeedback training, carried out by a physical therapist (**Appendix 1**). To keep the number of return visits for EMG biofeedback training to a minimum for out-of-town participants, two 90-minute biofeedback sessions were often scheduled for a single visit, with one session in the morning and a second session in the afternoon. Outcome assessment (posttest) was carried out 2 weeks after the final biofeedback session, 10 weeks after the first exercise session.

EMG biofeedback training targeted 4 key muscles: upper trapezius, lower trapezius, anterior deltoid, and infraspinatus, on both right and left sides. Surface EMG was recorded using standard skin preparation techniques and electrode placements using 0.5 cm diameter, silver-silver

chloride electrodes spaced 2 cm center-to-center, placed over the muscle belly and aligned with the direction of the muscle fibers. For the upper trapezius, electrodes were placed lateral to the midpoint between the spinous process of C7 and the acromion. For baseline assessment and 10-week posttest reassessment, EMG was recorded with a bandwidth of 20 to 500 Hz, sampled at 1,000 per second, with analog to digital conversion at 12 bit resolution. EMG biofeedback training was carried out with the 4-channel J & J I-330 (J+J Engineering, Poulsbo, WA) (20-1,000 Hz bandwidth) using a color-coded visual display of EMG signals for 2 to 4 muscles at a time. EMG biofeedback training was also carried out during active wheelchair propulsion in a long hallway using 2 single-channel portables (J & J M56A; 100-200 Hz bandwidth) that produced a continuous auditory tone that varied in pitch in proportion to EMG amplitude (above a set threshold).

Work/rest cycle and muscle balance training. EMG biofeedback training began by training rapid relaxation of the right and left upper trapezius following contraction, first with biofeedback trials, then alternating biofeedback trials with nonfeedback trials, and finally with nonfeedback trials only (with EMG still monitored by the therapist). Training started with simple movements carried out in a stationary wheelchair: shoulder shrug/relax; shoulder abduction (raise arm to horizontal) then relax (return hand to lap); shoulder forward flexion (raise arm to horizontal) then relax (return hand to lap). The emphasis was on relaxing the target muscles quickly in the relax phase. Training then progressed to wheelchair propulsion in a hallway, at first slowly and then at normal speed, focusing initially (a) on decreasing upper trapezius use during push and relaxing to a criterion level before the next push and then (b) on increasing lower trapezius during push and relaxing to a criterion level before the next push. Finally, participants were trained to intersperse longer rests during wheelchair propulsion by alternating 3 to 6 pushes (as trained above) with a 2- to 3-second cruise (with both upper and lower trapezius relaxed). This wheelchair propulsion

training sequence was repeated with the anterior deltoid and infraspinatus muscles.

Posture training. EMG biofeedback was also used to improve posture during wheelchair propulsion. Elevated and protracted shoulders, with a “forward” head position, is often seen in individuals with cervical and shoulder pain,^{13,14,33} and elevated upper trapezius EMG is associated with this posture.^{19,20} Accordingly, EMG biofeedback training to reduce upper trapezius activity included attention to posture and verbal cues to “keep the head up and shoulders down” (in a relaxed manner, without forcing a corrected posture).

Spot checks. Change requires frequent practice of new skills until they become habitual, and spot checks were used to encourage this. The participants were asked to frequently check their muscles and posture throughout the day and then briefly correct whatever problem was noticed. As new skills were added, these became part of the “spot check and correct” process.

Outcome assessment

Primary outcome for both groups was assessed by re-administration of the WUSPI at posttest, 10 weeks after the start of the exercise program. Participants also completed an exit interview. Compliance was rated (by the research assistant and the physical therapist) on a 10-cm VAS for the exercise component (for both groups) and for biofeedback skills (group B) based on daily logs, exercise progression, and demonstrated biofeedback skills. Fourteen of 15 participants returned to the study site for this 10-week outcome assessment. One participant (group A) was interviewed by phone and completed the WUSPI by mail. All participants were encouraged to continue with the strength exercises 3 times per week and stretches 5 times per week to maintain gains and potentially make further improvements. Group B participants were encouraged to continue to apply the skills learned with biofeedback. All were told, however, that the formal study period was finished and it was their choice to continue with a home program or not.

Follow-up assessment

Sixteen weeks after the posttest (6 months after the start of the exercise program), participants were re-contacted and asked to provide consent for a telephone interview and completion of the WUSPI by mail (follow-up). One participant (group B) provided interview data only and not follow-up WUSPI data due to an acute shoulder injury (from a fall) and the associated treatment. The group B mean was used as an estimate for this missing value. Follow-up was not part of the planned prospective study but was an exploratory addition. The purpose was to find out whether participants chose to continue with the exercises and skills learned in the program (by interview) and whether the reductions in cervical and shoulder pain found at 10 weeks were maintained or improved upon (by WUSPI). Participants also rated, on a scale of 1 to 10, the extent to which they had benefited from participation in the study.

Statistical analysis

Because of the small group sizes (group A = 7; group B = 8) statistical analysis of the primary outcome measure, the WUSPI Total Score, employed within-group comparisons using a 2-tailed *t* test for correlated means at a significance level of $P = .05$. Power analysis³⁴ using an expected effect size (*es*) of 1.2 for the WUSPI¹⁸ indicated that 6 participants were sufficient to detect within-group differences at $P = .05$ with a power of .80 ($\beta = .20$), whereas 12 per group would be needed for between-group comparisons. Accordingly, the effect of each intervention was tested separately as the within-group change in WUSPI score between 2 time points. First, stability of pain report was tested by comparison of baseline 1 with baseline 2. Next, intervention outcome was tested by comparison of baseline 2 with posttest (10-week outcome). Then, for exploratory purposes, follow-up was compared with the posttest to assess maintenance of gains. Follow-up was also compared with baseline 2 to assess overall change during the 6-month period. Mean, SD, and SEM are provided for all data points in **Table 2**.

Table 2. WUSPI total score for group A versus group B at each assessment

	Group A: Exercise only			Group B: Biofeedback + exercise		
	Mean	SD	SEM	Mean	SD	SEM
Baseline 1	46.23	39.03	14.75	58.01	36.84	13.03
Baseline 2	43.59	38.44	14.53	56.95	37.79	13.36
Posttest	31.69	24.77	9.36	19.99	20.20	7.14
Follow-up	16.14	14.74	5.57	10.10	11.58	4.09

Note: WUSPI = Wheelchair Users Shoulder Pain Index.^a

Results

Baseline

There was no significant difference in WUSPI score between baseline 1 and baseline 2 for either group A or group B, as determined by *t* test for the difference between correlated means (within-group comparison). Baseline 1 was significantly correlated with baseline 2 for group A ($r = .92$, $P \leq .01$) and for group B ($r = .81$, $P \leq .01$). These findings indicated stable values for shoulder pain report as measured by the WUSPI. Accordingly, only baseline 2 was included in subsequent analyses (below) as the pre-intervention baseline value.

Intervention outcome

As shown in **Figure 1**, group A had a non-significant reduction in WUSPI score (27.3% change) from baseline 2 to the 10-week posttest ($t = .87$, $df = 6$, $P = .42$, $es = .38$). This finding indicated that group A improved, but this improvement did not reach statistical significance. Group B had a significant reduction (64% change) in WUSPI score ($t = 3.15$, $df = 7$, $P = .02$, $es = 1.3$). This finding indicated a beneficial effect of adding EMG biofeedback training to the intervention protocol.

The compliance ratings for the exercise component of the study were similar for group A (mean = 7.9; range, 4.5-10) and group B (mean = 8.9; range, 1-10). Compliance ratings for the EMG biofeedback component (group B) averaged 8.2 (range, 2.4-10). These findings indicated a high

degree of compliance with the study protocols for both groups during the 10-week intervention period.

Follow-up outcome

As shown in **Figure 1**, group A had a significant reduction (63% change) in WUSPI score from baseline 2 to follow-up, 6 months later ($t = 2.86$, $df = 6$, $P = .03$, $es = 1.03$). Of this 63% overall change, 27.3% occurred between baseline 2 and posttest (see above) and 35.7% occurred later as a nonsignificant decrease between posttest and

Effect of Treatment Intervention

Figure 1. Shoulder pain measured by Wheelchair Users Shoulder Pain Index (WUSPI) Total Score was stable from baseline 1 to baseline 2. Letters (a, b, c) denote significant decreases in pain from baseline 2 to (a) posttest ($P = .02$) for group B (biofeedback); (b) follow-up ($P = .03$) for Group A (exercise); and (c) follow-up ($P = .004$) for group B (biofeedback).

follow-up ($t = 1.66$, $df = 6$, $P = .15$, $es = .79$). Group B had a significant reduction (82.3% change) in WUSPI score from baseline 2 to follow-up ($t = 4.18$, $df = 7$, $P = .004$, $es = 1.9$). Of this 82.3% overall change, 64% occurred between baseline and 10-week posttest (see above), whereas 18.3% occurred later as a nonsignificant decrease between posttest and follow-up ($t = 2.17$, $df = 7$, $P = .07$, $es = .62$). These findings indicate that group A benefited significantly from the exercise program over the longer, 6-month time period. However, group A did not catch up with group B, either with respect to overall percent change, endpoint WUSPI score, or effect size. In contrast, group B achieved most of its improvement during the 10-week study period but also made modest improvements after posttest. There was no reversal of gains for either group A or group B between the 10-week posttest and follow-up 16 weeks later; rather, both groups continued to improve.

In the follow-up interview, 5 of 7 in group A and all 8 in group B reported continuing the stretching exercises: for group A, on average 2.8 times per week (range, 1.5-7) and for group B, on average 4 times per week (range, 1.5-7). Also, 5 in each group reported performing the strengthening exercises: for group A, on average 2.8 times per week (range, 3-7) and for group B, 2.3 times per week (range, 1-7). All group B participants reported continued use of biofeedback skills by attending to how they used their muscles and giving their muscles rest breaks. Overall benefit from participation was rated by group A as 7.7 out of 10 (range, 4.5-10) and by group B as 8.8 (range, 7-10).

EMG biofeedback training

Figure 2 and **Figure 3** illustrate the muscle activity patterns that were the focus of EMG biofeedback training for group B. **Figure 2** shows EMG recorded from the upper trapezius and lower trapezius in a group B participant (T9 SCI) while pushing a wheelchair down a hallway, for 14 consecutive pushes, performed without biofeedback. At pretest, prior to EMG biofeedback training (**Figure 2A**), the upper trapezius shows little rest ($<10 \mu v$) between push cycles (peaks) while the lower trapezius shows

irregular participation. After biofeedback training (**Figure 2B**), both muscles show an improved work/rest cycle. The upper trapezius shows good rest ($<10 \mu v$) between pushes and the lower trapezius shows increased, regular participation. **Figure 3** shows EMG recorded from the anterior deltoid and infraspinatus from the same individual while pushing a wheelchair down the hallway, performed without biofeedback. At pretest (**Figure 3A**), the deltoid shows little rest ($<10 \mu v$) during 20 push cycles and the infraspinatus shows low participation. After training (**Figure 3B**), both muscles show an improved work/rest cycle with good participation and regular rest ($<10 \mu v$) during 14 push cycles.

Discussion

The results of this study offer preliminary support for the premise that muscle training with EMG biofeedback adds value, as measured by reduced shoulder pain (WUSPI Total Score), when added to a standard exercise program. A substantial benefit from EMG biofeedback was found at 10 weeks (**Figure 1**), when participants who received EMG biofeedback plus exercise (group B) had a significant reduction in shoulder pain ($P = .02$) with a large effect size (1.3), whereas participants who received exercise only (group A) did not. The reduction in shoulder pain with EMG biofeedback training (64%) was twice that of exercise alone (27.3%).

EMG biofeedback was an effective method for training improved muscle use during functional wheelchair propulsion. This training was easily done in 3 to 4 sessions; once these skills were learned with EMG biofeedback, they could be correctly performed without EMG biofeedback (**Figures 2** and **3**). Adding EMG biofeedback training takes extra time, but this training can overlap with exercise instruction to minimize treatment visits and time. In this study, exercise instruction came first, before introducing EMG biofeedback training, to ensure that both groups received identical exercise instruction and had the same length of time on the exercise home program before the 10-week outcome assessment.

Figure 2. EMG recorded from the upper trapezius (UT) and lower trapezius (LT) muscles during wheelchair propulsion before and after biofeedback training for a group B participant with T9 SCI. Before training (A), UT shows little rest ($<10 \mu\text{v}$) between push cycles (peaks) while LT shows irregular participation. After training (B), UT shows improved rest ($<10 \mu\text{v}$) between push cycles (peaks) and LT shows increased, regular participation.

There was no evidence that the strong performance of participants receiving EMG biofeedback training (group B) was due to increased compliance with the exercise program. Group A participants were contacted on a weekly

basis, by phone, for a detailed check of the home-based exercise program, both as a control for attention and motivation and to optimize the home exercise program. As a result, compliance ratings were similarly high for both groups for

Figure 3. EMG recorded from the anterior deltoid (AD) and infraspinatus (IF) muscles during wheelchair propulsion before and after biofeedback training for a group B participant with T9 SCI. Before training (A), AD shows little rest ($<10 \mu\text{V}$) between push cycles (peaks) while IF shows low participation. After training (B), AD shows improved rest ($<10 \mu\text{V}$) between push cycles (peaks) and IF shows increased, regular participation.

the 10-week intervention period. Also, all study participants, in both groups, completed the 10-week study protocol.

The exercise protocol in this study was effective in reducing shoulder pain in the longer term, as

expected, based on an earlier study of shoulder pain in manual wheelchair users. Curtis et al¹⁷ reported an initial increase in shoulder pain with a similar exercise program at 2 months, followed by a decrease at 4 months and further improvement at

6 months. In our study, we phased in the exercises to avoid an increase in shoulder pain. Accordingly, group A showed a modest pain reduction (23.7%) at 10 weeks. At the 6-month follow-up, group A showed solid improvement, with a statistically significant 63% reduction in shoulder pain. This outcome is comparable to those reported in other studies of home exercise programs for shoulder pain in manual wheelchair users with SCI.^{15,17,18} Although there was no untreated control group in the present study, untreated control groups in 2 previous studies of shoulder pain in manual wheelchair users with SCI showed no spontaneous improvement over 4 to 6 months.^{17,18}

The time course of improvement with EMG biofeedback is substantially different than improvement with exercise alone. Group B made most of its gains relatively rapidly, in the first 10 weeks, whereas group A made the majority of its gains between 10 weeks and 6 months. This indicates that a different therapeutic process is at work with EMG biofeedback training, as would be expected from an intervention that is designed to change how muscles are used for a functional task. The learning curve for such motor learning is often fast and steep, which is in contrast with gains in muscle strength and endurance that occur as a more gradual process with an exercise program. The benefit from EMG biofeedback appears to be long-lasting. At 6-month follow-up, group B achieved an 82.3% reduction in shoulder pain and a WUSPI score (10.1) numerically lower than that of group A (16.2). These findings are, of course, limited by the small number of participants and the inherent difficulties of demonstrating differences between 2 effective treatment approaches. Yet, the consistency of the findings and the substantial difference in the time course of improvement for the 2 interventions make it possible to draw preliminary conclusions, as discussed previously. These preliminary conclusions will need to be studied and verified through future work.

Limitations of the study

The study has several limitations, which should be recognized. Sample size was small, which

limited the ability of the statistical analysis to detect between-group changes and thus making this a pilot study. Future research should be conducted with more participants and between-group comparisons. Translation of the findings in the present study to practical settings may be limited by an individual's access to treatment. In our case, remuneration to defray the cost of transportation likely enhanced participants' ability to receive the interventions. Also, the sample of participants included in the study possibly consisted of a very motivated group of individuals, recruited for a research study, all of whom followed through with recommendations. Even though this can be viewed as a strength of the study, nonetheless in actual clinical settings, there may be less adherence.

As a next step, the study needs to be replicated with a sufficient number of participants in each of 2 groups, one receiving exercise only and the other receiving exercise plus EMG biofeedback training, to permit statistical comparison of treatment outcomes in the 2 treatment groups. Power analysis³⁴ using an expected effect size (es) of 1.2 for the WUSPI¹⁸ indicates that 12 participants per group would be sufficient to detect within-group differences at $P = .05$ with a power of .80 ($\beta = .20$). Allowing for a possible 20% dropout rate and an intention-to-treat model, a minimum of 15 per group should be recruited. A planned follow-up period of 2 months after the end of treatment should be included. WUSPI scores should be tested by a repeated measures analysis of variance for 2 (Treatment Groups) $\times$ 3 (Time Periods). A measure of muscle strength should be added to aid interpretation of between-group differences in WUSPI scores. Increases in muscle strength should be closely correlated with decreases in pain for the exercise-only group.

Conclusion

This study provides preliminary evidence that EMG biofeedback adds value when combined with an exercise intervention to reduce shoulder pain in manual wheelchair users with SCI. The small study size allowed only indirect, parallel comparisons between 2 interventions: Exercise only (group

A) and EMG Biofeedback plus Exercise (group B). Yet the findings for the 10-week intervention indicated a benefit from adding EMG biofeedback: Group B improved substantially while group A did not. Both interventions demonstrated effectiveness over 6 months; yet, an advantage from EMG biofeedback training was still discernible at follow-up. These findings indicate that EMG biofeedback may be valuable in preventing and remediating musculoskeletal pain as a secondary

condition in SCI. This preliminary conclusion will need to be studied and verified through future work.

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APPENDIX 1

EMG BIOFEEDBACK PROTOCOL

Biofeedback Session 1:

4 EMG channels: Right and left upper trapezius (UT) and lower trapezius (LT)

Biofeedback: Basic shoulder shrug/relax, abduct/relax, flexion/relax

Work/rest cycle and muscle fatigue education

Basic posture principles and corrections

- Brief trial of lower trapezius increases during shoulder flexion
- Brief evaluation of wheelchair (WC) push in lab (I-330) and/or hallway (portable)

Homework: Spot check/relax UT; relax shoulders after arm movements

Biofeedback Session 2:

Review homework: Check, review, and reinforce: spot checks/relax

4 EMG channels: Right and left UT and LT

Biofeedback: Check shrug, abduct, flexion without biofeedback; repeat basics

- Reinforce work/rest cycle principles
- Continue/reinforce posture principles and corrections
- Train LT increases during shoulder forward flexion, shoulders relaxed down, and relate this to WC push.
- Evaluate WC push in lab and in hallway (UT and LT)
- Train UT: push/relax, and push 3-6x / relax 2-3 seconds, in hall

Homework: Spot checks, posture, WC push/relax.

Biofeedback Session 3:

Review homework: Check, review, and reinforce: spot checks, posture, WC work/rest

4 EMG channels: Right and Left UT and LT

Biofeedback: Check/repeat training LT use during shoulder flexion, WC push

- Advanced UT training in hallway, slow vs fast pushing
- Evaluate WC push in lab for anterior deltoid and infraspinatus
- Eval WC push in hall for anterior deltoid and infraspinatus

Homework: Posture checks, LT with shoulder flexion, WC work/rest cycle, fast vs slow WC push

Biofeedback Session 4:

Review homework: Posture, LT, WC work/rest cycle, slow vs fast WC push

4 EMG channels: UT, LT, anterior deltoid, and infraspinatus

- Select muscles as needed based on previous session progress

Biofeedback: Brief check/repeat training LT if needed

- Continue UT training in hallway, slow vs fast pushing
- Train WC push in lab, anterior deltoid and infraspinatus
- Train WC push in hall for anterior deltoid and infraspinatus
- Application of work/rest principles to sports

Homework: Spot checks, posture, applying work/rest cycles to WC, activities of daily living, and sports