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A Clinical Guide to Surface-EMG-Assisted Stretching as an Adjunct to Chronic Musculoskeletal Pain Rehabilitation

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Therapeutic stretching is a vital component of chronic musculoskeletal pain rehabilitation for increasing range of motion and counteracting the effects of physical deconditioning. Surface EMG biofeedback is currently being used to facilitate movement and to maximize effective stretching with patients in an interdisciplinary chronic pain rehabilitation program for disabled workers. A clinical protocol with case examples is presented.

KEY WORDS: stretching; surface EMG; range of motion; flexion–relaxation; biofeedback.

Surface EMG (SEMG) biofeedback is currently being used in an interdisciplinary rehabilitation program to help patients with chronic musculoskeletal pain to overcome inhibited movement and to develop effective stretching techniques. The patient population is almost exclusively injured workers who have suffered with chronic pain and disability (from a minimum of 4 months up to many years), been unsuccessful with previous physical therapies and modalities, and become deconditioned. The general treatment approach of this program, called *functional restoration*, involves whole body physical reconditioning (including weight training and work hardening activities), quantitative physical and psychological measures to guide patients through treatment, objective outcome measures, and an emphasis on vocational integration (Kinney, Gatchel, Polatin, & Mayer, 1991; Mayer & Gatchel, 1988).

Muscle stretching is a vital component of *functional restoration*. The initial goal of stretching is to counter the physiological effects of deconditioning and to begin to reestablish normal range of motion (ROM). Increasing the ROM of stiff muscles and joints is an important precursor to strength training to prevent injury and minimize pain "flare-ups." Stretching is emphasized throughout treatment, as both a preventative strategy to help curb

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the onset of pain “flare-ups” and a pain control technique to address pain “flare-ups” when they occur.

This paper offers a clinical protocol, with case examples, for using SEMG biofeedback to help chronic musculoskeletal patients overcome pain-related and fear-related movement inhibition, to facilitate effective stretching, and to help regain normal mobility.

A REVIEW OF THE LUMBAR FLEXION–RELAXATION PHENOMENON

The use of SEMG-assisted stretching within *functional restoration* treatment began with a research project on the lumbar flexion–relaxation (FR) phenomenon (Neblett et al., in press). FR refers to a pattern of muscle activity in which the lumbar muscles relax completely during full trunk flexion. The FR phenomenon has been demonstrated to be a consistent and reproducible pattern in most normal participants with no history of back pain (Andersson, Oddsson, Grundstrom, Nilsson, & Thorstensson, 1996; Basmajian & De Luca, 1985; Cram, Kasman, & Holtz, 1998; Donisch & Basmajian, 1972; Kippers & Parker, 1984; Mathieu & Forin, 2000; Morris, Benner, & Lucas, 1962; Portnoy & Morin 1956; Sihvonen, 1988; Steventon & Ng, 1995; Tanii & Masuda, 1985). Participants with chronic low back pain (CLBP) have often shown an absence of lumbar paraspinal relaxation during full trunk flexion (Ahern, Follick, Council, Laser-Wolston, & Litchman, 1988; Cram, 1990; Floyd & Silver, 1955; Golding, 1952; Kaigle, Wessberg, & Hansson, 1998; Kasman, Cram, Wolf, & Barton, 1998; Nouwen, Van Akkerveeken, & Versloot, 1987; Paquet, Malouin, & Richards, 1994; Shirado, Ito, Kaneda, & Strax, 1995; Sihvonen, Partanen, Hänninen, & Soimakallio, 1991; Triano & Schultz, 1987; Watson, Booker, Main, & Chen, 1997).

Neblett et al. (in press) measured L3 paraspinal SEMG (see Plate 2 in Appendix) concurrently with maximum voluntary flexion (MVF) ROM in a group of disabled workers with CLBP and a group of asymptomatic control participants. ROM was measured with a two-inclinometer technique described by Mayer, Tencer, Kristoferson, and Mooney (1984). Participants stood in a neutral posture with legs straight. After identifying bony landmarks, one inclinometer was placed over the T12 spinous process and one over the sacrum. Participants were then asked to bend toward the floor and focus on complete relaxation of lower back muscles while MVF ROM and SEMG were measured. By subtracting the *hip flexion* angle (the lower inclinometer) from the *gross flexion* angle (the upper inclinometer), *true lumbar* ROM was identified.

Thirty-four treatment participants were tested before and after completing a standard *functional restoration* rehabilitation program. At the premeasure, all 12 control participants, and 14 of the 34 treatment participants, were determined to have reached FR ($<$3.3 uV RMS), and 5 of the treatment participants showed normal MVF ROM. Following the treatment program, 32 of 34 treatment participants were able to achieve FR, and 27 showed normal MVF ROM. To our knowledge, no previous studies have demonstrated that an absence of FR in CLBP participants can be corrected with treatment.

In addition to the standard rehabilitation program, treatment participants participated in SEMG biofeedback training to learn lumbar paraspinal relaxation while bending. Because standing trunk flexion is one of the standard stretches assigned to the CLBP patients, treatment participants were offered the rationale that SEMG training could help them produce a more effective stretch, resulting in increased ROM and improved functioning. The SEMG-assisted stretching protocol has since become a standard part of *functional* *restoration* treatment. To date, hundreds of CLBP patients have been trained to achieve FR during MVF who were initially unable to do so. The basic strategies of this protocol have since been used for a variety of other stretches, many of which are presented in the Appendix.

A REVIEW OF STRETCHING WITH SEMG BIOFEEDBACK

There are relatively few references available on the use of SEMG biofeedback and stretching. Cummings, Wilson, and Bird (1984) compared pre- and posthip flexibility and sprint performance in three groups of athletes. Both SEMG training of hamstring muscles and progressive muscle relaxation training resulted in increased flexibility gains in a post-treatment retention period, but not during the treatment period, when compared to a control condition. EMG training was performed while supine, sitting still, and during stretch, but no microvolt levels or SEMG patterns were reported. Fogel (1995) described three case examples, one with low back pain, one with post-knee-surgery, and one with post-hand-surgery, who used SEMG training to reduce muscle activity during stretches of hamstring, quadriceps, and forearm flexor–extensor muscles. Kasman and Wolf (2002) described two other case examples. A patient with post-knee-injury used SEMG training to facilitate quadriceps relaxation during knee flexion stretches, and a patient with hip pain used SEMG training to produce a relaxed hamstring stretch and to learn how ballistic stretching (bouncing up and down), which the patient was accustomed to using, resulted in elevated SEMG activity. Peper and Gibney (2000) discussed the use of SEMG biofeedback to identify and control muscle tension during forearm stretches in the prevention and treatment of repetitive strain disorders. They reported that wrist stretches, in both flexion and extension, performed on a tabletop tended to produce lower SEMG levels than stretching the wrist with the opposite hand.

The most detailed description of SEMG-assisted stretching has been provided by Cram (1990) and Cram et al. (1998). Neck stretches, in flexion, extension, rotation, and lateral bending, were described for addressing neck and upper quadrant pain. In this procedure, patients were encouraged to focus on “breathing into the stretch” and relaxing more with each exhale as auditory SEMG feedback was provided. Stretches were maintained for 20–60 s. Cram reported decreased resting tension and reduction of resting asymmetries in pain patients. Restricted ROM associated with pain was attributed to exaggerated stretch reflexes in the gamma motor system. Theoretically, this treatment procedure trained patients to quiet the stretch receptor drive on the alpha motor system during the stretch, allowing the stretch receptor threshold in the gamma motor system to recalibrate to a lower level of activity.

CLINICAL GUIDE TO SEMG-ASSISTED STRETCHING

From the 1st day of *functional restoration* treatment, muscle stretching (along with an intensive strengthening regime) is emphasized as a way for patients to increase mobility and function. Group stretching is performed several times during the day, and patients are encouraged to stretch independently at other times. Individualized stretches, to address specific areas of tightness, are also provided by the physical therapy staff. ROM is measured periodically during the program to assess progress.

An SEMG stretch evaluation is often initiated when restricted movement is identified during routine ROM, when a patient is having difficulty with an assigned stretch, and/or when fear behaviors associated with movement are indicated. Electrodes are placed over the target muscle(s), parallel to the movement of the stretch, and the patient is asked to demonstrate the stretch. If SEMG levels are within a normal, relaxed range (from <3.5 to <2.0 uV RMS, depending on the placement), then it is assumed that the patient is indeed reaching the end point of the movement, and simply needs to put more time into stretching independently in order to increase his or her ROM. If elevated SEMG levels are identified, then it is assumed that the patient is consciously or unconsciously inhibiting the stretch. Table I provides an outline of specific treatment components that have been found most helpful for addressing inhibited movement and teaching effective stretching techniques with SEMG biofeedback.

Many SEMG treatment protocols require narrow, specific placements to decrease “cross talk” and volume conduction (see Kasman et al., 1998; Kasman & Wolf, 2002; Sella, 2002). Because SEMG-assisted stretching is a form of relaxation down-training, “cross talk” and volume conduction are of less concern. In fact, wider placements are often used to encourage a certain amount of volume conduction from surrounding muscles. The Appendix provides a list of common stretches and the SEMG placements that have been found to be most useful for training. Training is done with a static stretch technique, which involves the slow application and maintenance of stretch torque on the target muscle over a period of time (Moore & Hutton, 1980; Taylor, Dalton, Seaber, & Garrett, 1990). Most of the stretches in the Appendix are gravity-assisted, which indicates that a body part is placed dependently in a gravitational plane (Kisner & Colby, 1990). Static, gravity-assisted stretches have been found to be the most amenable to SEMG biofeedback training.

Table I. Clinical Protocol for Surface EMG-Assisted Stretching

1. Provide rational why stretching a relaxing muscle is more desirable than stretching a contracted muscle
2. Emphasize proper stretching technique and fine-tune the technique to maximize relaxation. Establish a specific stretching strategy, and have the patient verbalize the strategy, to promote independence with the technique
3. Maintain a smooth breathing pattern and avoid breath holding during the stretch
4. Focus on passive relaxation during the stretch rather than actively forcing the movement. Verbal cues might include

Let your body go soft and allow gravity to do the work
Imagine the muscles getting longer and longer
Focus on letting go more with each exhale
jiggle your limb slightly, then let it drop again

5. Address fear-related inhibition when it is identified
    a. Acknowledge the patient’s fear of movement and pain
    b. Clarify exactly what is scary about the movement. For instance, “are you concerned that you will re-injure yourself?” or “are you concerned that if you stretch further that your pain will increase?”
    c. Address specific fears. For instance, the doctor can provide reinforcement that increased movement is not likely to cause reinjury. Or it can be suggested to the patient that a relaxed stretch may hurt less than a tense, forced stretch (which is often true in our clinical experience)
    d. Educate the patient about the relationship between fear, tension, and pain. Suggest that increased fear and tension might exacerbate pain and that decreased fear and tension might result in decreased pain

The Appendix is certainly not an exhaustive list of therapeutic stretches, or the only stretches for which SEMG biofeedback training may be appropriate. In addition, other therapists may find alternative SEMG placements to be equally as effective for training. There may also be other treatment populations besides injured workers with chronic musculoskeletal pain who may be appropriate for SEMG-assisted stretching. Four case examples are provided to demonstrate how the SEMG-assisted stretching protocol has helped to facilitate treatment success.

CASE EXAMPLES

Case #1

S.J.L. initially showed inhibition with neck stretches, but he learned to relax relatively easily with one session of SEMG biofeedback training. He was a 48-year-old male who injured his neck when a 27-in. television set fell off a high shelf and hit him in the back of his head about 18 months previously, resulting in a C6/7 bulging disc and mild head injury. He had been working off and on in a light duty position since his injury. He had failed to respond to previous physical therapies and was unable to complete previous work hardening because of increased pain. He described constant pain in his neck and shoulders and rated his pain 7 out of 10 at his initial doctor visit.

A physical examination revealed inhibited neck movement, with neck flexion of 20°. An initial SEMG evaluation with a cervical to middle trapezius placement (see Plate 10) showed elevated muscle activity to about 9.0 uV on both his left and right sides during flexion. During his baseline stretch, he appeared to be pulling his chin straight down, resulting in shortened cervical muscles. He was encouraged to adjust this strategy by allowing the bottom of his skull to roll forward and down, and allowing his chin to move toward his chest, as auditory feedback and delayed visual feedback were provided. He was able to reduce SEMG levels to about 3.5 uV with moderate cuing. His ROM increased from 20° to 26° during the session, and his pain level improved from 3 to 1 during the stretch.

He reported substantial practice with neck stretching between his first and second sessions. His second session baseline SEMG levels were about 2.3 uV on both his left and right sides, and his baseline flexion ROM was 44°. By the end of his treatment program, he was demonstrating 55° of cervical flexion and reporting general pain levels of about 1 out of 10.

Case #2

C.N. showed more difficulty initially, and required several sessions of coaching and practice to become independent with relaxed hamstring stretches. He was a 42-year-old male who hurt his low back about 15 months previously, when he caught a 250-pound engine head as it began to roll off a table. He denied any previous back injuries. A recent IDET surgical procedure, to address a small L4 herniation, resulted in increased pain. A discogram/CT also showed degenerative disc disease. He had been working off and on since his injury, and he had failed to respond to previous chiropractic and physical therapies. He described constant low back pain radiating down to both feet, with his left leg being worse, with an 8 out of 10 pain rating at his initial doctor visit.

A physical evaluation revealed severely shortened hamstrings with a straight leg raise to 40° on his right and 45° on his left. He was instructed to stretch his hamstrings frequently by his physical therapist, and he was referred for biofeedback therapy to evaluate his technique. An initial SEMG hamstring placement showed average muscle activity in his left to be about 16.5 uV, and his right to be about 32.0 uV, during his stretches (see Plate 12). He was able to reduce his left side to about 2.5 uV, and his right to about 3.5 uV, within the first session with verbal coaching and visual–auditory feedback from a portable SEMG unit. Verbal hints included breathing focus, imagining softer and longer muscles, and encouraging slight adjustments with his leg and hips when SEMG readings showed stubbornness with relaxation. He was unable to relax completely with the opposite leg flat on the floor, so he had to bend the opposite knee during the stretch. He reported a decreased pain level, from an 8 to a 2 out of 10, with lower SEMG during the stretch.

C.N. participated in three subsequent treatment sessions, in which initial baseline levels, without feedback, reduced to between 5.0 and 8.0 uV on his right, but remained between 18.0 and 22.0 uV on his left. He became very good at relaxing both hamstrings to <2.5 uV immediately upon receiving visual–auditory feedback and was quickly able to lay his opposite leg flat onto the floor, but he had difficulty identifying increased and decreased tension without feedback. During his fourth training session, he discovered a tendency to pull his hips up from the floor slightly in reaction to the stretch. He was encouraged to focus on allowing his hips to rest completely onto the floor as part of his strategy. He showed good carryover in his fifth session, with baselines of 3.2 uV on the left and 3.0 uV on the right. By the end of his treatment program, C.N. was demonstrating 72° of motion on his right and 78° of motion on his left during a straight leg raise test.

Case #3

Fear was a primary obstacle in achieving an effective shoulder stretch for T.L. She was a 44-year-old female who ruptured a cervical disc while stretching in her desk chair at work. For the following 2 years, she worked in a light duty position with restrictions before being taken off work completely. After about 5 months, she underwent a surgical fusion at C5, and she began her treatment program about 6 months later. She described constant pain in her neck and left shoulder, stabbing between her shoulder blades, and tingling and numbness in her left hand. Initial examination by her physical therapist showed 160° of flexion in her right shoulder, but only 90° of flexion in her left shoulder, while standing.

During the initial biofeedback evaluation, she demonstrated significant protective guarding with her left arm, as well as symptoms of general anxiety. One of her primary shoulder stretches involved lying on her back and bringing her arms back over her head toward the floor into shoulder flexion (see Plate 16). When asked to demonstrate her shoulder stretch, she showed obvious muscle bracing, severely restricted movement far short of a stretch point, grimacing, and breath holding.

Her first two biofeedback sessions focused on simple breathing and relaxation techniques as she lay on her back and gradually moved her left arm out to her side into greater abduction. Initially, electrodes were placed between her left cervical and upper trapezius muscles to provide her with feedback about general muscle bracing. She was receptive and cooperative, and able to learn effective breathing relatively quickly, but had difficulty with even the slightest increase in ROM. During these initial sessions, she denied any emotional component to her guarded movement, and attributed it exclusively to pain. Significant session time was spent on rapport building, processing her feelings, and educating her about the relationship between pain, fear, and tension. She began to "open up" and to verbalize her fears during the second and third sessions. Even after acknowledging and processing her feelings, the idea of shoulder stretches was especially scary and challenging for her due to her mechanism of injury. Despite constant reassurance from her doctor and therapists, she initially had great difficulty trying to suppress her fear of pain and reinjury and to allow her arm to move out of her restricted and guarded ROM.

Sessions 3, 4, and 5 focused on her shoulder flexion stretch. Electrodes were placed between the posterior deltoid and the triceps (see Plate 16). The initial treatment strategy was to have her bring her left arm back and let it rest into the therapist's hands. The arm was then allowed to move backward gradually into increased extension while T.L. focused on breathing and relaxing. Of primary concern in these treatment sessions was to promote a feeling of trust and to assure that her arm and shoulder felt safe. During Session 3, she was able to reduce SEMG levels during her stretch from about 23.0 uV at baseline to about 4.0 uV with visual feedback and verbal coaching. Over the next two sessions, she demonstrated gradual gains with flexion ROM, showed increasingly independent success with relaxation down to 2.5 uV, and reported decreased fear and pain during the stretch. Eventually, she was able to bring her arm back to a good stretch point independently and then hold onto the leg of a chair with her hand. In this way, she was able to achieve an effective stretch while maintaining a feeling of safety in her arm and shoulder. Her standing left shoulder flexion ROM improved to 150° by the end of her program.

Case #4

J.N. presented a variety of obstacles to achieving FR of his low back, which he was eventually successful in overcoming. He was a 44-year-old male who injured his low back when he slipped and fell on a wet floor. He had a two level fusion, at L4-5 and L5-S1, 3 years prior to treatment. A recent X-ray confirmed that his fusion was solid. He had been unable to work since his surgery and had failed to respond to previous physical therapies and work hardening. Upon entering the treatment program, he expressed significant feelings of depression and anxiety, showed severely inhibited movement with his back, and reported a pain level of 9 out of 10 at his initial doctor visit.

An SEMG evaluation at L3 (see Plate 2) showed elevated muscle activity to 15.5 uV on his left, and 18.6 uV on his right, during full trunk flexion. During the movement, he demonstrated breath holding, shaking, a flat back, and minimal hip rotation (see Plate 4). His initial ROM upon entering the program was 20° of true lumbar flexion and 30° of pelvic flexion. He reported severe pain with bending and appeared fearful of movement. Supportive intervention revealed that he was concerned that he might break his fusion or cause reinjury if he allowed his back to bend fully. He met with his doctor to go over his diagnostics and to get reassurance that his fusion was strong and that stretching his back was not contraindicated. Education was also provided during biofeedback treatment sessions about the relationship between pain, fear, and tension.

J.N. participated in seven SEMG biofeedback training sessions before he demonstrated independence with FR. Because of his level of pain and fear, training began with "chair stretches," in which he flexed his back while seating in a chair. At first, several pillows were placed in his lap, and he was instructed to lean onto the pillows, allow the pillows to support his torso, and to focus on breathing and relaxing. Verbal feedback, intermittent auditory feedback, and delayed visual feedback were provided, as well as verbal coaching and encouragement. Pillows were gradually removed as he demonstrated increased ability to bend and relax in the chair. By the end of the second session, he was able to relax into the chair stretch (<2.0 uV) with no pillow supports (see Plates 6–9). His pain report during the chair stretch went from 7 to 3 (out of 10), which encouraged him.

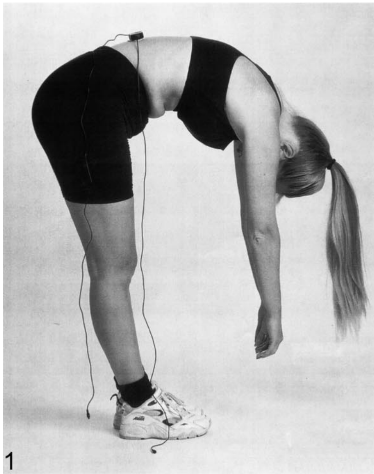
Standing FR was more difficult for him to achieve. He showed some relaxation success during Sessions 3 and 4, but he required moderate to maximum cuing, and his carryover between sessions was poor. He appeared to be bending mostly from his hips and reported significant tightness in his hamstrings during his stretch. Emphasis was placed on establishing a specific strategy for relaxing his back more easily. He found that bending about two thirds of the way, then focusing on bowing his back first, and then finally releasing the rest of the way from his hips, helped improve his relaxation success and decreased strain on his hamstrings. At first, it took at least 20–30 seconds for his back to relax fully during flexion. He had to focus on relaxing more with each exhale, and remaining very patient, until his back muscles released completely. By Session 6, he was showing consistent success. After one or two initial stretches with a slower decline in muscle activity, he was able to relax relatively quickly and easily during subsequent stretches.

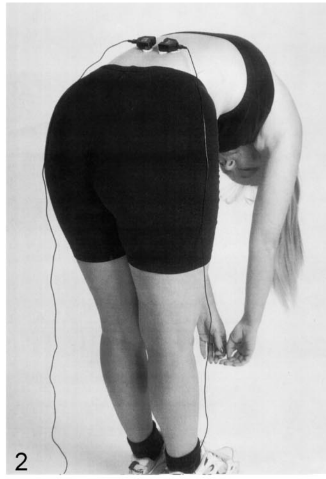
Despite his success in Sessions 5 and 6, he complained that his back would tighten up and begin hurting almost immediately upon strength training in the physical therapy gym. During Sessions 6 and 7, he utilized a portable SEMG unit with auditory feedback while working in the gym. Each time he felt his back begin to tighten, he was encouraged to bend and stretch. By the end of Session 7, he was able to relax his back quickly and independently during full trunk flexion, both during and after the gym, and he reported less pain and tightness during his workout. He was encouraged to continue frequent stretches after graduating from the program and beginning new employment to prevent pain from "flaring back up." By the end of his treatment program, J.N. showed improved pelvic flexion ROM to 54° and true lumbar flexion to 54° (despite his fusion).

CONCLUSION

The average patient that is referred for *functional restoration* treatment is pain-focused and emotionally distressed, has been unable to work or perform many activities of daily living, and has habitually restricted the movement around the area of injury for months or years. Initiating movement and increasing ROM for these patients is often painful and fear-provoking at first. If patients are able to learn good relaxed stretching techniques with basic verbal instruction, then most find that stretching quickly becomes less fear-provoking and begins to result in decreased pain and stiffness. These patients then tend to experience less discomfort during physical conditioning and weight training. Many chronic pain patients do not seem to be able to learn relaxed stretching with basic verbal instruction. They often show poor technique and have difficulty verbalizing specific strategies for achieving the most effective stretch. Often, these patients either restrict the movement far short of the stretch point, because of fear of pain and/or reinjury, or do they try to force the movement by gritting their teeth, holding their breath, and "pushing through" the pain. A combination of individual instruction on stretching technique, SEMG biofeedback training to teach muscular relaxation during stretches, and supportive intervention to address fear, has made a positive contribution to the success of many patients referred for *functional restoration* treatment.

APPENDIX: COMMON THERAPEUTIC STRETCHES AND SEMG PLACEMENTS





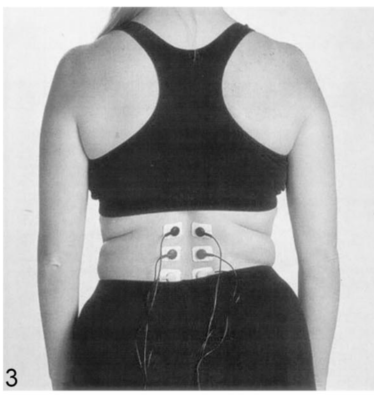
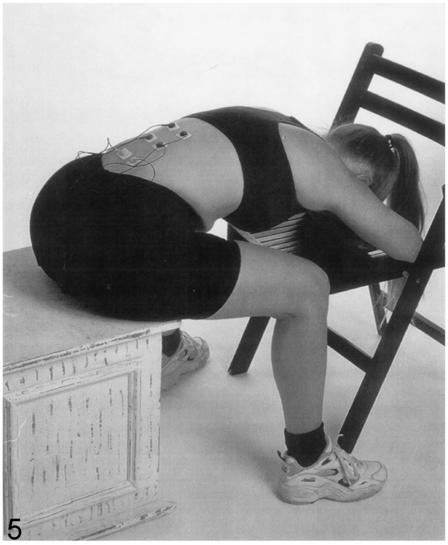


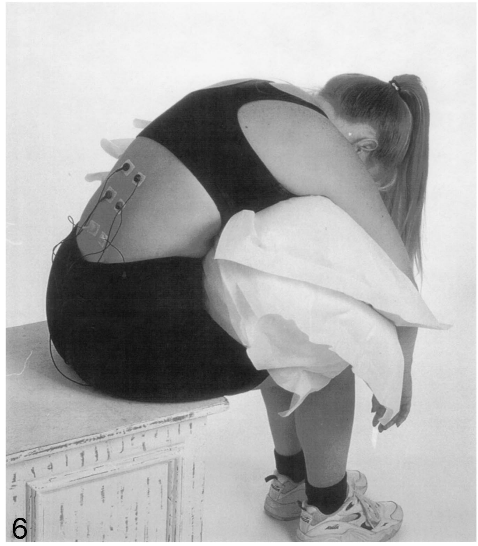
Plate 1. This is a common stretch for low back and hamstring muscles. The patient is instructed to stand with legs straight but unlocked, then to bend and allow the arms and torso to hang toward the floor. Notice that the back is rounded over and the head is dropped down.

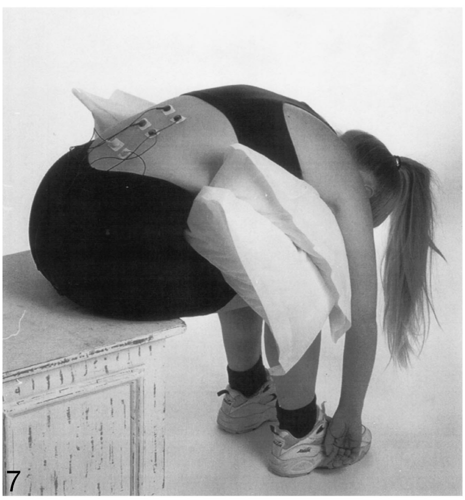
Plate 2. For research assessment of flexion–relaxation, the active electrodes are placed 2 cm apart at the L3 level of the paraspinal muscles with a wide band pass (20–500 Hz). Because the electrodes are attached, the 2-cm spacing is maintained through the flexion motion.

Plate 3. During biofeedback training, larger, separated electrodes (with a wide band pass) are often used, which allows the electrodes to separate wider as the skin lengthens during trunk flexion. This wider placement has been useful for measuring a larger area of the lumbar musculature and for addressing signal attenuation problems caused by excessive audipose tissue.

Plate 4. This is an example of inhibited lumbar flexion commonly observed in patients with chronic low back pain. Notice that the back is flat and the head is up, with arms and upper body held rigid.







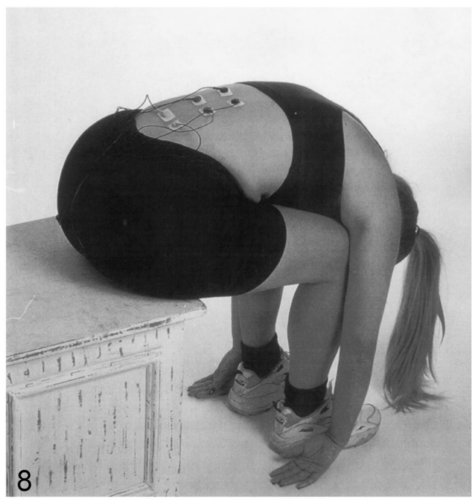
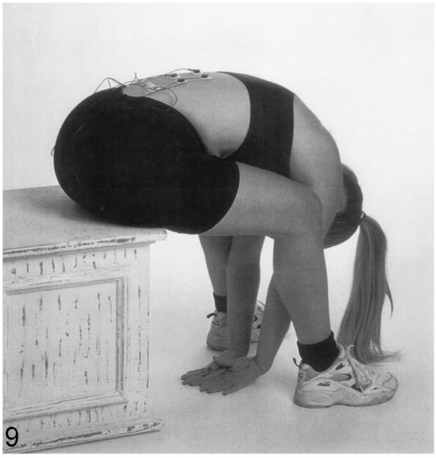


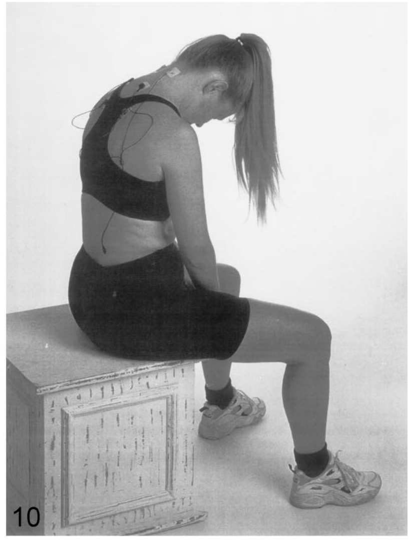
Plate 5. When a patient demonstrates inhibited standing flexion and difficulty with muscle relaxation training, it is often helpful to begin slowly with chair stretches. Use of props, such as stool or a chair, can help the patient to de-sensitize to bending, even though the back remains relatively flat and true lumbar motion is minimal. The patient is instructed to simply lean onto the stool and focus on back relaxation.

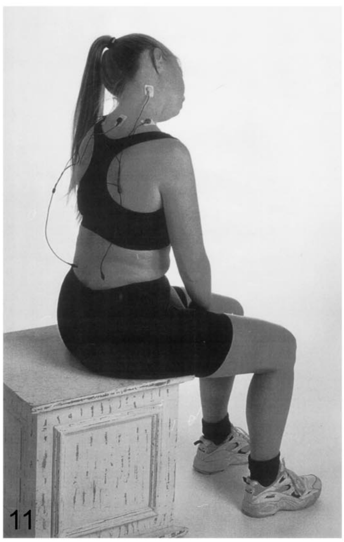
Plate 6. Pillows provide additional props to allow the patient to slowly begin adding roundness to the back. The patient is instructed to let the back bow over and let the pillows support the weight of the upper body.

Plate 7. Pillows are gradually removed as the patient demonstrates success with muscle relaxation.

Plate 8. When pillows are no longer needed, the patient is instructed to put the legs together, let the upper body weight rest on the lap, and continue to focus on relaxation.







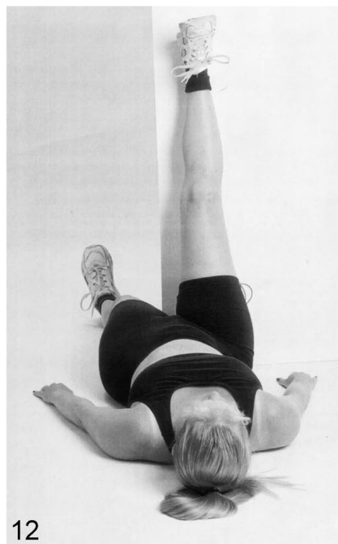
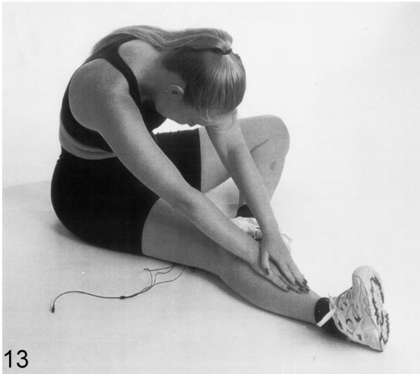


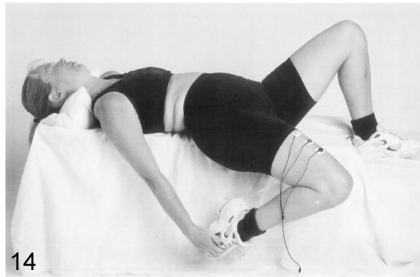
Plate 9. Finally, the patient should be able to perform a complete chair stretch, allowing the torso to hang out into space between parted legs.

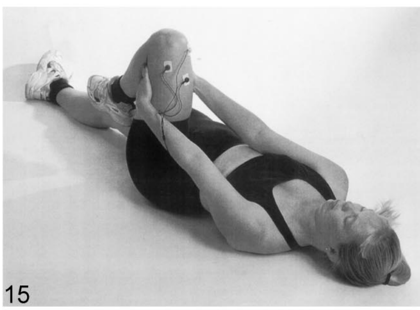
Plate 10. This is a basic stretch for the cervical and thoracic muscles. The patient is instructed to sit straight, drop the head down toward the floor, and allow the stretch to extend from the bottom of the skull to the shoulder blades. The active electrodes are placed between the cervical paraspinal and middle trapezius muscles with a narrow band pass (100–200 Hz) to reduce heart rate artifact.

Plate 11. This is a lateral side bend stretch for the neck. The patient is instructed to sit straight, allow the head to fall to the side, and let the ear move closer to the shoulder. The active electrodes are placed between the upper trapezius and the side of the neck, parallel to the movement of the stretch with a narrow band pass to reduce heart rate artifact.

Plate 12. There are many ways to stretch a hamstring. This stretch involves lying supine and supporting one leg vertically on the corner of a wall. The active electrodes are placed midway between the fold of the knee and the fold of the buttocks over the biceps femoris with a wide band pass.







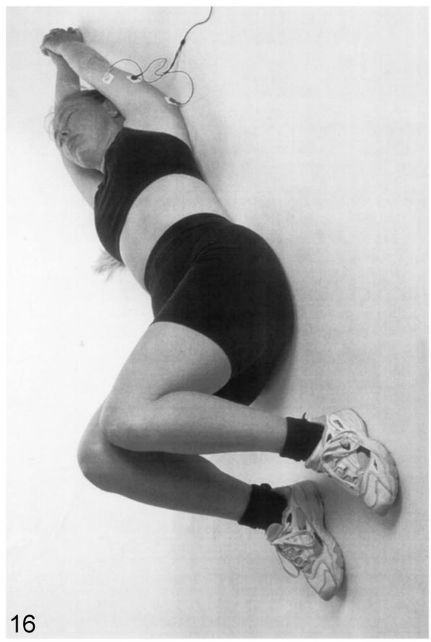
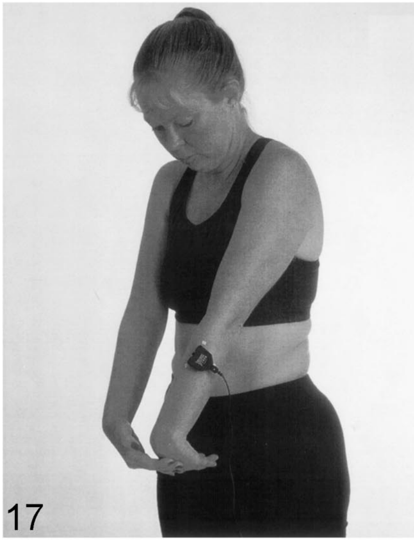


Plate 13. This is one alternative hamstring stretch with a biceps femoris placement.

Plate 14. This is a hip flexor stretch. The patient is instructed to lie supine on a raised mat, bend the opposite knee, hold the ankle on the target leg, drop the knee toward the floor, and allow the hip flexors to lengthen. The active electrodes are placed over the rectus femoris muscle, midway between the knee and the hip joint, with a wide band pass.

Plate 15. This is a typical knee stretch. The patient is instructed to lie supine, to interlace the fingers under the knee to support the leg vertically, then to drop the foot toward the floor and allow the knee to bend. The active electrodes are placed between the vastus medialis oblique and the vastus lateralis with a wide band pass.

Plate 16. This is a typical shoulder stretch. The patient is instructed to lie supine, interlace the fingers, and allow the arms to drop back over the head toward the floor. The active electrodes are placed between the posterior deltoid and the triceps with a wide band pass.



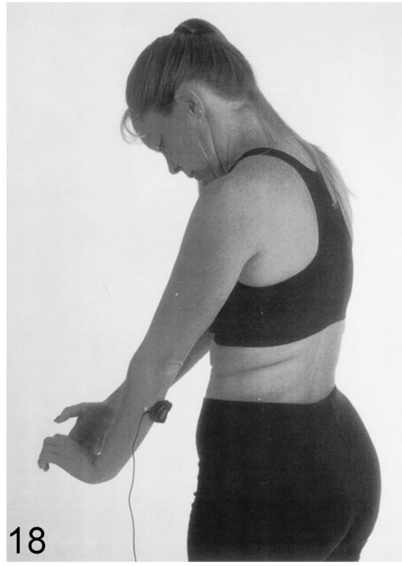


Plate 17. This is a typical stretch for the forearm extensor muscles. The active electrodes are placed directly over the wrist extensors with a wide band pass. Note that Peper and Gibney (2000) have found decreased SEMG with passive stretching on a tabletop.

Plate 18. This is a typical stretch for the forearm flexor muscles. The active electrodes are placed directly over the wrist flexors with a wide band pass. Again, note that Peper and Gibney (2000) have found decreased SEMG with passive stretching on a tabletop.

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