NIH-PA Author Manuscript
NIH-PA Author Manuscript
NIH-PA Author Manuscript

NIH Public Access
Author Manuscript
Clin J Pain. Author manuscript; available in PMC 2011 June 1.

Published in final edited form as:
Clin J Pain. 2010 June ; 26(5): 403–409. doi:10.1097/AJP.0b013e3181d2bd8c.

Correcting Abnormal Flexion-Relaxation in Chronic Lumbar Pain: Responsiveness to a New Biofeedback Training Protocol

Randy Neblett, M.A., L.P.C., BCIA-C[*], **Tom G. Mayer, M.D.**[**], **Emily Brede, R.N., M.S. candidate**[*], and **Robert J. Gatchel, Ph.D.**[***]

[*]PRIDE Research Foundation, 5701 Maple Ave. #100, Dallas, TX 75235

[**]Department of Orthopedic Surgery, University of Texas Southwestern Medical Center, 5323 Harry Hines Blvd., Dallas, TX 75235

[***]Department of Psychology, College of Science, The University of Texas at Arlington, 313 Life Science Building, Arlington, TX 76019 Supported in part by grant numbers 2K02 MH01107, 2R01 MH46402, and 2R01 DE10713 from the National Institutes of Health

Abstract

Objectives—Lumbar flexion-relaxation is a well-known phenomenon that can reliably be seen in normal subjects, but not in most chronic low back pain (CLBP) subjects. No previous studies have investigated any specific clinical intervention designed to correct abnormal flexion-relaxation. The objective of the current study was to evaluate the contribution of a surface EMG-assisted stretching (SEMGAS) biofeedback training protocol, within a functional restoration treatment program, on flexion range of motion (ROM) and erector spinae surface EMG (SEMG) during maximum voluntary flexion (MVF).

Methods—Lumbar flexion ROM and MVF SEMG were assessed in two groups of CLBP patients at the beginning and end of rehabilitation. One group participated in functional restoration only, while the other group participated in functional restoration plus SEMGAS biofeedback training. Both treatment groups were compared to a separate control group of normal, pain-free subjects.

Results—Pre-treatment ROM and MVF SEMG measures were similar in both treatment groups, but were very different than the control group. At post-treatment, the functional restoration only group remained statistically different than the control group on MVF SEMG and some ROM measures, but the SEMGAS group was statistically equivalent to the control subjects on all post-treatment measures, including the ability to demonstrate flexion-relaxation.

Discussion—Interdisciplinary functional restoration rehabilitation of CLBP subjects is effective for increasing ROM and other functional measures, but the addition of a SEMGAS biofeedback training protocol can result in normalization of the flexion-relaxation phenomenon, so that these subjects are comparable to a pain-free control group.

Keywords

Flexion-relaxation; chronic low back pain; surface electromyography; SEMG-assisted stretching; biofeedback; maximum voluntary flexion

---

Corresponding Author: Tom G. Mayer, M.D., 5701 Maple Ave. #100, Dallas, TX 75235, Phone: (214) 351-6000, Fax: (214) 351-6453, tgmayer@pridedallas.com.

NIH-PA Author Manuscript

Introduction

Flexion-relaxation refers to a stereotypical pattern of muscle activity in which the lumbar muscles relax at the end range of trunk flexion. This pattern of relaxation during maximum voluntary flexion (MVF) is demonstrated by most normal, pain-free subjects, but is often absent in chronic low back pain (CLBP) subjects.[1-7,11-12,39-40] Measures of FR have been shown to successfully distinguish between CLBP subjects and controls.[7] Studies have also demonstrated that abnormal flexion-relaxation patterns can be improved within physical therapy,[9] chronic pain management,[10] and functional restoration[6,8] treatment programs. In addition, positive treatment changes in flexion-relaxation patterns have been shown to be a sign of clinical improvement in self-efficacy beliefs, fear avoidance beliefs,[10] pain, and function.[8] No previous studies have investigated clinical interventions designed specifically to correct abnormal flexion-relaxation patterns in chronic low back pain subjects.

In assessing absolute root mean square SEMG values with an empirically derived cut-off score during MVF, Neblett and colleagues[6] have previously demonstrated that functional restoration treatment was effective in correcting abnormal flexion-relaxation patterns in 32 of 34 chronic low back pain subjects who completed the treatment program. About 30% of the subjects demonstrated flexion-relaxation (e.g., MVF SEMG below the target cutoff score) at the beginning of treatment, and 94% demonstrated flexion-relaxation at the end of the treatment program. With regard to cut-off scores, it should be pointed out that 3.2 μV was used in this original study. [6] As a result of further empirical investigation, and the inclusion of additional control subjects, 3.5 μV was determined to be the best cutoff point for determining flexion-relaxation in the current cohort.[8] Embedded in the functional restoration treatment program for the Neblett et al[6] cohort was a SEMG-assisted stretching (SEMGAS) biofeedback protocol. The treatment goal of SEMGAS is to “down-train” elevated muscle activity during a target stretch below a threshold (e.g. 3.5 μV). Other authors have reported using similar SEMG thresholds, ranging from 2.0 μV to 3.5 μV, depending on the muscle sites being measured and the assessment procedure or biofeedback training protocol utilized.[13-15] The SEMGAS protocol was developed to address movement inhibition in CLBP patients by teaching them how to relax the lumbar muscles during trunk flexion so that maximum stretch effectiveness and normal ROM can be achieved.[16-18] SEMGAS has become a standard part of functional restoration in our center and has been expanded to address inhibited stretching with other joints, such as necks, knees, hips, shoulders, and wrists. However, it has not yet been systematically evaluated.

The goals of this present investigation, therefore, were to evaluate the clinical effectiveness of a SEMGAS biofeedback treatment protocol with CLBP patients in a functional restoration program; to compare lumbar flexion ROM and MVF SEMG outcome measures with a pain free control group; and to determine if SEMGAS was more effective than functional restoration only in normalizing flexion-relaxation and ROM post-treatment.

Materials and Methods

Subjects

A group of 140 CLBP patients, with compensable occupational lumbar injuries with worker's compensation claims consented to, and were enrolled in, an interdisciplinary functional restoration rehabilitation program. They were evaluated at the beginning of treatment with a standard SEMG and ROM assessment protocol. All patients were referred to treatment due to CLBP and disability resulting from their work-related injuries. The average length of disability was 23.2 months upon admission to the program. The average age of the patients was 42.8 years, with 61% being male. Patients participated in one of two treatment groups: functional restoration treatment only (N=36); or functional restoration

NIH-PA Author Manuscript
NIH-PA Author Manuscript
NIH-PA Author Manuscript

plus a surface EMG-assisted stretching (SEMGAS) biofeedback training protocol (N=104). The treatment groups were formed by two cohorts of patients with compensable lumbar injuries who were admitted consecutively into the functional restoration treatment program within two separate time periods. Group assignment was based solely on the specific time period that each subject entered the treatment program. Patients in the functional restoration only group participated in all aspects of treatment, including SEMG biofeedback training for relaxation and stress management, but did not participate in the specific SEMGAS biofeedback training protocol to teach lumbar relaxation during trunk flexion. The functional restoration staff, except for the lead investigator who provided the biofeedback training, was unaware that a functional restoration only experimental group had been created, and was therefore blinded to group assignment of the patient cohort.

Twenty-four SEMGAS patients and 9 functional restoration only patients failed to complete the functional restoration treatment program due to issues such as non-compliance, so ROM and SEMG measures were assessed only at pre-treatment. Also, four patients who completed the treatment program were not assessed at post-treatment due to scheduling issues. In addition, 6 patients received functional restoration only within the consecutive SEMGAS cohort group, and 3 patients received SEMGAS within the consecutive functional restoration only cohort group. These 13 subjects were therefore eliminated from post-treatment analyses. This resulted in 94 patients who completed the prescribed course of treatment and were retested with the identical protocol at the conclusion of the functional restoration program, including 23 in the functional restoration only group and 71 in the SEMGAS group. There were no significant differences between the subjects included, and the subjects excluded, from the post-treatment analysis in terms of demographics, ROM, or SEMG measures.

In addition to the CLBP patients, a group of 30 asymptomatic control group subjects were recruited among PRIDE staff and colleagues. All control subjects had no history of low back pain over the prior one year, no prior low back disability, no previous low back surgery, and no evidence of a gross scoliosis curve that might alter myoelectric behaviors. They were measured with the identical SEMG and ROM methodology as the treatment subjects. Basic demographic data for both treatment subjects and controls are included in Table 1. There were no significant demographic differences between the functional restoration only group and the SEMGAS group. The control group was significantly younger as compared to the two treatment groups.

Assessment Procedure

A standard methodology was used for electrode placement and SEMG and ROM measurements.[19] The skin was cleaned with an alcohol swab, and silver-silver chloride electrodes from Noromed (1 cm. in diameter and spaced 2 cm. apart) were placed vertically on the left and right erector spinae muscles at L3, approximately 2 cm. from the midline. To help eliminate movement artifact, the electrode style was a recessed design, so that the electrode surface did not touch the skin, but only made contact with the electrode gel. To prevent electrode slippage during full flexion, subjects were asked to bend forward with hands on knees during attachment of the electrodes. A physical therapist noted bony landmarks and produced skin marks at the point of manual application of inclinometers at T12 and the sacrum.

Patients and control subjects were given standardized instructions for data collection. They were asked to: stand comfortably with arms to their sides and to look straight ahead with eyes level; then to bend forward into full flexion with knees straight and to let their arms and upper body “hang loose and dangle freely” and to allow their backs to “relax completely;” and then to return to standing. The experimenter demonstrated proper form and speed of

NIH-PA Author Manuscript

NIH-PA Author Manuscript

NIH-PA Author Manuscript

movement of the trunk flexion test. The timing of flexion and re-extension was verbally guided by the experimenter. Some researchers have recommended strict timing of the flexion and re-extension movements with a metronome.[4] We used a metronome to time each subject's movement in previous research[6] but found that this timing procedure sometimes confused subjects and interfered with performance. Therefore, strict timing of the movement was abandoned during the present study. After two or more practice trials to make sure that the proper form was used, statistical analysis was performed on the next subsequent clean trial (proper form and no electrode slippage or other noticeable artifact in the SEMG reading). If any signal problems were observed, the source of artifact was identified and corrected (such as replacing electrodes) and additional trials were performed until a clean reading was achieved. Five specific SEMG measures were taken, including a 10-second standing mean, the maximum SEMG during the flexion movement, approximately 2 seconds of mean SEMG during maximum voluntary flexion, the maximum SEMG during re-extension, and approximately 10 seconds of recovery following a return to standing. During flexion trials, a physical therapist held inclinometers at T12 and the sacrum and recorded degrees of movement using a standard two-inclinometer technique, in which pelvic motion (measured from the sacrum) was subtracted from the gross motion (measured from T12) to determine true lumbar motion.[20-21]

SEMG readings were recorded with a Procomp+ biofeedback system (Thought Technology Ltd., Montreal, Quebec). A root mean squared rectified SEMG signal, with a frequency response of 20-500 Hz, was averaged by .5 seconds to smooth the signal and was presented in the form of a numeric display and a line graph to the experimenter. For each measurement, microvolt (μV) levels from the left and right side electrodes were averaged to obtain a single mean SEMG μV number.

Treatment Procedure

Functional restoration is an intensive interdisciplinary program designed to rehabilitate patients with disability and functional restrictions due to chronic pain.[22-25] Patients typically attend treatment between two and five days per week over two or more months for a total of 160 to 240 hours, depending on the severity of their disability and deconditioning. The primary treatment goal is to help patients regain normal functioning so that they can more successfully participate in whole-person activities of daily living, including employment. Objective measures of physical deconditioning, including ROM, strength, and cardiovascular testing, are performed pre- and post-treatment, as well as periodically during treatment to assess progress. Patients participate in gradually intensified physical exercise, including daily group and individual stretch training (with an emphasis on lumbar ROM for CLBP patients) to help regain mobility, strength, and endurance in the injured “weak link” musculoskeletal area, as well as improving cardiovascular performance. In addition, patients participate in educational classes, cognitive behavioral counseling, biofeedback, relaxation, and stress management training, and multi-modal disability management. Most patients ultimately experience a reduction in pain and improvement in function, with measured socioeconomic outcomes persisting 1-2 years later, which have been well-demonstrated in the scientific literature.[23,25,26-37]

The SEMG-assisted stretching biofeedback protocol is designed to help chronic pain patients overcome pain and fear-related movement inhibition.[16-18] This treatment protocol involves the following steps:

- Biofeedback assessment graphs, showing elevated SEMG during the target stretch, are reviewed with the patient. Rationale for stretching a relaxed muscle vs. stretching a contracted muscle is explained.

NIH-PA Author Manuscript

NIH-PA Author Manuscript

NIH-PA Author Manuscript

- Fear of pain and/or re-injury with stretching is evaluated and addressed with supportive re-assurance, cognitive behavioral intervention, and diagnostic evidence of the structural integrity of the patient's spine.
- Specific strategies for achieving muscle relaxation during the target stretch are provided, including verbal cues, demonstration of proper technique, and focus on breathing and “letting go” with each exhale.
- Stretching trials are performed with visual and/or auditory SEMG feedback, with the training goal of relaxation below 3.5 μV.
- Frequent follow-through outside of treatment is recommended, and success with relaxed stretching is re-evaluated in subsequent sessions.

Statistical materials

In all statistical analyses, gross and true lumbar ROM were corrected by eight degrees per fusion level for those patients with lumbar fusions, as has been recommended previously.[6] Differences among the SEMGAS group, the functional restoration only group, and the pain-free control group were evaluated using one-way ANOVA tests and Tukey's correction for multiple comparisons. Next, differences from pre- to post-treatment were analyzed using an ANOVA with repeated measures, with Bonferroni's correction for multiple comparisons. For an alpha of .05 and power of .80, a sample size of 87 would be required for a medium-large effect size, and a sample size of 48 would be required for a large effect size. As the results show, we had more than adequate power to detect medium-large to large effect sizes.[38]

Results

Table 2 shows the pre-treatment measures for both treatment groups and for the control group on SEMG levels during maximum voluntary flexion (MVF) and on gross, pelvic, and true lumbar ROM. Significant differences were found among groups for MVF SEMG, ($p < .001$), gross ROM, ($p < .001$), pelvic ROM, ($p < .001$), and true ROM, ($p < .001$). Post-hoc testing using the Tukey correction for multiple comparisons revealed that MVF SEMG and ROM measures were significantly better in the pain-free control group when compared with either treatment group. There were no significant differences in MVF SEMG and ROM measures between the two treatment groups.

Table 3 presents the post-treatment measures for both treatment groups and for the control group. Differences among the groups at post-treatment were significant for MVF SEMG, ($p < .001$), gross ROM, ($p < .001$), and pelvic ROM, ($p = .003$). Post-hoc testing, using the Tukey correction for multiple comparisons, showed that MVF SEMG and ROM measures in the functional restoration only group were significantly worse when compared with both the SEMGAS group and the control group. No significant MVF SEMG or ROM differences were found between the SEMGAS group and the control group at post-treatment.

Table 4 shows changes in ROM and MVF SEMG measures from pre- to post-treatment for each of the two treatment groups. Both groups improved significantly from pre-treatment to post-treatment on MVF SEMG, ($p < .001$), gross ROM, ($p < .001$), pelvic ROM, ($p < .001$), and true ROM, ($p < .001$). Interactions between treatment group and time were significant for the MVF SEMG, ($p =.050$), indicating that the SEMGAS group improved significantly more on these measures than the functional restoration only group.

Table 5 presents the number and percentage of treatment subjects who demonstrated flexion-relaxation (e.g., MVF SEMG < 3.5 μV). Only subjects who completed the full

NIH-PA Author Manuscript

course of functional restoration treatment are represented in this table. At pre-treatment, 4 (17%) of the functional restoration only subjects, and (24) 34% of the SEMGAS subjects, achieved flexion-relaxation. At post-treatment, 6 (26%) of the functional restoration only subjects, and 61 (86%) of the SEMGAS subjects, achieved flexion-relaxation.

Thirty-seven of the 47 subjects in the SEMGAS group, who failed to demonstrate flexion-relaxation at the pre-treatment measure, were able to achieve flexion-relaxation (MVF relaxation below 3.5 μV) within an average of 2.4 biofeedback training sessions, with a standard deviation of 1.4. Some patients required up to 6 sessions before consistently achieving flexion-relaxation (See the bottom of table 1). The number of biofeedback training sessions was determined by each individual's success with achieving flexion-relaxation. Ten of these 47 SEMGAS subjects were unable to achieve flexion-relaxation despite multiple training sessions. The 24 subjects in the SEMGAS group who did demonstrate flexion-relaxation at the pre-treatment measure received one or two sessions of instruction and practice with lumbar SEMG biofeedback during the treatment program.

Discussion

It has been well-documented that CLBP patients tend to show abnormal flexion-relaxation patterns.[1-4,7,11-12,39-40] It has also been demonstrated that abnormal flexion-relaxation is generally associated with limited flexion ROM at MVF, and that improvements in ROM in CLBP patients may be correlated with correcting abnormal flexion-relaxation.[6,8,18] In addition, positive changes in flexion-relaxation, in response to treatment of CLBP, have been associated with increased self-efficacy beliefs and decreased fear avoidance beliefs[10] and improvements in self-reported pain and functional outcomes. [8]

The results of the present study confirm that abnormal flexion-relaxation patterns in CLBP patients can be improved with functional restoration treatment and can be normalized in most subjects with the addition of SEMGAS. In the present cohort, both SEMGAS and functional restoration only groups were significantly worse than the control group on maximum voluntary flexion (MVF) SEMG and all lumbar flexion ROM measures at pre-treatment. Both treatment groups, though, made significant improvements in MVF SEMG and flexion ROM from pre- to post-treatment, although the SEMGAS group showed significantly more improvement in MVF SEMG compared with the functional restoration only group. At post-treatment, the functional restoration only group remained significantly different than the control group in MVF SEMG and gross and pelvic ROM, but no significant differences were found between the SEMGAS group and the control group on MVF SEMG or any of the ROM measures. Two previous studies have shown significant improvement in flexion-relaxation patterns following rehabilitation.[9,10] However, only treatments which have included SEMGAS, including Neblett, et al,[6] Mayer et al,[8] and the present study, have demonstrated that abnormal flexion-relaxation patterns can be corrected, so that post-treatment MVF SEMG levels are comparable to a pain-free control group. When looking at individual patients who completed the full course of treatment, the number of SEMGAS subjects who achieved flexion-relaxation increased from 35% at pre- to 86% at post-treatment, while the functional restoration only subjects showed less improvement, from 17% at pre- to 26% at post-treatment. Without the specific SEMGAS training component, CLBP patients may achieve normal true lumbar flexion ROM, but are unlikely to achieve normal lumbar muscular relaxation at MVF or normal hip (pelvic) flexion ROM.

There is no consensus on why CLBP subjects tend to demonstrate abnormal flexion-relaxation patterns, but fear-avoidance has been implicated as a primary factor.[7,9] The fear-avoidance model of chronic pain asserts that fear of pain leads to a cycle of decreased physical activity and increasingly exaggerated pain perception. As chronic pain develops,

NIH-PA Author Manuscript
NIH-PA Author Manuscript
NIH-PA Author Manuscript

pain behavior becomes less a reaction to nocioceptive pain signals and more of a fear-avoidance response to prevent further pain.[42] Within this model, abnormal flexion-relaxation can theoretically develop as an initial fear-avoidance reaction to pain following an injury and, over time, become a non-voluntary habitual pattern. It is our clinical experience that inhibited CLBP patients, who demonstrate abnormal flexion-relaxation, are often unaware that they are contracting their lumbar muscles during MVF. There is evidence to support the tendency of chronic pain subjects to be poor judges of muscle tension levels. [43]

Many patients seen in functional restoration treatment have great difficulty overcoming fear-avoidance beliefs, which can result in movement inhibition, guarded stretching technique, and abnormal flexion-relaxation patterns. The SEMGAS treatment protocol directly addresses fear-avoidance issues and habitual inhibition in the following ways: it demonstrates to the subject that he or she is indeed inhibiting movement (whether the subject is aware of this or not); it provides a rationale for learning to reduce inhibition and increase relaxation during stretches; and it provides a training tool (SEMG biofeedback) for creating positive clinical changes.

Although standard functional restoration treatment of CLBP subjects is effective for increasing lumbar flexion ROM and for improving MVF SEMG levels, the addition of a SEMGAS biofeedback training protocol can result in normalization of the flexion-relaxation phenomenon, so that these subjects are comparable to a pain free control group. The limitations of this study, and the conclusions that can be drawn from it, include a lack of proper randomization, unequal sample sizes, and the potential bias of having the same researcher involved with both assessment and treatment. Future research should investigate whether SEMGAS biofeedback training alone, or in other rehabilitation settings other than functional restoration, can be effective for correcting abnormal flexion-relaxation patterns. The effect of prior spinal surgeries on the flexion-relaxation phenomenon, treatment outcomes, and the effectiveness of SEMGAS training, also warrants further study.

References

1. Triano JJ, Schultz AB. Correlation of objective measure of trunk motion and muscle function with low back disability ratings. SPINE 1987;12:561–5. [PubMed: 2958944]
2. Ahern D, Follick M, Council J, et al. Comparison of lumbar paravertebral EMG patterns in chronic low back pain patients and non-patient controls. Pain 1988;34:153–60. [PubMed: 2971912]
3. Sihvonen T, Partanen J, Hänninen O, et al. Electric behavior of low back muscles during lumbar pelvic rhythm in low back pain patients and healthy controls. Arch Phys Med Rehabil 1991;72:1080–7. [PubMed: 1835833]
4. Shirado O, Ito T, Kaneda K, et al. Flexion-relaxation phenomenon in the back muscles: A comparative study between healthy subjects and patients with chronic low back pain. Am J Phys Med Rehabil 1995;74:139–44. [PubMed: 7710729]
5. Watson P, Booker CK, Main CJ, et al. Surface electromyography in the identification of chronic low back pain patients: The development of the flexion relaxation ratio. Clin Biomech 1997a;2:165–71.
6. Neblett R, Mayer TG, Gatchel RJ, Keeley J, Proctor T, Anagnostis C. Quantifying the lumbar flexion-relaxation phenomenon: theory, normative data, and clinical applications. SPINE 2003;28:1435–1446. [PubMed: 12838103]
7. Geisser M, Ranavaya M, Haig A, et al. A Meta-Analytic Review of Surface Electromyography Among Persons with Low Back Pain and Normal, Healthy Controls. Pain 2005;6(11):711–26.
8. Mayer T, Neblett R, Brede E, Gatchel R. The quantified lumbar flexion-relaxation phenomenon (QLFRP) is an excellent measurement of improvement in a functional restoration program. SPINE 2009;34(22):2458–2465. [PubMed: 19789467]
9. Marshall P, Sci D, Murphy B. Changes in the flexion relaxation response following an exercise intervention. SPINE 2006;31(23):877–883.

NIH-PA Author Manuscript

NIH-PA Author Manuscript

NIH-PA Author Manuscript

10. Watson PJ, Booker CK, Main CJ. Evidence for the role of psychological factors in abnormal paraspinal activity in patients with chronic low back pain. J Musculoskeletal Pain 1997b;5(4):41–56.
11. Floyd WF, Silver PHS. The function of the erector spinae muscles in certain movements and postures in man. J Physiol 1955;129:184–203. [PubMed: 13252593]
12. Golding JSR. Electromyography of the erector spinae in low back pain. Postgrad Med J 1952:401–6. [PubMed: 14957661]
13. Sella, GS. Muscles in motion: the SEMG of the ROM of the Human Body. Martins Ferry, OH: GENMED Publishing; 2002.
14. 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(1):23–31. [PubMed: 11706774]
15. Peper, E.; Gibney, KH. Healthy computing with muscle biofeedback.: A practical manual for preventing repetitive motion injury. Edisonweg, The Netherlands: Biofeedback Foundation of Europe; 2000.
16. Neblett R. Correcting abnormal lumbar flexion surface electromyography patterns in chronic low back pain patients. Biofeedback 2007;35(1):17–22.
17. Neblett R, Mayer TG, Gatchel RJ. Theory and rationale for surface EMG-assisted stretching as an adjunct to chronic musculoskeletal pain rehabilitation. Appl Biofeedback Self Regul 2003;28(2): 139–146.
18. Neblett R, Gatchel RJ, Mayer TG. A clinical guide to surface EMG-assisted stretching as an adjunct to chronic musculoskeletal pain rehabilitation. Appl Biofeedback Self Regul 2003;28(2): 147–160.
19. Cram, JR.; Kasman, G. Introduction to surface electromyography. Gaithersburg, MD: Aspen Publishers, Inc.; 1998.
20. Mayer T, Tencer A, Kristoferson S, et al. Use of Noninvasive Techniques for Quantification of Spinal Range-of-Motion in Normal Subjects and Chronic Low-Back Dysfunction Patients. SPINE 1984;9:588–95. [PubMed: 6238424]
21. Keeley J, Mayer T, Cox R, et al. Quantification of Lumbar Function Part 5: Reliability of Range of Motion Measures in the Sagittal Plane and an In Vivo Torso Rotation Measurement Technique. SPINE 1986;11:31–5. [PubMed: 2939567]
22. Mayer, T.; Gatchel, R. Functional Restoration for Spinal Disorders: The Sports Medicine Approach. Philadelphia: Lea & Febiger; 1988.
23. Mayer T, Gatchel R, Mayer H, Kishino N, Keeley J, Mooney V. A Prospective Two-Year Study of Functional Restoration in Industrial Low Back Injury: An Objective Assessment Procedure. JAMA 1987;258:1763–1767. [PubMed: 2957520]
24. Mayer T, Gatchel R, Kishino N, et al. Objective Assessment of Spine Function Following Industrial Accident: A Prospective Study with Comparison Group and One-Year Follow-Up; Volvo Award in Clinical Sciences, 1985. SPINE 1985;10:482–493. [PubMed: 2934829]
25. Mayer T, Polatin P, Smith B, et al. Spine Rehabilitation: Secondary and Tertiary Nonoperative Care. North American Spine Society: Contemporary Concepts Review Committee. Spine J 2003;3:28S–36S. [PubMed: 14589215]
26. Curtis L, Mayer T, Gatchel R. Physical Progress and Residual Impairment After Functional Restoration, Part III: Isokinetic and Isoinertial Lifting Capacity. SPINE 1994;18:401–405. [PubMed: 8178226]
27. Brady S, Mayer T, Gatchel R. Physical Progress and Residual Impairment Quantification After Functional Restoration, Part II: Isokinetic Trunk Strength. SPINE 1994;18:395–400. [PubMed: 8178225]
28. Mayer T, Pope P, Tabor J, Bovasso E, Gatchel R. Physical Progress and Residual Impairment Quantification After Functional Restoration, Part I: Lumbar Mobility. SPINE 1994;18:389–394. [PubMed: 8178224]
29. Garcy P, Mayer T, Gatchel R. Recurrent or New Injury Outcomes After Return to Work in Chronic Disabling Spinal Disorders: Tertiary Prevention Efficacy of Functional Restoration Treatment. SPINE 1996;21:952–959. [PubMed: 8726199]

NIH-PA Author Manuscript

NIH-PA Author Manuscript

NIH-PA Author Manuscript

30. Mayer T, McMahon M, Gatchel R, Sparks B, Wright A, Pegues P. Socioeconomic Outcomes of Combined Spine Surgery and Functional Restoration in Workers' Compensation Spinal Disorders With Matched Controls. SPINE 1998;23:598–606. [PubMed: 9530792]
31. Jordan K, Mayer T, Gatchel R. Should Extended Disability Be An Exclusion Criterion For Tertiary Rehabilitation?: Socioeconomic Outcomes of Early vs Late Functional Restoration in Compensation Spinal Disorders. SPINE 1998;23:2110–2117. [PubMed: 9794056]
32. Wright A, Mayer T, Gatchel R. Outcomes of Disabling Cervical Spine Disorders in Compensation Injuries: A Prospective Comparison to Tertiary Rehabilitation Response for Chronic Lumbar Spinal Disorders. SPINE 1999;24:178–183. [PubMed: 9926390]
33. Mayer T, Gatchel R, Polatin P, Evans T. Outcomes Comparison of Treatment for Chronic Disabling Work-Related Upper Extremity Disorders and Spinal Disorders. J Occup Environ Med 1999;41:761–770. [PubMed: 10491792]
34. Mayer T, Gatchel R, Evans T. Effect of Age on Outcomes of Tertiary Rehabilitation for Chronic Disabling Spinal Disorders. SPINE 2001;26:1378–1384. [PubMed: 11426155]
35. Mayer T, Anagnostis C, Gatchel R, Evans T. Impact of Functional Restoration After Anterior Cervical Fusion on Chronic Disability in Work-Related Neck Pain. Spine J 2002;2:267–273. [PubMed: 14589478]
36. Proctor T, Mayer T, Gatchel R, McGeary D. Unremitting Health-Care-Utilization Outcomes of Tertiary Rehabilitation of Chronic Musculoskeletal Disorders. J Bone Joint Surg 2004;86:62–69. [PubMed: 14711947]
37. McGeary D, Mayer T, Gatchel R. High Pain Ratings Predict Treatment Failure in Chronic Occupational Musculoskeletal Disorders. J Bone Joint Surg 2006;88-A:317–325. [PubMed: 16452743]
38. Faul F, Erdfelder E, Lang AG, Buchner A. G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav Res Methods 2007;39:175–191. [PubMed: 17695343]
39. Paquet N, Malouin F, Richards C. Hip-spine movement interaction and muscle activation patterns during sagittal trunk movements in low back patients. SPINE 1994;19(5):596–603. [PubMed: 8184355]
40. Nouwen A, Van Akkerveeken PF, Versloot JM. Patterns of muscular activity during movement in patients with chronic low back pain. SPINE 1987;12:777–82. [PubMed: 2961090]
41. Geisser ME, Haig AJ, Wallborn AS, Wiggert EA. Pain-related fear, lumbar flexion, and dynamic EMG among persons with chronic musculoskeletal low back pain. Clin J Pain 2004;20(2):61–69. [PubMed: 14770044]
42. Lethem J, Slade P, Troup J, Bentley G. Outline of a fear-avoidance model of exaggerated pain perception. Behav Res Ther 1983;21:401–8. [PubMed: 6626110]
43. Flor H, Fürst M, Birbaumer N. Deficient discrimination of EMG levels and overestimation of perceived tension in chronic pain patients. Appl Psychophysiol Biofeedback 1999;24(1):55–66. [PubMed: 10553483]

NIH-PA Author Manuscript
NIH-PA Author Manuscript
NIH-PA Author Manuscript

Table 1

Demographic data of the three groups

Values	SEMG-Assisted Stretching (N=104)	Functional Restoration Only (N=36)	Control group (N=30)	P
Age (mean/SD)	44.3 (10.0)	42.7 (10.1)	37.6 (9.3)	.005
Gender (% male)	58 % (n=60)	72% (n=26)	53% (n=16)	NS
Race (%)				
Caucasian	54% (n=56)	50% (n=18)	80% (n=24)	NS
African-American	27% (n=28)	25% (n=9)	10% (n=3)	
Hispanic	11% (n=11)	19% (n=7)	6.7% (n=2)	
Asian	1% (n=1)	0 (n=0)	3% (n=1)	
Other	4% (n=4)	3% (n=1)	0 (n=0)	
Not answered	4% (n=4)	3% (n=1)	0 (n=0)	
Length of Disability in Months (mean/SD)	23.8 (27.5)	21.4 (23.4)	NA	NS
Pre-treatment Surgery (%)				
Spinal fusion	31% (n=32)	25% (n=9)	NA	NS
Lumbar spine surgery other than fusion	18% (n=19)	22% (n=8)		NS
Completion Status (%)	77% (n=80)	75% (n=27)	NA	NS
Number of SEMGAS				
Sessions (for those patients who failed to demonstrate FR at pre-treatment)				
Mean (SD)	2.42 (1.4)	NA	NA	
Median	2	NA	NA	
Range	1-6	NA	NA	

NIH-PA Author Manuscript

NIH-PA Author Manuscript

NIH-PA Author Manuscript

Table 2

Group means and standard deviations at pre-treatment for surface EMG (μV RMS) and degrees of lumbar range of motion during maximum voluntary flexion with comparison to control group.

Values	SEMG- Assisted Stretching (N=104)	Functional Restoration Only (N=36)	Control group † (N=30)	P*
Mean SEMG	11.2 (9.5)	13.5 (10.4)		.354
Gross Lumbar Flexion	71.9 (24.6)	69.8 (23.0)		.884
Pelvic Flexion	33.4 (17.0)	30.8 (15.8)		.674
True Lumbar Flexion	38.5 (13.1)	39.0 (10.7)		.971
Mean SEMG	11.2 (9.5)		2.0 (0.64)	.000
Gross Lumbar Flexion	71.9 (24.6)		109.9 (11.7)	.000
Pelvic Flexion	33.4 (17.0)		56.0 (10.0)	.000
True Lumbar Flexion	38.5 (13.1)		53.9 (8.2)	.000
Mean SEMG		13.5 (10.4)	2.0 (0.64)	.000
Gross Lumbar Flexion		69.8 (23.0)	109.9 (11.7)	.000
Pelvic Flexion		30.8 (15.8)	56.0 (10.0)	.000
True Lumbar Flexion		39.0 (10.7)	53.9 (8.2)	.000

*Uses Tukey's correction for multiple comparisons

†Note: Patient subjects were evaluated pre- and post-treatment, but pain-free control subjects were only evaluated one time.

NIH-PA Author Manuscript
NIH-PA Author Manuscript
NIH-PA Author Manuscript

Table 3

Group means and standard deviations at post-treatment for surface EMG (μV RMS) and degrees of lumbar range of motion during maximum voluntary flexion with comparison to control group.

Values	SEMG-Assisted Stretching (N=71)	Functional Restoration Only (N=23)	Control group † (N=30)	P*
Mean SEMG	3.3 (4.1)	11.8 (10.7)		.000
Gross Lumbar Flexion	109.7 (16.0)	94.4 (19.7)		.000
Pelvic Flexion	58.0 (15.2)	46.1 (15.9)		.002
True Lumbar Flexion	52.0 (9.6)	48.3 (11.9)		.253
Mean SEMG	3.3 (4.1)		2.0 (0.64)	.534
Gross Lumbar Flexion	109.7 (16.0)		109.9 (11.7)	.999
Pelvic Flexion	58.0 (15.2)		56.0 (10.0)	.786
True Lumbar Flexion	52.0 (9.6)		53.9 (8.2)	.647
Mean SEMG		11.8 (10.7)	2.0 (0.64)	.000
Gross Lumbar Flexion		94.4 (19.7)	109.9 (11.7)	.002
Pelvic Flexion		46.1 (15.9)	56.0 (10.0)	.038
True Lumbar Flexion		48.3 (11.9)	53.9 (8.2)	.098

*Uses Tukey's correction for multiple comparisons

†Note: Patient subjects were evaluated pre- and post-treatment, but pain-free control subjects were only evaluated one time.

NIH-PA Author Manuscript
NIH-PA Author Manuscript
NIH-PA Author Manuscript

Table 4

Pre to post treatment changes in group means with standard deviations for surface EMG (μV RMS) and degrees of lumbar range of motion during maximum voluntary flexion.

Group	Measure	Pre-treatment	Post-treatment	p *
SEMG-Assisted Stretching (N=71)	Mean SEMG†	11.2 (9.4)	3.3 (4.1)	.000
	Gross Lumbar Flexion	73.5 (23.6)	109.7 (15.9)	.000
	Pelvic Flexion	33.9 (16.5)	58.0 (15.2)	.000
	True Lumbar Flexion	39.9 (13.2)	52.0 (9.6)	.000
Functional Restoration Only (N=23)	Mean SEMG†	15.8 (10.1)	11.8 (10.7)	.020
	Gross Lumbar Flexion	62.2 (17.6)	94.4 (19.7)	.000
	Pelvic Flexion	25.3 (12.0)	46.1 (15.9)	.000
	True Lumbar Flexion	36.9 (9.3)	48.3 (11.9)	.000

* Uses Bonferroni's correction for multiple comparisons.

† Interaction between time and treatment group is significant at $p<.05$, that is, the difference between the groups changed significantly from pre-treatment to post-treatment.

NIH-PA Author Manuscript

NIH-PA Author Manuscript

NIH-PA Author Manuscript

Table 5

Pre to post-treatment changes, with subjects who completed the full course of treatment, in their ability to demonstrate flexion relaxation (SEMG < 3.5 μV RMS).

SEMG-Assisted Stretching Group	**Pre-treatment (N=71)**	**Post-treatment (N=71)**
Flexion-relaxation achieved	34% (n=24)	86% (n=61)
Flexion-relaxation not achieved	66% (n=47)	14% (n=10)
Functional Restoration Only Group	Pre-treatment (N= 23)	Post-treatment (N=23)
Flexion-relaxation achieved	17% (n=4)	26% (n=6)
Flexion-relaxation not achieved	83% (n=19)	74% (n=17)