# Clinical Efficacy of Psychophysiological Assessments and Biofeedback Interventions for Chronic Pain Disorders other than Head Area Pain

Richard A. Sherman* and Christiane Hermann#

*Richard A. Sherman, Ph.D.
Behavioral Medicine Research and Training Foundation
Port Angeles, Washington, USA rsherman@nwinet.com

#Christiane Hermann, Ph.D.
Dept. of Clinical and Cognitive Neuroscience
Central Institute of Mental Health
Mannheim, Germany

## ABSTRACT

Psychophysiological assessments and biofeedback based interventions for disorders whose main symptom of interest is chronic pain can be highly effective and useful in the clinical environment. The evidence supporting the effectiveness of psychophysiological assessments and interventions for phantom limb pain, upper and lower back pain, non-cardiac chest pain, and pelvic floor pain disorders is reviewed to provide examples of how these techniques are applied to problems having differing etiologies. There is a dearth of controlled studies in this area so the supporting evidence is not as strong as it might be given the clear clinical utility of the techniques. The evidence from formal studies shows that efficacy ranges from efficacious (e.g., irritable bowel syndrome, migraine and tension headaches) through probably efficacious (e.g. back pain, phantom limb pain) and possibly efficacious (e.g., pelvic pain, Raynauds syndrome) to not empirically supported (e.g. complex regional pain syndrome / reflex sympathetic dystrophy).

# OVERVIEW

Although pain accompanies numerous chronic disorders, for many, pain is the symptom of concern to both the sufferers and their therapists. Examples of such disorders are headache, phantom limb pain, and complex regional pain syndrome (A.K.A. Reflex Sympathetic Dystrophy). The underlying pathophysiology of these disorders is seldom well understood and similar symptom complexes are frequently caused by different underlying problems. Thus, patients with ostensibly similar symptoms may have very different disorders. For example, phantom limb pain can be caused by at least three mutually exclusive physiological problems in the residual limb including spasms in key muscles, insufficient blood flow, and trigger points. For most pain problems, there is little relationship between ongoing tissue damage and extent of pain. In other words, pain may not be an accurate warning that continued activity will cause additional damage to the body.

Chronic pain commonly stems from specific physiological imbalances such as: (1) tension maintained at too high a level for too long and/or spasms in specific muscles as may be found in tension related jaw pain and cramping phantom limb pain, or (2) significantly decreased blood flow to a specific area as may be found in early complex regional pain syndrome (CRPS) and Raynaud's syndrome.

Stress responses and anxiety frequently magnify or cause intermittent chronic pain. For example, non-cardiac chest pain often occurs due to incorrect breathing patterns which cause anxiety. The pain, of course, results in more anxiety which then magnifies the pain. As will be discussed later, correction of the incorrect breathing patterns has been shown to resolve the anxiety and eliminate the non-cardiac chest pain. As Yucha and Gilbert (2004) point out, chronic pain can be widespread at least partially due to such factors as neural sensitization, altered neurotransmitter levels, inflammation, muscle guarding, magnification through psychological mechanisms as noted above, etc. Thus, chronic pain is most often not tied to one precipitating incident and rectification of one cause may not end pain which has become pervasive.

As might be imagined, chronic pain disorders are far more amenable to successful intervention when the underlying physiological dysfunctions can be identified and changes in those dysfunctions tracked through treatment attempts. For example, treatments of cramping and burning phantom limb pain have abysmal seven percent success rates when underlying mechanisms are ignored, but about ninety percent success rates when treatments are aimed at correcting the specific dysfunctions underlying each descriptor (Sherman, Devor, Jones, Katz, & Marbach, 1996). Psychophysiological assessments have been shown to provide uniquely objective ways to demonstrate relationships between underlying physiological problems and the resulting pain. This information can be used to: (1) track changes in the underlying pathophysiology, and (2) provide information for self control strategies so the therapist and patient can tell exactly how the physiology is responding in real time. For example, Geisser et al (2005) conducted a meta-analytic review of surface electromyography (SEMG) among persons with low back pain and healthy controls. They concluded that "SEMG measures of flexion-relaxation appear to distinguish LBP subjects from controls with good accuracy ".

Figure 1 illustrates how psychophysiological recordings are used to track changes in a disorder over time. This figure shows how changes in near surface blood flow coincide with changes in the intensity of burning phantom pain (Sherman, et al., 1996). Figure 2 illustrates how these recordings are used to demonstrate physiological changes resulting from biofeedback interventions (Sherman, Evans, & Arena, 1993). It shows the differences in shoulder area muscle tension patterns before and after biofeedback training.

There is far too much information available on too many chronic pain disorders to cover all of them here. This paper uses five disorders -- phantom limb pain, musculoskeletal back pain, pelvic floor pain, and non-cardiac chest pain -- to exemplify the evidence and logic for using psychophysiological assessments and biofeedback interventions for pain problems having varied etiologies including vascular dysfunctions, muscular dysfunctions, postural problems, and anxiety/stress responses. Citations were gleaned from searches of: (1) the National Library of Medicine's data bases, (2) the web, and (3) indexes of journals frequently publishing biofeedback related articles.

Readers wanting further information on the plethora of disorders amenable to psychophysiological assessment interventional techniques are referred to the book *Pain Assessment and Intervention from a Psychophysiological Perspective* (Sherman, 2004). Tan, Sherman, and Shanti (2003) summarized the overall logic for using biofeedback to treat chronic pain disorders and assessed the effectiveness of biofeedback for those disorders. Specific reviews of the efficacy of biofeedback for the treatment of headaches, irritable bowel syndrome, facial pain, and Raynaud's syndrome are provided by Yucha and Gilbert (2004).

**Figure 1. Relationship between intensity of burning phantom pain and near surface blood flow.** *The figure shows redrawn color videothermograms of an amputee missing the index finger on the left hand. Size of dots represents relative warmth at the skin's surface with the largest dots showing the most warmth and blank areas being coolest. Blank areas are essentially the same temperature as the surrounding room. Burning phantom pain intensity is rated on a scale of 0 - 10.*

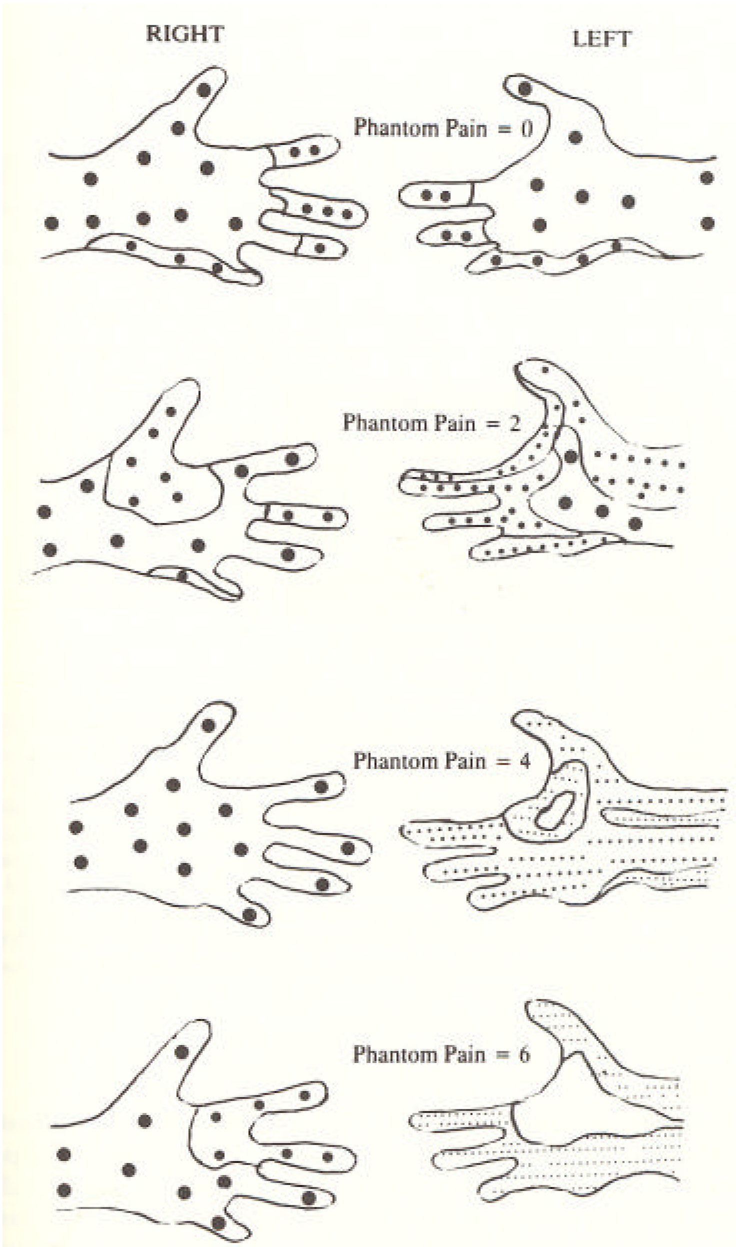
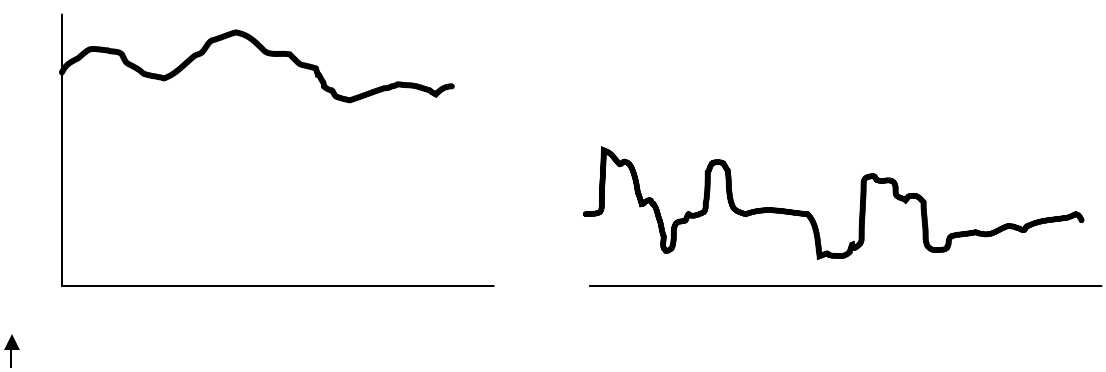


**Figure 2. Relationships between trapezius EMG and tension headache intensity recorded in a subject's normal environment before and after muscle tension awareness and control training.** Before training the signal is relatively high and doesn't change much over time. After training the signal is (a) generally lower in tension, (b) much more responsive and correlates well with task intensity, and (c) with periods of very low tension. (Simulation derived from a compilation of raw data). Time scale is approximately 1 hour per cm.



Tension

**Before training** **After training**

## TYPICAL PAIN DISORDERS TREATED USING BIOFEEDBACK

Phantom limb pain, musculoskeletal back pain, pelvic floor pain, and non-cardiac chest pain are presented to exemplify the evidence and logic for using psychophysiological assessments and biofeedback interventions for pain problems having varied etiologies including vascular dysfunctions, muscular dysfunctions, postural problems, and anxiety/stress responses.

### 1. Phantom Limb Pain

Phantom limb pain is used an example for the integration of psychophysiological assessment techniques with biofeedback interventions. Patient selection criteria and assessment protocols are briefly described. These techniques parallel those for the other chronic pain conditions discussed in the paper, so will not be detailed elsewhere.

**Overview:** The evidence supporting the use of applied psychophysiological techniques for the treatment of phantom limb pain comes from two directions. The first consists of a solid body of clinical research which establishes psychophysiological mechanisms for the burning and cramping descriptors of phantom pain. Both the mechanisms and the symptoms are responsive to applied psychophysiological interventions. The second consists of a few uncontrolled efficacy studies combined with moderately widely replicated clinical experience supporting the effectiveness of psychophysiological techniques in correcting the problems identified in the mechanism literature. The literature on both mechanisms and treatment is complex, contradictory, and potentially misleading. Anyone seriously interested in tackling phantom limb pain on a regular basis would be well advised to read one of the reviews of the field such as that by Sherman (1994) or Flor (2002a). For an 'in depth' look at the entire area of phantom pain, one might read the book *Phantom Pain* by Sherman, et al.,(1996).

**Psychophysiological Mechanisms:** Numerous studies have demonstrated that phantom pain described as burning and tingling is related to decreased blood flow in the residual limb, while phantom pain described as cramping is related to high frequency spasms in the residual limb. No studies have demonstrated underlying physiological mechanisms for the relatively rare phantom pain described as shocking and shooting (Sherman, 1996).

**Efficacy Studies:** This review of efficacy studies is adapted with modifications from Sherman, et al. (1996).

**Relationships between Description of Phantom Pain and Type of Treatment Likely to Succeed:** Several small studies summarized in Sherman (1996) have related the effectiveness of behavioral and medical treatments of phantom pain to underlying physiological correlates. When research on amputees demonstrated that decreased blood flow in the stump was related to increased burning phantom limb pain, peripheral vasodilators and temperature biofeedback were used to decrease the phantom pain. When increased muscle tension and spasms in the stump were related to episodes of cramping phantom pain, muscle relaxants and muscle tension biofeedback were used to control the pain.

Researchers found EMG biofeedback to be effective for thirteen of fourteen trials for cramping phantom pain. EMG biofeedback had minimal success with two and no success with ten of twelve trials for burning phantom pain. It had no success with eight trials of shocking phantom pain. Temperature biofeedback was ineffective for four trials of cramping phantom pain, was effective for six of seven trials with burning phantom pain, and had no success with three trials for shocking phantom pain. Nitroglycerine ointment (a topical vasodilator) was ineffective for one trial of cramping phantom pain and one of shocking phantom pain but successful for two trials of burning phantom pain.

Trental (a blood viscosity enhancer) was ineffective for two trials of cramping phantom pain and one of shocking phantom pain. Nifedipine (a systemic vasodilator) was effective for three trials of burning phantom pain but ineffective for one trial of cramping and two trials of shocking phantom pain. Flexeril (a muscle relaxant) was effective for two trials of cramping phantom pain but ineffective for one with shocking phantom pain. Indocin (an anti-inflammatory agent) was ineffective for two trials of cramping phantom pain. The overall conclusion from this investigation is that varying types of phantom pain respond virtually only to interventions which alter the underlying mechanisms.

**Follow-up Durations**: Only one study with significant follow-ups has been reported (cf., review in Sherman et al., 1996). Use of EMG biofeedback combined with home use of progressive muscle relaxation exercises showed excellent success with six month to three year follow-up for fourteen of sixteen successive phantom pain patients.

**Treatment Success vs. Learning to Control the Appropriate Physiological Parameter**: The major difference between those patients in the above study who succeeded in learning to control their pain and those who did not was the ability to relax in any measurable way. The two failures neither (a) demonstrated the ability to relax, nor (b) reported subjective feelings which would be associated with learning to relax or to control their muscle tensions.

**Recommended Interventions:** These recommendations were adapted with modifications from Sherman, et al. (1996). It is clear that burning phantom pain responds to interventions which increase blood flow to the residual limb while cramping phantom pain responds to interventions which decrease tension and spasms in major muscles of the residual limb. Shocking and shooting phantom pain does not respond well or consistently to either type of intervention. It is recommended that biofeedback of appropriate parameters be used in conjunction with other self-control training strategies to treat cramping/squeezing and burning/tingling phantom limb pain.

It is important for clinicians to recognize that biofeedback as utilized for control of phantom limb pain is not some kind of black box magic. Rather, it is simply the process of recording the physiological parameters (such as muscle tension in the residual limb) which precede changes in phantom pain, and showing these signals to patients. The patient uses the information to change the signal. The patient also learns to associate sensations related to onset of phantom pain with tension in the muscle, decreased blood flow, etc. and to use the learned ability to control the parameter to prevent the onset of or to stop it if it has already begun. Ten one-hour long sessions are typically required for efficacy. Both Belleggia and Birbaumer (2001) and Harden, Houle, Green et al. (2005) have used these methods successfully.

**Treatment Protocols for Burning Phantom Pain.** If the patient reports burning phantom pain (including tingling and similar descriptions), increased phantom pain with decreased atmospheric temperature, or decreased stump temperature before an increase in phantom pain, first conduct a trial of temperature biofeedback from the residual limb in conjunction with relaxation training containing warming exercises. If this is not effective, undertake a trial with peripheral vasodilators (such as nitroglycerine paste applied to the distal end of the residual limb) and, if necessary, multiple sympathetic blocks. Single blocks tend to be of short duration and ineffective as a treatment, but may be a useful diagnostic tool.

**Treatment Protocols for Cramping Phantom Pain**. If the patient reports cramping phantom pain (including twisting, gripping, etc.) or the stump shows spikes in the EMG and/or spasms during phantom pain, perform muscle tension biofeedback from the residual limb in conjunction with muscle tension awareness and control training. The intervention may take as many as ten sessions (usually twice per week) during which the patient watches the raw muscle tension signal (SEMG) recorded from the major muscles of the residual limb on a display screen and attempts to stop the spasms preceding bursts of phantom pain. If this is not effective, conduct a lengthy trial with muscle relaxants.

**2. Upper and Lower Back Pain, Including Pain Due to Postural Problems:**

**Rationale:** Psychophysiological assessments and biofeedback interventions are most effective for muscle related back pain. Two main assessment strategies have been followed. One approach focuses on the assessment of muscle activity related to physical activity such as different body postures and movements. The following section is taken almost verbatim from *Pain Assessment and Intervention* (Sherman, 2004). Relationships between sustained level of muscle contraction and occurrence of pain in the back are not well understood and the literature is confusing. For example, Basmajian (1981), Wolf and Basmajian (1979), and Kravitz, Moore, and Glaros (1981) found that the paralumbar muscles of relaxed low back pain patients were less contracted than those of "normal" controls. Collins, Cohen, Naliboff, and Schandler (1982) found that in the standing position, the tension in the paraspinal muscles of low back pain subjects was similar to that in controls. Many other groups have reported similar findings while at least as many have reported just the opposite under apparently similar recording conditions. Hoyt, Hunt, DePauw, Bard, and Shaffer (1981) showed that surface EMG recordings of low back pain patients differ most from those of normals for the standing positions with low back pain patients being tenser by one third to one half. These types of results have been reported by many others including Grabel (1974), who also found that there were no differences in tension in response to simulated psychological stresses between groups with and without low back pain. Dorpat and Holmes (1952) did find such a relationship among several patients identified as having both high levels of anxiety and back pain. With the important exception of Dorpat and Holmes' few subjects, none of the research groups divided their subjects by diagnosed etiology of their subjects' pain. Many groups (e.g., Cram & Steger, 1983) have found trends toward asymmetry in muscle tension in the left vs. right sides of the low back among subjects with low back pain.

Many psychological factors complicate the relationship between reported intensity of low back pain and paraspinal EMG. Psychological influences on perception of pain intensity are especially difficult to evaluate. For this reason, our research design eliminates all subjects with significantly abnormal psychological patterns from our studies and requires all subjects to keep logs of their perceived stress intensities (Sherman, et al., 1992, 1993, 1996).

A second approach for understanding the role of psychophysiological response patterns in chronic musculoskeletal pain has looked at muscular activity elicited by exposure to stress. Based on a comprehensive review of studies on patterns of stress-dependent psychophysiological activity in chronic back pain, Flor and Turk (1989) argued that standard stress tasks such as mental arithmetic are not particularly well suited to detect stress-dependent and symptom-specific response patterns. They concluded that personally relevant stressors are most likely to unravel symptom-specific elevations in paraspinal EMG levels which distinguish low back pain patients from non-pain controls.

Sherman (1985) showed that much of the confusion and high variability in reports of muscle tension in back pain is caused by (1) recording all of the subjects in only one or two positions regardless of the most painful position, and (2) recording the subjects only once without regard to current level of pain. He showed that a consistent relationship exists between low back pain intensity and muscle tension when they recorded each subject in six different positions and at differing pain intensities. One hundred and twenty-six subjects participated in the study. Each was recorded while standing, sitting supported and unsupported, prone, bending, and rising. Recordings were performed on days when subjects were at various pain intensities. Each subject reporting pain at the time of recording showed one or more positions in which their muscle tension was different from that of controls. When the "low back pain" subjects were recorded without pain, their recordings were similar to those of the controls. For those positions in which a subject showed abnormal muscle tension, there was a high correlation between reported pain intensity and number of microvolts showing in the recordings over the series of recordings (Spearman's Rho = 0.92). Since that time, an additional 256 subjects have been recorded. Each subject had medical diagnoses based on thorough orthopedic tests. The original findings have been confirmed and it has been determined that there are significant differences in muscle tension among pain free controls, subjects with muscle related back pain, and subjects with diagnoses not related to muscle tension (Arena, Goldberg, Saul, & Hobbs, 1989). The electromyographic recording techniques are consistent between recordings so the results are not significantly confused by unrecognized factors (Arena, Sherman, Bruno, & Young, 1988).

Herta Flor and Niels Birbaumer (Flor & Birbaumer, 1994) concluded that chronic musculoskeletal pain, in the absence of an obvious, current precipitating factor, is likely to have any of several potential bases:

**Pain Causes Sympathetic Activation and Reflex Muscle Spasms:** The sympathetic activation combined with the pain resulting from the reflex muscle spasms could cause a conditioned response to "innocuous stimuli present in the pain-eliciting situation." Thus, the reactions to innocuous stimuli, such as pressure on muscles that spasmed when they were acutely hurt, would cause a conditioned reflex and set of spasms. Gevirtz and his group (e.g., Lewis, et al., 1994) have now shown that sympathetic activation of spindle fibers in muscles related to the vestibular system (such as the trapezius) can cause muscle contraction. Thus, the proposed reaction is essentially doubled in magnitude for those areas such as the shoulder muscles that have sympathetically innervated spindle fibers.

**Overreactivity in Response to an Innocuous Stimulus:** Flor's group has been able to classically condition forearm muscle responses to stimuli which originally were not pain-related (Flor et al., 1996; Schneider, Palomba, & Flor, 2004). Such learning processes can result in a stereotyped response to a variety of stimuli which originally elicited no or only a minimal response in the musculoskeletal system. A corollary to this would be that the musculoskeletal system would be more reactive than other systems. This would lead to over-utilization of the responding group of muscles and, then to pain from over-utilization. They showed that, in fact, the low back muscles of low back pain subjects are far more reactive to stressors such as mental stressors (math, images, etc.) than are either healthy controls or people with other types of chronic pain. Interestingly, the back pain patients do not have higher resting levels of EMG than the other groups. They also found that the back pain patients' back muscles reacted more than their biceps. These people's heart rates were far less responsive to mental stressors than the other groups'. Jensen, Rasmussen, Pedersen and, Olesen (1993) and Bendtsen, Jensen and Olesen (1996) found that when muscles are pressed against with increasing force, relatively tender muscles hurt with much less force than non-tender ones. Jensen concluded that the abnormal pain response of muscles with histories of pain is sufficient to account for muscle tension related headaches and most other muscle related pain.

Susan Middaugh and her team (e.g. Middaugh et al 1994, 1995, 1998, 1999) have conducted numerous studies relating posture to development of muscle tension related pain. For example, twenty pain free subjects sat at a keyboard and typed with either relatively proper posture or thirty degrees of forward shoulder flexion for twenty minutes. Trapezius EMG began about twice as high with incorrect posture as with normal posture and continued rising throughout the session while remaining constantly low for the correct posture period. The muscle quickly fatigued and discomfort set in. A group of 35 consecutive headache patients was shown to have an average of 16 degrees of forward head posture with a variance of 60 to 128 percent above the values considered sufficient to cause pain. They found that shoulder muscle tension when sitting quietly was relatively elevated among 65 % of cervical pain patients, 57 % of headache patients, and 25% of normals. However, when they shrugged or abducted the shoulder, 90 to 94 % of the cervical and headache patients had abnormal levels while only 9 to 19 % of the normals had abnormal levels.

The above evidence shows that there is a strong relationship between posture related pain and abnormal levels of muscle tension, Hence, correction of abnormal muscle tension and correction of posture may result in reduction of the pain.

**Interventions:** The use of psychophysiological treatments for chronic musculoskeletal pain is one of the staples of clinical psychophysiology. The basic concept is that much of the pain people experience is caused by muscles being kept too tense for too long. They may be kept that way due to guarding (preventing movement due to pain from some other source), poor posture, stress reactions, incorrect sequencing of muscles during movement etc.

Most people who use biofeedback and other psychophysiological interventions for chronic back pain mix them relatively randomly with every other intervention available at their sites (e.g., Roberts, Sternbach, & Polich, 1993, Arena and Blanchard, 2002 ) and it is frequently impossible to determine whether the psychophysiological intervention had any effect or even just how it was applied. A major problem with multimodal programs which simultaneously deliver several interventions is that they preclude conclusions about the effectiveness of any particular intervention. Moreover, one cannot learn anything about how to apply a certain intervention (e.g., treatment length) such that it produces a clinical effect.

Flor's group (e.g., Flor & Birbaumer, 1993) has done a succession of studies with chronic back pain patients. They included patients with all diagnoses of chronic low back pain. They found an overall improvement rate of about 65 percent at short-term follow-up relative to about a one third improvement rate for placebo controls and no improvement for non-treatment controls. The improvement was sustained on two-year follow-up and resulted in a corresponding decrease in use of the health care system (Flor & Birbaumer, 1994). Patients participated in eight to twelve biofeedback sessions of 60 min duration during which they had to decrease muscle tension while in uncomfortable positions and while imagining stressful events. The group performed similar studies comparing the efficacy of biofeedback to cognitive-behavioral and standard medical treatments with similar results. The duration of pain was significantly correlated with extent of success in this series of studies. In a previous small-scale study of the same group (Flor, Haag, & Turk, 1986) EMG biofeedback was evaluated in chronic rheumatic back pain patients. A 2.5 year follow-up of 22 of the original 24 participants showed that those treated with biofeedback maintained gains more than “pseudotherapy” and standard therapy alone.

Newton-John, Spence, and Shotte (1995) compared a cognitive behavioral treatment (CBT) program, EMG biofeedback and a wait list control condition in chronic back patients. Both CBT and EMG-biofeedback showed similar beneficial effects and were both superior to the wait-list control group. Effects persisted at a six-month follow-up. There were no differences in effectiveness between CBT and EMG-biofeedback. Vlaeyen and colleagues (Vlaeyen, Haazen, Schuerman, Kole-Snijders, & van Eek, 1995) studied the differential effectiveness of EMG biofeedback combined with operant treatment, cognitive-operant treatment and an operant treatment program in 71 low back pain patients. All treatment groups yielded significantly greater improvement than the wait-list control. In addition, the combined programs, i.e. EMG-biofeedback plus operant and cognitive-operant treatment, were more efficacious than the operant alone treatment in reducing pain behaviors, increasing healthy behaviors and perceived self-efficacy.

Susan Middaugh and her team (e.g., Middaugh, Kee & Nicholson, 1994) have conducted numerous studies in which abnormal muscle tension was usually assessed as being due to incorrect posture. Correction of the postural problem resulted in alleviation or elimination of the pain. She emphasizes the need for patients to be trained to minimize tension in painful muscles during normal activities involving the muscle and keeping the muscle quiet during activities which do not involve the muscle. This means that tension in the painful muscles is shown to the patients ("fed back") while they are performing a variety of activities found to be associated with pain. Patients are shown the differences in muscle tension when posture is correct and incorrect. Neblett, Gatchell and Mayer (2003) have published a series of EMG feedback assisted exercises which are useful for helping patients stretch tight muscles. The article includes photos illustrating how the exercises should be performed. However, caution should be used in recommending such exercises if the therapist is not trained in providing them.

Barbara Headley (1990, 1993), Eric Fogel (1995), and Glenn Kasman (1990) have developed specific protocols for physical therapists to use which incorporate surface EMG into pain evaluation and treatment (including biofeedback) programs. Unfortunately, none conducted nor reported large studies which verify their logical recommendations. Thus, numerous case reports and clinical lore form the basis for conducting these evaluations and treatments. They are very similar to Middaugh's work in that they involve using surface EMG to assess the functioning of a muscle or muscle group while normal activities are attempted. EMG biofeedback is incorporated into standard physical therapy to give the therapist and patient an excellent idea of how the muscle is performing. This permits rapid change of activity to desired levels.

Sherman and Arena (1992) and Arena and Blanchard (2002) have extensively reviewed the literature on the use of psychophysiological techniques for treatment of low back pain (see also Morley , Eccleston & Williams, 1999). Sherman and Arena's (1992) review of twenty-nine clinical studies as well as the authors' own review of several more recent studies indicates that biofeedback is likely to help at least some people with muscle tension related low back pain to some extent. Almost all of the studies have serious flaws in design including:

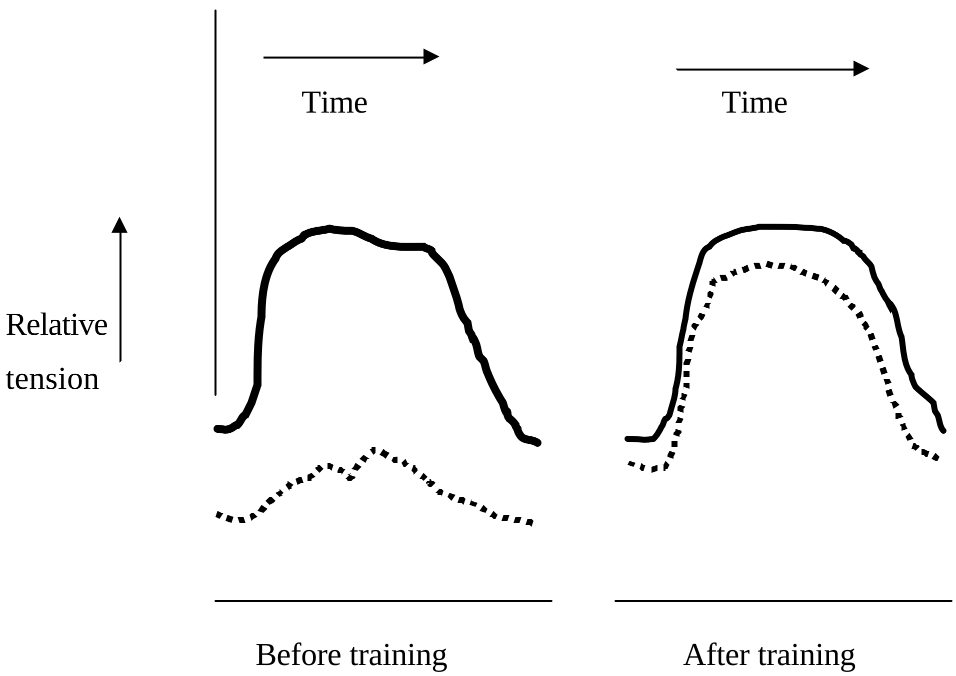
> Only about half of the studies have sample sizes over nine.
> Only a few specify the diagnostic methodology.
> Less than half of the studies have any controls (e.g. waiting lists, etc.)
> Only a few factored changes in medication into their results.
> Only very few had follow-ups of six months or more.
> Only several had subjects keep pain diaries or had multiple objective outcome measures.

Gevirtz, Hubbard and Harpin (1996) also reviewed the literature and found that psychophysiological treatments for chronic low back pain are generally efficacious although the mechanisms through which treatments work are poorly understood. However, there have been no large single group or multi-practitioner studies of applied psychophysiological interventions for back pain similar to those performed with headache patients. This lack of larger-scale randomized controlled trials (RCTs) on the effectiveness of psychophysiological interventions becomes apparent in the systematic and repeatedly updated reviews of RCTs by the "Cochrane Back Review Group". This group of researchs provides up-to-date reviews of RCTs for chronic back pain based on the guidelines of the Cochrane collaboration (http://www.cochrane.org; Bouter, Pennick, & Bombardier, 2003). Since 1997, several such reviews have been published (e.g., Ostelo et al., 2006; van Tulder, Koes, & Bouter, 1997; van Tulder et al., 2001; van Tulder & Koes, 2004). In light of the dearth of RCTs on psychophysiological interventions for chronic back pain, these reviews do not list biofeedback as a well-established treatment. Clearly, there is a need for RCTs which would help promoting biofeedback as an empirically validated intervention for chronic back pain.

**Specific Protocols:** Most people applying the techniques involved with retraining muscles to tense correctly (e.g., Ettare & Ettare 1990) emphasize that this is a behavioral conditioning process more similar to learning to ride a bicycle than to learning to play chess. Development of unconscious control through repetition of specific small tasks taken in steps is emphasized. Usually biofeedback devices are used with their thresholds set so that it is easy to reach an immediate goal. When that level is reached, the threshold is reset so the next goal can be strived for and met. Thus, muscle tension is gradually shaped to the correct pattern.

While it is certainly true that large studies with long follow-ups confirming the effectiveness of these techniques have not been performed, the problems with muscle activity are so apparent during multichannel recordings of bending and rising that viewers have little doubt that an actual problem exists. When the levels of activity are altered to “normal” through the use of biofeedback, the difference is obvious and patients report rapid resolution of the problem. Figure 3 illustrates a typical example of changes in symmetry of the paraspinal muscles from a pre- treatment session through mid treatment.  Changes from great asymmetry to relative symmetry are usually accompanied by corresponding decreases in pain.

**Figure 3. EMG recordings of bilateral paraspinal muscle activity during a symmetrical activity (simulation).** *Both muscles should follow approximately the same pattern of tensing and relaxing during a motion and should reach about the same levels of tension. The solid line is the left paraspinal and the dotted line is the right paraspinal. The figure shows a patient attempting to tense both sets of muscles, hold the tension, and relax again. The patterns are obviously less symmetrical before than after training.*




It is important to emphasize teaching patients to instantly shut off the paraspinal muscles after straightening up following a bend and rise cycle. If the trapezius is involved, teach patients to instantly shut them off after a shrug. Most patients with low back pain have far more tension in their paraspinals than is normal – even given the incredible range of “normal” discussed earlier. For these patients, virtually the same protocol as described for headaches can be used except that tension in both the left and right paraspinals and, as appropriate, the trapezius, is fed back. Patients are given the same tension awareness/relaxation exercise and are told to practice it the same way as are headache patients. They are taught to become very aware of when they are tensing their back muscles inappropriately at home and then in the work environment.

**Typical protocol:** During the first half of a typical biofeedback session have patients begin in a standing position. First they work on relaxing their muscle to normal levels using shaping techniques as necessary. Then they tense the lower back for about two seconds and then relax for about five seconds. Have the patient repeat this cycle at least ten times while we both watch the monitor and work to correct abnormalities. Remember that most patients with low back pain cannot tell how tense their muscles are so you are training them to recognize how tense they actually are at various levels of tension. This is the calibration exercise discussed earlier. For the last half of the session, have the patient bend forward 30 degrees and then stand back up slowly. The key is to get them to keep the signals of the two EMG channels within about fifteen percent of symmetrical (about the normal amount of left – right variability) and to relax quickly when they stand up.

Physical therapists with extensive experience incorporating biofeedback into back pain interventions such as Glenn Kasman (1998), Susan Middaugh (2003), Randy Neblett (2002, 2004), Steve Wolf (1998), and many others have developed detailed protocols for treating musculoskeletal back pain. The protocols usually center around (1) correcting posture – especially during work, (2) correcting incorrect motions, and (3) strengthening weak muscles. These form the basis for the authors' treatments as well. Always attempt to simulate the environment in which the back pain occurs. Thus, for people who spend a great deal of time working at computers, simulate the computer work station and do both an ergonomic and muscle tension evaluation of their position and work habits. The lack of very brief breaks during typing and similar work is very evident when watching the recording.

A crucial part of training is to incorporate the "five percent" rule into the biofeedback regime. It is based on Susan Middaugh's philosophy that limbs kept only five degrees away from proper posture (e.g. arms slightly forward of vertical while using a keyboard), muscles kept only five percent tenser than necessary while working (e.g. shoulders tense while typing), and (from Glaros's work) muscles kept minimally tense only five percent longer than necessary (e.g. after the task is completed) can result in severe pain which quickly becomes chronic. Thus, it is important to insure that any problems of this nature are noted. The patient is trained to become aware of these muscular problems and to correct them immediately. When dealing with people who do manual labor, the therapist should be especially careful to train them to be very aware of (1) when muscles are inappropriately tense during the task and (2) when muscles remain inappropriately tense after the task. This training virtually always requires training patients in muscle tension awareness and relaxation skills.

**Correcting Concurrent Problems**

Posture. Correcting postural problems is as important as correcting the static and motion problems described above so patients must be taught to be aware of and to correct any such problems which became evident during the assessment. See the appendices for exercises.

Improper Back Utilization and Weakness. Often patients use their back incorrectly at the work place, sit incorrectly, or simply have muscles too weak to perform the required tasks. Evaluation of these problems is normally performed by physical and occupational therapists trained in ergonomics. They frequently perform biofeedback interventions in the work place or work with therapists trained to perform biofeedback to correct muscle use problems. They tend to prescribe a very wide variety of muscle strengthening exercises as discussed earlier.

Treatments for Piriformis Syndrome and Trigger Points**.** If piriformis syndrome or trigger points are present, they have to be treated either before or concurrently with the psychophysiological intervention or the odds of making real progress are minimal.

## 3. Non-Cardiac Chest Pain

Gevirtz and his team (DeGuire, Gevirtz, Hawkinson, & Dixon, 1996; Gevirtz, 2001; Moynihan & Gevirtz, 2001) have shown that there is a solid relationship between anxiety and non-cardiac related chest pain. They have also shown that abnormal patterns of respiration, which are well known to lead to feelings of anxiety due to changes in concentration of carbon dioxide, also result in non-cardiac chest pain. Their review of the literature indicates that between 51 and 90% of non-cardiac related chest pain is associated with hyperventilation. Retraining breathing patterns results in long term (at least three years) control of stress-related cardiac pain symptoms and hyperventilation-related symptoms such as anxiety. DeGuire, et al. evaluated the long-term effects of paced diaphragmatic breathing on subjects who reported functional cardiac symptoms and who also demonstrated associated signs of hyperventilation syndrome. Subjects were a representative sample composed of 10 out of the original 41 subjects who had participated three years previously in a study designed to evaluate the short-term effects of breathing retraining on functional cardiac symptoms and respiratory parameters (respiratory rate and end-tidal carbon dioxide). The results of this follow-up study indicate that breathing retraining had lasting effects on both respiratory parameters measured. Subjects evidenced significantly higher end-tidal carbon dioxide levels and lower respiratory rates when compared to pretreatment levels measured three years earlier. Subjects also continued to report a decrease in the frequency of functional cardiac symptoms when compared to pretreatment levels. Their study shows that correction of abnormal breathing patterns relieves the chest pain or eliminates it all together without further intervention to correct an anxiety disorder. Thus, it is the sequelae of incorrect breathing which create both anxiety and chest pain for many patients – not an underlying anxiety disorder which results in incorrect breathing.

Potts, Lewin, Fox, and Johnstone (1999) used a combination of: education, relaxation, breathing training, graded exposure to activity and exercise, and challenging automatic thoughts about heart disease to treat 60 patients who had continuing chest pain despite cardiological reassurance following haemodynamically normal angiography. The treatment was delivered in six sessions over eight weeks to groups of up to six patients. The patients kept daily records of chest pain episode frequency and nitrate use. Questionnaires were used to assess anxiety, depression and disability. Exercise tolerance was tested by treadmill electrocardiography, with capnographic assessment of hyperventilation. As compared to a waiting-list control group, treatment significantly reduced the number of chest pain episodes (median pre: 6.5 per week to post 2.5 per week). In addition, anxiety and depression scores as well as perceived disability decreased, and exercise tolerance increased. These improvements were maintained at six month follow-up. Treatment reduced the prevalence of hyperventilation from 54% to 34%, but the prevalence of ECG-positive exercise tests was unaltered. Patients continuing to attribute their pain to heart disease had poorer outcomes.

There is now substantial evidence from studies by Gevirtz and others that psychophysiological approaches such as (1) respiration training (2) resonant frequency training (heart rate variability (HRV) biofeedback), and (3) autogenic training should all produce at least some success. Not enough studies have been done to estimate success rates in relation to initial severity, or to establish the duration of effectiveness. Autogenic training for treatment of angina pectoris is supported by one good controlled study with a four year follow-up (Laberke, 1952, as reviewed by Linden, 1994).

Del Pozo, Gevirtz, Scher, and Guarneri (2004) demonstrated that cardiorespiratory (heart rate variability) biofeedback effectively increased heart rate variability in patients with documented coronary artery disease (CAD). They used patients with established CAD (n = 63; mean age 67 years) who were randomly assigned to conventional therapy or to 6 biofeedback sessions consisting of abdominal breathing training, heart and respiratory physiologic feedback, and daily breathing practice. HRV was measured by the standard deviation of normal-to-normal QRS complexes (SDNN) at week 1 (pretreatment), week 6 (after treatment), and week 18 (follow-up). Baseline characteristics were similar for the treatment and control groups. The SDNN for the biofeedback and control groups did not differ at baseline or at week 6 but were significantly different at week 18. The biofeedback group, but not the control subjects showed a significant increase in SDNN from baseline to week 6 and to week 18.

It is concluded that psychophysiological techniques can be applied with confidence to the amelioration of non-cardiac chest pain.

**4. Pelvic Floor Pain Disorders Amenable To Psychophysiological Interventions**

There is moderate evidence supporting the effectiveness of psychophysiological interventions for pelvic floor related pain disorders including chronic pelvic pain of unknown origin, prementruals symdrome (PMS), Dysmenorrhea, Vulvar vestibulitis, and Constipation related pain

Virtually all of the articles identified in a recent literature search are relatively small clinical studies and have short follow-up periods so little is known about the long term impact of biofeedback on work related deficits related to either PMS or dysmenorrhea. Dietvorst and Osborne (as quoted in Sherman, 2004) published a case study in 1978 in which they used temperature biofeedback and autogenic relaxation training to successfully treat a woman with chronic primary dysmenorrhea. Breckenridge, Gates, Hall and Evans (1983) gave 12 weekly EMG feedback sessions to eight young women with primary dysmenorrhea. They showed a significant decrease in severity of dysmenorrhea symptom scores on the Menstrual Symptom

Questionnaire. Balick, Elfner, May, and Moore (1982) did a similar study with the addition of temperature feedback given to nine dysmenorrheic women (aged 20 - 33) and found similar results upon six month follow-up. Bennink, Hulst, and Benthem (1982) did a controlled study in which subjects who received only relaxation training or a no treatment control did not change while those receiving biofeedback did. Hart, Mathisen, and Prater (1981) used a self-controlled design in which two month baseline and follow-up periods were compared for eleven subjects with primary dysmenorrhea. They used both skin conductance and EMG feedback and found a significant reduction in symptoms upon follow-up. Mathew, Claghorn, Largen and Dobbins (1979) treated twelve women with PMS with temperature biofeedback and found changes on the Menstrual Distress Questionnaire. The author's team (Hamblen, Sherman & Powell, 1996) completed an open study in which thirty female soldiers with mixed PMS and dysmenorrhea were treated with a combination of progressive muscle relaxation exercises, frontal EMG biofeedback, and fingertip temperature biofeedback. Each kept a one month log of symptom severity and work impact before and after the standardized eight week treatment. Reports to the therapist indicated that most showed dramatic improvements but (a) only five subjects actually handed in a fully completed post treatment long and (b) the long term follow-up was not funded so it is not known whether the effects were maintained.

The use of psychophysiological interventions for amelioration of pelvic floor muscle related pain has become a staple of clinical practice. Studies such as that by Hetrick et al. (2006) clearly support the ability of SEMG evaluations to differentiate between men with chronic pelvic pain syndrome and pain free controls. Similar studies of women with vulvar vestibulitis show that muscle functioning is different among women with and without the problem (Reissing, Brown, Lord, Binik & Khalife, 2005). Clinical studies show that muscle tension biofeedback is an effective intervention for pelvic floor pain of unknown etiology for adults (Nadler, 2002) and children (Hoebeke et al., 2004). The technique is clearly effective for men with chronic pelvic pain syndrome (Clemens, Nadler, Schaeffer, Belani, Albaugh & Bushman, 2000, Cornel, van Haarst, Schaarsberg & Geels, 2005). However, there are no controlled studies of biofeedback for pelvic pain which compare the effectiveness of biofeedback with other techniques or placebos. This lack of evidence is not to be confused with the reasonably strong evidence supporting the use of biofeedback for strengthening and reducing both spasms and instability in the pelvic floor as part of treatments for incontinence. The key elements in any of the treatment approaches are:

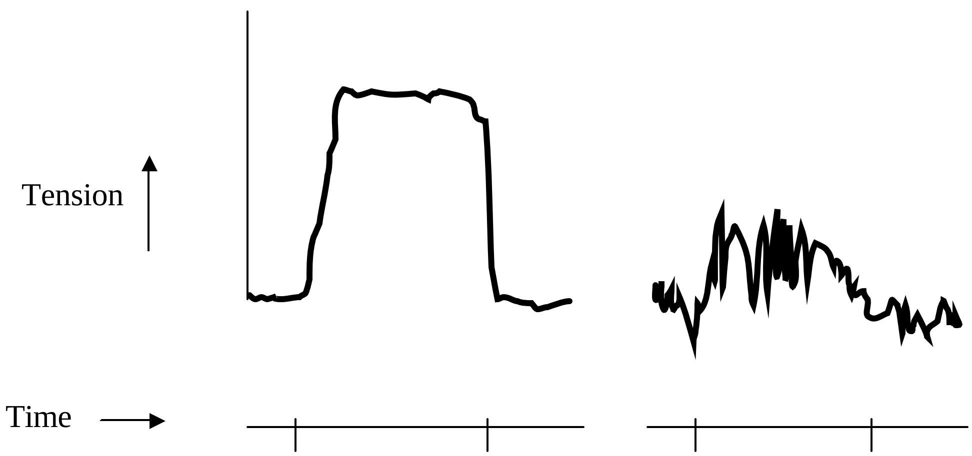
(a) perform a surface EMG evaluation to determine whether the muscles are inappropriately tense or relaxed and whether accessory muscles (such as those in the abdomen) are tensing at the wrong time, (b) teach subjects to recognize when they are inappropriately tense or relaxed, and (c) teach the subjects to tense or relax appropriately. This obviously can not be done without a very solid understanding of what the muscles are supposed to be doing and how tense they are supposed to be, at each point in the sequence leading to urination. Tries and Eisman's review (1995) provides the best information for this area.

Glazer, Rodke, Swencionis, Hertz, and Young (1995) studied 33 women having pain due to vulvar vestibulitis syndrome in which they gave SEMG biofeedback and relaxation training from the pelvic floor twice per week for 16 weeks to correct muscular instability, irritability, and weakness. After training, pelvic floor muscle contractions increased by 95.4%, resting tension levels decreased by 68%, and instability at rest decreased by 62%. Of great importance, pain decreased by 83% from baseline levels. McKay et al (2001) found that 20 of 29 women treated with biofeedback were able to become sexually active and to control their vulvar vestibulitis related pain after SEMG biofeedback.

Turnbull and Ritvo (1992) used biofeedback and relaxation exercises to treat painful constipation among five women. Pain decreased significantly along with the other symptoms. Palsson, Heymen and Whitehead (2004) found three studies on the use of biofeedback to relieve anorectal pain which showed that the technique was efficacious.

Glazer's approach to treatment includes biofeedback assisted exercises to stabilize the pelvic floor. He has patients perform 60 cycles of contracting the floor muscles and holding for 10 seconds then relaxing for ten seconds. The session takes about 20 minutes. Reducing fatigue is accomplished by holding tension for 10 seconds while reducing variability. This permits reduction of resting tension to 0.5 to 1 microvolt. The difference between normal readings and those made from a patient with vestibulitis is illustrated in Figure 4. White, Jantos and Glazer (1997) have found similar patterns and published good illustrations of what can be expected before and after therapy.

**Figure 4.** Differences between normal pelvic floor muscle tension recordings and those typical of patients with vestibulitis. *Simulation based on a compilation of our data and reading White et al.'s (1997) work.*




Normal baseline and pattern of tensing

Elevated, unstable baseline and ineffective, spasmodic pattern of tensing shown by patients with vulvar vestibulitis

# EFFICACY RATINGS FOR PSYCHOPHYSIOLOGICAL ASSESSMENT AND BIOFEEDBACK OF CHRONIC PAIN PROBLEMS

**Rating Criteria:**

The Association for Applied Psychophysiology has developed the following criteria for setting the level of evidence for efficacy (Moss & Gunkelman, 2002, LaVaque et al., 2002):

Level 1: Not empirically supported: Supported only by anecdotal reports and/or case studies in non-peer reviewed venues.

Level 2: Possibly Efficacious: At least one study of sufficient statistical power with well identified outcome measures, but lacking randomized assignment to a control condition internal to the study.

Level 3: Probably Efficacious: Multiple observational studies, clinical studies, wait list controlled studies, and within subject and intersubject replication studies that demonstrate efficacy.

Level 4: Efficacious:

a.) In a comparison with a no-treatment control group, alternative treatment group, or sham (placebo) control utilizing randomized assignment, the investigational treatment is shown to be statistically significantly superior to the control condition or the investigational treatment is equivalent to a treatment of established efficacy in a study with sufficient power to detect moderate differences, and

b.) The studies have been conducted with a population treated for a specific problem, for whom inclusion criteria are delineated in a reliable, operationally defined manner, and

c.) The study used valid and clearly specified outcome measures related to the problem being treated and

d.) The data are subjected to appropriate data analysis, and e.) The diagnostic and treatment variables and procedures are clearly defined in a manner that permits replication of the study by independent researchers, and

f.) The superiority or equivalence of the investigational treatment have been shown in at least two independent research settings.

Level 5: Efficacious and specific: The investigational treatment has been shown to be statistically superior to credible sham therapy, pill, or alternative bona fide treatment in at least two independent research settings.

**Ratings of the efficacy of biofeedback based interventions for disorders whose main symptom of interest is chronic pain:**

Chronic pain includes too broad a range of disorders to assign a single efficacy rating. Table 1 contains ratings for each chronic pain disorder along with citations to studies supporting the rating.

**Table 1. Efficacy Ratings of Chronic Pain Disorders**

**Efficacious and specific (Fifth level):**

(a) Migraine headache in adults and children (Review by Blanchard 1992, Yucha and Gilbert 2004)

(b) Tension headache in both adults and children (Review by Blanchard 1992)

**Efficacious (Fourth Level):**

*(a) Muscle related orofacial pain (reviews by Glaros* & Lausten, 2002, Crider, Glaros & Gevirtz 2005).

(b)) Irritable bowel syndrome (differing reviews, by Blanchard, 1993, and by Humphries & Gevirtz, 2000)

*(c) Anxiety related to incorrect breathing patterns causing non-cardiac chest pain (Reviews by Gevirtz, 2001, DeGuire, Gevirtz, Hawkinson, & Dixon,* 1996)

*(d) Posture related pain problems such as forward head thrust (Review by Middaugh,* 1994)

**Probably efficacious (Third level):**

(a) Muscle related low back pain (Reviews by Flor & Birbaumer, 1994; Morley, Eccleston & Williams, 1999; van Tulder et al., 2006)

*(b) Cramping and burning phantom limb pain (Belleggia & Birbaumer, 2001, Harden et al., 2005, Reviews by Sherman, Devore, Jones, Katz,* & Marbach, 1996, Flor, 2002b)

(c) PMS and Dysmenorrhea (Breckenridge, 1983)

(d) Pain from spastic muscles and muscle spasms (Kasman, 1998)

e) Magnification of pain by stress & anxiety (Yucha & Gilbert, 2004)

*(f) Pelvic floor pain syndromes (Tries & Eisman, 1995, Glazer,* Rodke, Swencionis, Hertz, &Young, 1995, Yucha & Gilbert, 2004)

(g) Subluxation of the Patella and patelofemoral pain (Ingersoll & Knight, 1991, Crossley, Bennell, Green, Cowan & McConnell, 2002, Dursun, Dursun & Kilic, 2001)

**Possibly Efficacious (Second level):**

(a) Pain from carpel tunnel syndromes related to upper arm and neck muscle tension (reviews by Donaldson, Nelson, Skubick, & Clasby, 1998; Skubick, Clasby, Donaldson, & Marshall, 1993)

*(b) Myofascial pain syndrome / trigger point related pain (reviews by Headley,* 1991; Gevirtz, 1995)

(c) Raynaud's syndrome (Review by Freedman, 1991)

(d) Repetitive strain injury (Moore & Weisner, 1996)

(e) Fibromyalgia (Buckelew, Conway, Parker et al 1998, Drexler, Mur & Gunther, 2002; Ferraccioli et al., 1987; Ferraccioli et al., 1987 Mueller, Donaldson, Nelson & Layman, 2001; van Stanten et al., 2002)

**Not empirically supported (First level of evidence):**

(a) Pain and spasticity due to not taking microbreaks among sign language translators, musicians, factory workers, computer workers, etc.

(b) Biofeedback for complex regional pain syndrome (reflex sympathetic dystrophy).

## CONCLUSION

Psychophysiological assessments and biofeedback based interventions for disorders whose main symptom of interest is chronic pain can be highly efficacious for selected disorders. There is a dearth of controlled studies in this area so the supporting evidence is not as strong as it might be. However, the evidence from formal studies shows that efficacy ranges from efficacious (e.g., treatment of migraine and tension headaches) to possibly efficacious and not empirically supported. There can be little doubt that psychophysiological measurements form a valuable part of the assessment process and that biofeedback based interventions should be given a trial for most chronic pain disorders.

## REFERENCES


Arena, J., & Blanchard, E.B. (2002). Biofeedback Therapy for Chronic Pain Disorders. In J.D. Loeser, D. Turk, R.C. Chapman, and S. Butler (Eds.). *Bonica's Management of Pain, 3rd Edition.* Baltimore: Williams & Wilkins, 1755-1763.

Arena, J., Goldberg, S., Saul, D., & Hobbs, S. (1989). Temporal stability of psychophysiological response profiles. *Behavior Therapy, 20*, 609- 618**.**

Arena, J., Sherman, R., Bruno, G. &, Young, T. (1989). Electromyographic recordings of ow back pain subjects and non-pain controls in different positions. *Pain,* 37, 57-65.

Balick, L., Elfner, L., May, J., & Moore, D. (1982). Biofeedback treatment of dysmenorrhea. *Biofeedback and Self-Regulation*, 7, 499-520.

Basmajian, J. (1981), Biofeedback and the placebo effect. *Psychiatric Annals,* 11, 42-49.

Bendtsen, L., Jensen, R., & Olesen, J. (1996). Qualitatively altered nociception in chronic myofascial pain. *Pain,* 65, 259-264.

Belleggia, G., Birbaumer, N. (2001). Treatment of phantom limb pain with combined EMG and thermal biofeedback: A case report. *Applied Psychophysiology and Biofeedback*, 26, 141-146.

Bennink, C,, Hulst, L., & Benthem, J. (1982). Effects of EMG biofeedback and relaxation training on primary dysmenorrhea. *Journal of Behavioral Medicine*, 5, 329-341.

Blanchard, E. (1992). Psychological treatment of benign headache disorders. *Journal of Consulting and Clinical Psychology*, 60, 537-551.

Blanchard, E., Greene, B., Scharff, L., & Schwarz-McMorris, S. (1993). Relaxation training as a treatment for irritable bowel syndrome, *Biofeedback and Self-Regulation*, 18,125-132.

Bouter, L. M., Pennick, V., & Bombardier, C. (2003). Cochrane back review group. *Spine, 28,* 1215-1218.

Breckenridge, R., Gates, D., Hall, H., & Evans, D. (1983). EMG biofeedback as a treatment for primary dysmenorrhea. *Southern Psychologist*, 1, 75-76.

Buckelew, S., Conway, R., Parker, J., Deuser, W., Read, J., Witty, T., Hewett, J., Minor, M., Johnson, J., Van Male, L., McIntosh, M., Nigh, M., Kay, D. (1998). Biofeedback/relaxation training and exercise interventions for fibromyalgia: a prospective trial. *Arthritis Care and Research,* 11, 196-209.

Clemens, J., Nadler, R., Schaeffer, A., Belani, J., Albaugh, J., Bushman, W. (2000). Biofeedback, pelvic floor re-education, and bladder training for male chronic pelvic pain syndrome. *Urology*, 56, 951-955.

Cornel, E., van Haarst, E., Schaarsberg, R., Geels, J. (2005). The effect of biofeedback physical therapy in men with Chronic Pelvic Pain Syndrome Type III. *European Urology*, 47, 607-611.

Collins, G., Cohen, M., Naliboff, B., & Schandler, S. (1982). Comparative analysis of paraspinal and frontalis EMG in chronic low back pain patients and normals to various postures. *Scadinavian Journal of Rehabilitation Medicine*, 14, 39-46.

Cram, J. & Steger, J. (1983). EMG scanning in the diagnosis of chronic pain. *Biofeedback and Self-Regulation,* 8, 229 -241.

Crider, A., Glaros, A., Gevirtz, R. (2005). Efficacy of biofeedback-based treatments for temporomandibular disorders. *Applied Psychophysiology and Biofeedback*, 30, 333 – 345.

Crossley, K., Bennell, K., Green, S., Cowan, S., McConnell, J. (2002). Physical therapy for patellofemoral pain: a randomized, double-blinded, placebo-controlled trial. *American Journal of Sports Medicine, 30,* 857-865.

DeGuire, S., Gevirtz, R., Hawkinson, D., & Dixon, K. (1996). Breathing retraining: a three-year follow-up study of treatment for hyperventilation syndrome and associated functional cardiac symptoms, *Biofeedback and Self-Regulation*, *21*, 191-198.

Del Pozo, J., Gevirtz, R., Scher, B., Guarneri, E. (2004). Biofeedback treatment increases heart rate variability in patients with known coronary artery disease. *American Heart Journal,* 147, E11.

Donaldson, C., Nelson, D., Skubick, D., & Clasby, R. (1998). Potential contributions of neck muscle dysfunctions to initiation and maintenance of carpal tunnel syndrome. *Applied Psychophysiology and Biofeedback*, 23,59-72.

Dorpat, T. & Holmes, T. (1952). Backache of muscle tension origin. In W. Kroger (Ed.), *Psychosomatic obstetrics, gynecology, and endocrinology (*pp. 425-438). Springfield: Charles C. Thomas.

Drexler, A., Mur, E., Gunther, V. (2002). Efficacy of an EMG-biofeedback therapy in fibromyalgia patients. A comparative study of patients with and without abnormality in (MMPI) psychological scales. *Clinical and Experimental Rheumatology,* 20, 677-682.

Dursun, N., Dursun, E., Kilie, Z. (2001). Electromyographic biofeedback-controlled exercise versus conservative care for patelofemoral pain syndrome. *Archives of Physical Medicine and Rehabilitation,* 82, 1692-1695.

Ettare, D. & Ettare, R. (1990). Muscle learning therapy - A treatment protocol. In J. Cram (Ed.), *Clinical EMG for surface recordings: Volume 2 (pp. 197-253),* Nevada City, California, Clinical Resources.

Ferraccioli, G., Ghirelli, L., Scita, F., Nolli, M., Mozzani, M., Fontana, S. et al. (1987). EMG-biofeedback training in fibromyalgia syndrome. *Journal of Rheumatology, 14,* 820-825. Colorado Springs, CO

Flor, H. (2002a). Phantom-limb pain: characteristics, causes, and treatment. *Lancet Neurology, 1,* 182-189.

Flor, H. (2002b) The modification of cortical reorganization and chronic pain by sensory feedback. *Applied Psychophysiology and Biofeedback*, 27, 215–227.

Flor, H. & Birbaumer, N. (1993). Comparison of the efficacy of electromyographic biofeedback, cognitive-behavioral therapy, and conservative medical interventions in the treatment of chronic musculoskeletal pain. *Journal of Consulting and Clinical Psychology, 61,* 653-658.

Flor, H. & Birbaumer, N. (1994). Psychophysiological methods in the assessment and treatment of chronic musculoskeletal pain. In J. Carlson, R. Seifert, & N. Birbaumer (Eds.), *Clinical Applied Psychophysiology (pp. 171-184).* New York, Plenum Press.

Flor, H., Birbaumer, N., Roberts, L. E., Feige, B., Lutzenberger, W., Hermann, C. et al. (1996). Slow potentials, event-related potentials, "gamma-band" activity, and motor responses during aversive conditioning in humans. *Experimental Brain Research, 112,* 298-312.

Flor, H., Haag, G., & Turk, D. (1986). Long-term efficacy of EMG biofeedback for chronic rheumatic back pain. *Pain,* 27, 195-202.

Flor, H. & Turk, D. (1989). Psychophysiology of chronic pain: Do chronic pain patients exhibit symptom-specific psychophysiological responses? *Psychological Bulletin*, 105, 215-259..

Flor, H., Turk, D., & Birbaumer, N. (1985). Assessment of stress-related psychophysiological reactions in chronic back pain patients. *Journal of Consulting and Clinical Psychology*, 53, 354 - 364.

Fogel, E. (1995). Biofeedback-assisted musculoskeletal therapy and neuromuscular re-education. In M. Schwartz (Ed.), *Biofeedback: A practitioner's Guide (pp. 560-593),* New York, Guilford Press.

Freedman, R. (1991). Physiological mechanisms of temperature biofeedback. *Biofeedback and Self-Regulation,* 16, 95-115.

Geisser, M., Ranavaya, M., Haig, A., Roth, A., Zucker, R., Ambroz, C., Caruso, M. (2005). A meta-analytic review of surface electromyography among persons with low back pain and normal, healthy controls. *Journal of Pain,* 6, 711-726.

Gevirtz, R. (1999). Irritable Bowel Syndrome. Biofeedback News magazine Winter Issue.

Gevirtz, R. (1999). Resonant frequency training to restore autonomic homeostasis for treatment of psychophysiological disorders. *Biofeedback*, 27, 7-9.

Gevirtz, R. (2002). The effect of resonant frequency cardiac biofeedback training on heart rate variability in a cardiac rehabilitation population. *Applied Psychophysiology and Biofeedback*, 27, 311.

Gevirtz, R., Hubbard, D., & Harpin, R. (1996). Psychophysiologic treatment of chronic lower back pain. *Professional Psychology: Research and Practice,* 27, 561–566.

Glaros, A. G., & Lausten, L. (2003). Temporomandibular disorders and facial pain. In D. M. Moss, A. McGrady, T. C. Davies, & I. Wickramasekera (Eds.), Handbook of mind-body medicine in primary care (pp. 223-233). Thousand Oaks, CA: Sage Publications.

Glazer, H., Rodke, G., Swencionis, C., Hertz, R., & Young, A. (1995). Treatment of vulvar vestibulitis syndrome with electromyographic biofeedback of pelvic floor musculature. *Journal of Reproductive Medicine*, 40, 283-290.

Grabel, J. (1974). Electromyographic study of low back muscle tension in subjects with and without chronic low back pain. Doctoral Thesis, US International University. *Dissertation Abstracts Internaional*, 34(6-B), 2929-2930.

Hamblen, E., Sherman, R., & Powell, B. (1996). The effect of premenstrual syndrome and primary dysmenorrhea on women's cognitive functioning and job performance before and after biofeedback treatment. *Biofeedback and Self-Regulation*, 21, 357.

Harden, R., Houle, T., Green, S., Remble, T., Weinland, S., Colio, S., Lauzon, J., Kuiken, T. (2005). Biofeedback in the treatment of phantom limb pain: a time-series analysis. *Applied Psychophysiology and Biofeedback*, 30, 83-93.

Hart, A., Mathisen, K., & Prater, J. (1981). A comparison of skin temperature and EMG training for primary dysmenorrhea. *Biofeedback and Self-regulation,* 6, 367-373.

Headley, B. (1990). *Dynamic EMG Evaluation: Interpreting postural dysfunction*. St. Paul, Mn., Pain Resources.

Headley, B. (1990). Evaluation and treatment of myofascial pain syndrome utilizing biofeedback. In: J. Cram (Ed,), *Clinical EMG for surface recordings: Volume 2 (pp. 235-254)*, Nevada City, California, Clinical Resources.

Headley, B. (1993). The use of biofeedback in pain management. *Physical Therapy Practice,* 2, 29-40.

Hetrick, D., Glazer, H., Liu, Y., Turner, J., Frest, M., Berger ,R. (2006). Pelvic floor electromyography in men with chronic pelvic pain syndrome: a case-control study. *Neurourology and Urodynamics,* 25, 46-49.

Hoebeke, P., Van Laecke, E., Renson, C., Raes, A., Dehoorne, J., Vermeiren, P., Vande Walle, J. (2004). Pelvic floor spasms in children: an unknown condition responding well to pelvic floor therapy. *European Urology,* 46, 651-654.

Hoyt, W., Hunt, H., DePauw, M., Bard, D., & Shaffer, F. (1981). EMG assessment of chronic low back pain syndrome. *Journal of the American Osteopathic Assocication*, 80, 728-730.

Humphreys, P. & Gevirtz, R. (2000) Treatment of recurrent abdominal pain: components analysis of four treatment protocols, *Journal of Pediatric Gastroenterologic Nutrition*, 31,47-51.

Ingersoll, C. & Knight, K. (1991). Patellar location changes following EMG biofeedback or progressive resistive exercises. *Medicine and Science in Sports & Exercise*, 23, 122-127.

Jensen, R., Rasmussen, B., Pedersen, B., & Olesen, J. (1993). Muscle tenderness and pressure pain thresholds in headache. *Pain,* 52,193-199.

Kasman, G., Cram, J., & Wolf, S. (1998). *Clinical applications in surface electromyography*. Gaithersburg: Aspen Publications.

Kasman, G. (1990). Use of integrative EMG for the assessment and treatment of musculoskeletal pain: Guidelines for physical medicine practitioners. In: J. Cram (Ed.), *Clinical EMG for surface recordings: Volume 2* (pp. 255 - 302). Nevada City, California, Clinical Resources.

Kravitz, E., Moore, M., & Glaros, A. (1981). Paralumbar muscle activity in chronic low back pain. Archives of Physical Medicine & Rehabilitation, 62, 172-176.

LaVaque, T., Hammond, D., Trudeau, D., Monastra, V., Perry, J., Lehrer, P., Matheson, D., & Sherman, R. (2002). Template for developing guidelines for the evaluation of the clinical efficacy of psychophysiological evaluations. *Applied Psychophysiology and Biofeedback*, 27, 273–281. Co-published in *Journal of Neurotherapy,* 6, 11–23.

Lewis, C., Gervirtz, R., Hubbard, D., & Berkoff, G. (1994). Needle trigger point and surface frontal EMG in tension-type headache. *Biofeedback and Self-Regulation*, 19, 274-275.

Linden, W. (1994). Autogenic training: A narrative and quantitative review of clinical outcome. *Biofeedback and Self-Regulation*, 19, 227-264.

Mathew, R., Claghorn, J., Largen, J., & Dobbins, K. (1979). Skin temperature control of PMS. *American Journal of Clinical Biofeedback* 2, 7–10.

McKay, E., Kaufman, R., Doctor, U., Berkova, Z., Glazer, H., Rdko, V. (2001). Treating vulvar vestibulitis with electromyograhic biofeedback of pelvic floor musculature. *Journal of Reproductive Medicine*, 46, 337-342.

Middaugh, S. (2003). *EMG biofeedback protocols for treatment of musculoskeletal pain.* Presented at the annual meeting of the Association for Applied Psychophysiology and Biofeedback in Jacksonville Florida, March 2003.

Middaugh, S. (1998). Physical therapy and exercise for headache. In D.E. DeGood (Ed.), *The Headache and Neck Pain Workbook (pp. 87-110),* Oakland, CA: The New Harbinger Publications, Inc.

Middaugh, S., Kee, W., & Nicholson, J. (1994). Muscle overuse and posture as factors in the development and maintenance of chronic musculoskeletal pain. In: R. Grzesiak & D. Cicconie (Eds.), *Psychological vulnerability to chronic pain (pp. 137-172).* New York: Springer.

Middaugh, S., Kee, W., Nicholson, J., & Allenback, G. (1995): Upper trapezius overuse in chronic headache and correction with EMG biofeedback training. *Proceedings of the 26th Annual Meeting of the Association for Applied Psychophysiology, pp.* 89-92.

Middaugh, S. & Morrisette, D. (2000). Combining EMG feedback with physical therapy for treatment of headache. *Biofeedback,* 28, 16-19.

Morley, S., Eccleston, C., & Williams, A. (1999). Systematic review and meta-analysis of randomized controlled trials of cognitive behaviour therapy and behaviour therapy for chronic pain in adults, excluding headache. *Pain, 80,* 1-13.

Moore, L, & Wiesner, S. (1996). Hypnotically-induced vasodilation in the treatment of repetitive strain injuries. *American Journal of Clinical Hypnosis*, 39, 97 – 104.

Moss, D. & Gunkelman, J. (2002). Task force report on methodology and empirically supported treatments: Introduction. *Applied Psychophysiology and Biofeedback*, 27, 261–262.

Moynihan, J., & Gevirtz, R. (2001). Respiratory and cognitive subtypes of panic. Preliminary validation of Ley's model. *Behavior Modification*, 25, 555-83.

Mueller, H., Donaldson, C., Nelson, D., Layman, M. (2001). Treatment of fibromyalgia incorporating EEG-Driven stimulation: A clinical outcomes study. *Journal of Clinical Psychology*, 57, 933-952.

Nadler, R. (2002). Bladder training biofeedback and pelvic floor myalgia. *Urology*, 60, 42-43.

Neblett, R. (2002). Active SEMG training strategies for chronic musculoskeletal pain. *Biofeedback*, 30, 28–31.

Neblett, R. (2004). Biofeedback therapy within an interdisciplinary chronic pain management program. *Biofeedback*, 32, 13–19.

Neblett, R., Gatchel, R., & Mayer, T. (2003). A clinical guide to surface EMG assisted stretching as an adjunct to chronic musculoskeletal pain rehabilitation. *Applied Psychophysiology and Biofeedback*, 28, 147–160.

Newton-John, T.R., Spence, S.H., & Schotte, D. (1995). Cognitive-behavioural therapy versus EMG biofeedback in the treatment of chronic low back pain. *Behavioural Research and Therapy*, 33, 691 – 697.

Ostelo, R. W. J. G., van Tulder, M. W., Vlaeyen, J. W. S., Linton, S. J., Morley, S. J., & Assendelft, W. J. J. (2006). Behavioural treatment for chronic low-back pain. *Cochrane Database of Systematic Reviews*.

Palsson, O., Heymen, S., Whitehead, W. (2004). Biofeedback treatment for functional anorectal disorders: a comprehensive efficacy review. *Applied Psychophysiology and Biofeedback*, 29, 153-174.

Potts, S., Lewin, R., Fox, K., & Johnstone, E. (1999). Group psychological treatment for chest pain with normal coronary arteries. *Quarterly Journal of Medicine*., 92, 81-86.

Reissing, E., Brown, C., Lord, M., Binik, Y., Khalife, S. (2005). Pelvic floor muscle functioning in women with vulvar vestibulitis syndrome.. *Journal of Psychosomatic Obstetrics and Gynaecology,* 26, 107-113.

Roberts, A., Sternbach, R., & Polich, J. (1993). Behavioral management of chronic pain and excess disability: Long term follow-up of an outpatient program. *Clinical Journal of Pain,* 9, 41-48.

Schneider, C., Palomba, D., & Flor, H. (2004). Pavlovian conditioning of muscular responses in chronic pain patients: central and peripheral correlates. *Pain, 112,* 239-247.

Sherman, R. (1985). Relationships between strength of low back muscle contraction and intensity of chronic low back pain. *American Journal of Physical Medicine, 64,* 190-200.

Sherman, R. (2004). *Pain assessment and intervention from a psychophysiological perspective.* Wheat Ridge, Colorado: Association for Applied Psychophysiology and Biofeedback.

Sherman R. (2003). Biofeedback .In Leskowitz, E. (Ed.), *Complementary and alternative medicine in rehabilitation* (pp 125-138). New York: Churchill Langston.

Sherman, R., & Arena, J. (1992). Phantom limb pain: Mechanisms, incidence, and treatment. *Critical Reviews in Physical and Rehabilitation Medicine, 4,*1-26.

Sherman, R., Devor, M., Jones, C., Katz, J., & Marbach, J. (1996). *Phantom pain,* New York: Plenum Press.

Sherman, R., Evans, C., & Arena, J. (1993). Environmental - temporal relationships between pain and muscle tension: Ramifications for the future of biofeedback treatment. In: M. Shtark & T. Sokhadze (Eds.), *Biofeedback: Theory and practice*. Novosibirsk, Nauka Publishers.

Skubick, D., Clasby, R., Donaldson, S., & Marshall, W. (1993). Carpal tunnel syndrome as an expression of muscular dysfunction in the neck. *Journal of Occupational Rehabilitation*, 3, 31-44.

Tan, G., Sherman, R., & Shanti, B. (2003). Biofeedback pain interventions. *Practical Pain Management*, 3,12-18.

Tries, J. & Eisman, E. (1995). Urinary incontinence: Evaluation and biofeedback treatment. In: M. Schwartz (Ed.), *Biofeedback: A practitioner's Guide (pp. 597-632), New York:* Guilford Press.

Turnbull, G. & Ritvo, P. (1992). Anal sphincter biofeedback relaxation treatment for women with intractable constipation symptoms. *Diseases of the Colon and Rectum*, 35, 530-536.

Van Santen, M., Bolwijn, P., Verstappen, F., Bakker, C., Hidding, A., Houben, H., van der Heijde, D., Landewe, R., van der Linden, S. (2002). A randomized clinical trial comparing fitness and biofeedback training versus basic treatment in patients with fibromyalgia. *Journal of Rheumatology,* 29, 575–582.

van Tulder, M. W. & Koes, B. (2004). Low back pain (chronic). *Clinical Evidence, 10,* 1659-1684.

van Tulder, M. W., Koes, B. W., & Bouter, L. M. (1997). Conservative treatment of acute and chronic nonspecific low back pain. A systematic review of randomized controlled trials of the most common interventions. *Spine, 22,* 2128-2156.

van Tulder, M. W., Ostelo, R., Vlaeyen, J. W., Linton, S. J., Morley, S. J., & Assendelft, W. J. (2001). Behavioral treatment for chronic low back pain: a systematic review within the framework of the Cochrane Back Review Group. *Spine, 26,* 270-281.

Vlaeyen, J. W., Haazen, I. W., Schuerman, J. A., Kole-Snijders, A. M., & van Eek, H. (1995). Behavioural rehabilitation of chronic low back pain: comparison of an operant treatment, an operant-cognitive treatment and an operant- respondent treatment. *Brtitish Journal of Clinical Psychology, 34,* 95-118.

White, G., Jantos, M., & Glazer, H. (1997). Establishing the diagnosis of vulvar vestibulitis. *Journal of Reproductive Medicine,* 42, 157–160.

Wolf, S. (1998). Low Back Dysfunction. Chapter 12 In: G. Kasman, J. Cram, & S. Wolf (Eds.),: *Clinical Applications in Surface Electromyography (pp. 321-345).* Gaithersburg: Aspen Publications.

Wolf, S. & Basmajian, J. (1979). Assessment of paraspinal activity in normal subjects and in chronic back pain patients using a muscle biofeedback device. In: E. Asmussen & J.

Gorgensen (Eds.), *International Series on Biomechanics VI-B* (pp. 319 - 323). Baltimore, Univ Park Press.

Yucha, C. & Gilbert, C. (2004). *Evidence-Based Priactice in Biofeedback and neurofeedback*. Colorado Springs, CO : Association for Applied Psychophysiology and Biofeedback.