In Electromyography in Ergonomics
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CHAPTER NINE

Surface electromyographic assessment of low back pain

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9.1 INTRODUCTION

Among the many possible uses of surface electromyographic (EMG) signals, the application to assessing paraspinal muscle function has been of growing interest to researchers and professionals in the field of ergonomics. The interest in this application of EMG measurement is undoubtedly related to the unique opportunity it provides in understanding and evaluating the muscular component to lower back pain (LBP) syndromes. Surface EMG techniques provide a window to the neuromuscular system by non-invasive means. Recent technological developments have overcome some of the previous limitations of multichannel EMG signal data acquisition and processing which have prevented this method from achieving widespread clinical or occupational use (Gilmore and De Luca, 1987; Merletti *et al.*, 1990; Roy, 1992). The primary challenge at this time is the development and validation of protocols to characterize normal back muscle functioning and identify specific impairments associated with LBP during various tasks. This chapter will summarize the progress being made in achieving these objectives.

The most common diagnosis reported for LBP is acute or chronic musculoskeletal injury (Bigos and Battie, 1987; Andersson *et al.*, 1989; Teufel and Traue, 1989). Although it is not possible at this time to identify definitively paraspinal muscles as the etiological site of LBP, muscular and other soft-tissue injuries are suspected when no other structural or neural abnormalities can be identified on the basis of radiographs or bone scans (White and Gordon, 1982; Andersson *et al.*, 1989). Regardless of whether the soft-tissue injury is located in the muscle or other components of the spinal complex, such as the intervertebral disc, facet joint, or ligament, normal muscle functioning is likely to be impaired secondary to pain or mechanical disorders (De Luca, 1993b). The importance of these structures to normal back functioning is underscored by the fact that the most common conservative treatment approaches currently recommended for LBP are targeted at reversing musculoskeletal dysfunction through exercise (Darling, 1993; D'Orazio, 1993). Prevention is an important adjunct to this approach and includes muscle sparing techniques, redesign of the work-site or modification of the job task (Isernhagen, 1993). The discipline of ergonomics and occupational safety and health have contributed greatly to these latter important aspects of LBP management (Isernhagen, 1993).

No other single musculoskeletal disorder has had such a profound effect on work productivity, medical costs and compensation claims as LBP (White and Gordon, 1982; Deyo, 1987). The high prevalence of LBP is second only to the common cold as a cause of work absenteeism (Deyo, 1987). Its cost to this society in monetary terms is currently estimated to be anywhere from $30 to $70 billion annually (Deyo and Tsui Wu, 1987; Deyo *et al.*, 1991). While the prevalence of LBP has not changed over the past 20 years, the costs have increased exponentially and show no signs of abatement (Deyo, 1987). The spiraling costs have created a crisis for the employer who has had to assume a greater responsibility in meeting the expenses incurred when an employee suffers a work-related back injury. Modifications to the work-site based on the implementation of ergonomic principles have proven to be cost-effective and have therefore assumed greater importance in decreasing the incidence of LBP (Bigos and Battie, 1987; Isernhagen, 1993). In addition, the chronicity of LBP in some patients has been reduced by new treatment approaches that have moved away from bed-rest and inactivity to recommendations favoring early mobilization and physical function (Mayer *et al.*, 1987). This functionally directed rehabilitation has emerged as the new basis for the therapeutic management of LBP. The approach relies more heavily upon objective musculoskeletal assessment procedures and prevention than pain measurement and is proving to be more effective than previous treatment approaches based primarily on pain management (Mayer *et al.*, 1986, 1987). As a result of these developments, more objective and reliable musculoskeletal evaluation techniques are needed to provide the basis for initiating and monitoring treatment progression. It is hoped that the techniques used to assess musculoskeletal function in the clinical research environment may also be incorporated into the work-site evaluation, particularly as these techniques become easier to use and therefore more adaptable outside of the laboratory.

This chapter provides a historical perspective on the use of surface EMG procedures to identify and characterize disturbances to normal paraspinal muscle function related to LBP. For the most part, it is intended as a general review rather than a critical review. The studies were selected for their relevance to the ergonomist or occupational health professional interested in new procedures to reduce the risks of LBP associated with the demands of the work-place. We begin with an overview of paraspinal muscle impairment and its role as either a primary or secondary component to LBP. EMG studies that describe paraspinal muscle function in patients with LBP will be discussed; first, for amplitude parameters of the EMG signal, and then for EMG spectral parameters. The topics are further organized according to the posture and task being studied and whether static or dynamic tasks were specified. Studies in which EMG spectral parameters were utilized to measure fatigue during sustained or repetitive tasks will also be reviewed. Work currently in progress to develop clinical assessment procedures and instrumentation for quantifying LBP impairment on the basis of these and other surface EMG parameters will be presented separately. The chapter will conclude with suggestions for future research.

9.2 MUSCLE IMPAIRMENT AND LOW BACK PAIN

Although the evidence linking paraspinal muscle impairment to LBP is compelling and of obvious relevance to the field of ergonomics, the precise nature of the linkage between muscle and LBP is not known. Our current understanding of paraspinal muscle impairment can best be understood on the basis of considering it as either a primary or a secondary disorder. This classification is based on whether the impairment is a direct or an indirect result of back injury.

9.2.1 Primary Muscle Disorders

Skeletal muscle disorders may occur as the result of direct muscle injury causing contusions, lacerations, compartment syndromes, or ischemia. Primary muscle disorders associated with LBP, however, are more commonly the result of muscle strain injuries rather than direct trauma. Muscle strain injury can be defined as 'indirect injury to the myotendinous unit caused by too much tension, stretching, or a combination of the two' (Garret *et al.*, 1989b). It is often cited as the most frequent type of LBP injury, particularly among the working population (Holbrook *et al.*, 1984). The likelihood of back muscle strain appears to increase after the age of 25 years, as does the risk of LBP (White and Gordon, 1982; Garret *et al.*, 1989b). Even though many of the clinical characteristics of acute lumbosacral strain are similar to the characteristics of muscle strain in the extremities, muscle is more often considered the locus of pain and disability in the extremities than in the back (O'Donoghue, 1984). This disparity may be the result of the historical emphasis placed on lumbosacral disc herniation as the source for almost all serious LBP conditions.

Of the few experimental studies conducted to investigate the cause of strain injuries, almost all were conducted on muscles located in the extremities rather than the back or trunk (Garret *et al.*, 1989b). Their findings indicated that injuries usually occur as a response to excessive load or stretch and are most common during eccentric contractions in muscles that span two or more joints (Brewer, 1960). Paraspinal muscles, particularly the erector spinae and multifidus muscles, cross two or more vertebral levels and are usually pre-loaded eccentrically during lifting, an activity commonly associated with musculoskeletal LBP injury (Andersson *et al.*, 1976a,b, 1979; Andersson and Schultz, 1979). Biomechanical and epidemiologic data also show that exposure of the lumbar spine to large loads is associated with a higher prevalence of LBP (Frymoyer *et al.*, 1983). Of the many work-place factors that have been considered as causes for LBP (for a review, see Bigos and Battie, 1987) exposure to heavy physical work (Magora, 1970; Chaffin and Park, 1973; Frymoyer, 1989) and vibration (Wilder *et al.*, 1982; Frymoyer *et al.*,) are often mentioned as possible sources of strain injury.

In addition to these well-accepted factors contributing to musculoskeletal injury, other more speculative mechanisms have been proposed. Some have theorized that the anatomical characteristics of motor units may contribute to muscle strain injuries. Muscle regions containing a relatively high concentration of motor units may produce strong localized muscle tension which could result in strains and other soft-tissue damage (Tidball, 1984). Secondly, if each muscle fiber is connected to a common tendon, rather than an individual tendon, the resulting strain would be more severe since it would be proportional to the sum total of the muscles being activated (Andersson *et al.*, 1989). The presence of muscle fatigue, defined as the reduced ability of a muscle to maintain a desired force (Edwards, 1981), may also contribute to the likelihood of muscle strain injury. Paraspinal muscle fatigue can decrease the muscular support to the spine and result in increased mechanical stress to its functional components (Seidel *et al.*, 1987). External loads are transmitted more readily to the soft tissue of the spine when the paraspinal musculature loses its ability to generate tension as a result of fatigue (Nicolaisen and Jorgensen, 1985; Garret *et al.*, 1989b). Ergonomic studies have demonstrated that muscle fatigue can impair motor coordination and control which in turn may lead to muscle strain injury (Bigos and Battie, 1987). A few experimental studies have indicated that appropriate muscle activation may protect muscle and limit strain injury by limiting the transference of loads to soft tissue (Garret *et al.*, 1987, 1989a,b). The possible benefits of pre-conditioning and 'warm-up' in preventing muscle strain injury is inconclusive at this time (Ekstrand and Gillquist, 1983; Wiktorsson-Mollter *et al.*, 1983; Safran *et al.*, 1988); however, it has been shown in an animal model that the force needed to rupture a muscle increases significantly in pre-conditioned muscles (via maximum isometric contraction exercise) when compared to a control group (Safran *et al.*, 1988).

9.2.2 Secondary Muscle Disorders

The onset of pain invariably initiates neuromuscular and behavioral responses that, for the most part, likely represent efforts to prevent or reduce further pain or injury by either 'splinting' the spinal segment(s), as for instance by muscle spasm, or by repositioning the back or altering muscle tension to relieve mechanical impingement on nerves or other sensitive tissue. Sustained or recurring episodes of these musculoskeletal compensations may result in rapid structural and functional adaptations of the muscular tissue. Generalized physical inactivity related to prolonged bed-rest or pain avoidance behavior can precipitate a deconditioning of back muscles. Deconditioning may lead to specific physiological adaptations, such as muscle fiber atrophy and changes to the relative fiber type proportions of a muscle (Kraus and Rabb, 1961; Booth, 1987; Andersson *et al.*, 1989).

Specific hypotheses have been proposed to explain the relationship between secondary sources of paraspinal muscle impairment and LBP (Nouwen and Bush, 1984; Lund *et al.*, 1991; Cassissi *et al.*, 1993). The notion that a pain–spasm–pain cycle underlies at least some LBP disorders is credited to Travell *et al.* (1942). A more recent version of this hypothesis, referred to as the reflex-spasm model, proposed a muscle spasm reflex mechanism to immobilize injured tissue (Collins *et al.*, 1982). The reflex-spasm model predicts that the body responds involuntarily to pain or injury by the production of a muscle spasm which immobilizes or protects the painful area to allow for recovery. Muscle spasm may even aggravate the sensation of pain by restricting circulation and promoting the accumulation of muscle metabolites which are irritants to nerve endings. Armstrong (1984) proposed that the accumulation of these acidic waste products either stimulates the nerve endings directly or through pressure from increased osmotic tension. Ischemic muscle conditions, considered to be an additional LBP factor, may also result from the prolonged tension of muscle spasm (Armstrong, 1984). Since it may be assumed that high metabolite levels are present in a muscle during ischemia and increased tension, pain may be produced following exercise of that muscle. Price *et al.* (1948) proposed that this mechanism is an important factor in explaining the relationship between muscle activity and aggravation of LBP. Muscle deficiency resulting from inactivity or disuse may also contribute to back pain. Kraus and Rabb (1961) proposed that when a muscle is used beyond its limit and is either constricted, unable to yield to fast movements, or unable to overcome resistance, pain will ensue. They further argued that the muscle constriction or 'tightness' not only exposes the muscles to pain and spasm but will produce the typical 'jelling' pain that one feels when arising in the morning or after sitting for a prolonged period of time.

Another hypothesis relates muscle spasm to psychological stress and is referred to as the 'stress-causality' model (Jacobsen, 1944). The model predicts that abnormal tension due to psychological stress may cause the back muscles to go into spasm. As a result, a spasm–pain–spasm cycle occurs as in the reflex-spasm model. There is also evidence that prolonged tension shortens muscles and deprives them of elasticity (Kraus and Rabb, 1961). Once a muscle has reached a sufficient level of tension and has weakened from lack of activity, it may become increasingly susceptible to muscle strain injury.

9.3 EMG STUDIES OF PARASPINAL MUSCLE FUNCTION DURING STATIC POSTURE

Paraspinal EMG activity has been studied extensively in patients with LBP, either at 'rest' or while exerting isometric trunk extension torques during static positions such as standing, sitting, or prone-lying (De Vries, 1968a,b; Jayasinghe *et al.*, 1978; Jorgensen and Nicolaisen, 1987; Garret *et al.*, 1989b; Biedermann, 1990; Biedermann *et al.*, 1991; Cassissi *et al.*, 1993; De Luca 1993b). Muscular models of LBP dysfunction that include spasm or hyperactivity of muscle as a key component, predict that during resting activity or static postures, the EMG amplitude should be higher in the paraspinal muscles of LBP patients compared to pain-free control subjects (Nouwen and Bush, 1984; Ahern *et al.*, 1988; Arena *et al.*, 1989). In a review that evaluated the likelihood of this possibility, Nouwen and Bush (1984) concluded that the evidence for higher EMG activity in chronic LBP was minimal, particularly when only well-matched control studies were considered. For those studies in which patients and controls were matched according to sex, age, and other factors (Collins *et al.*, 1982; Ahern *et al.*, 1988), no significant differences between groups were found. In another review of the EMG literature, higher resting levels of integrated EMG activity were reported in lumbar paraspinal muscles of patients with chronic LBP compared to control subjects for tests conducted during prone-lying at rest (Grabel, 1973; Miller, 1985) and during standing for a 10 min period (Hoyt *et al.*, 1981; Miller, 1985). In this latter study, it was also reported that no significant increases in integrated EMG were observed for subjects tested during a semi-Fowler's position (a reclined sitting position), or in upright sitting. Other studies conducted from a sitting posture indicated that patients with chronic LBP had consistently lower integrated EMG activity than normal controls (Cassissi *et al.*, 1993). The lower EMG activity when combined with lower peak torque capability has been referred to as a 'muscle deficiency model' of chronic LBP (Cassissi *et al.*, 1993). In another study in which various activities were compared while subjects were asked to produce a minimal contraction of their lower back muscles (Kravitz *et al.*, 1981; Miller, 1985), only one activity out of the 11 activities tested resulted in a significantly different EMG activity between LBP patients and controls.

It should be recognized, however, that many of these studies have been criticized for their failure to normalize the integrated EMG data, their use of questionably high band-pass filtering techniques to attenuate signal noise artefact, their failure to report variability of the data between subjects, and the possibility that the increases in EMG activity were fatigue related (Miller, 1985). Comparing the EMG signal to a standardized or reference contraction is considered essential to the validity of intersubject comparisons (De Luca, 1979; Perry and Bekey, 1981; Basmajian and De Luca, 1985; Miller, 1985). In a well-controlled and normalized EMG study comparing three experimental tasks (quiet sitting, standing, and sitting during a repetitive unilateral upper extremity task), no significant differences in integrated EMG activity were observed between chronic LBP patients and non-pain controls (Miller, 1985). In one of the few publications in which the evidence for a pain–spasm–pain cycle was reviewed (Roland, 1986), methodological limitations were also identified. These limitations included the observation that patient populations were poorly described, the role of muscle spasm in the LBP patients remained obscure, and technical difficulties were often present regarding the positioning of the subjects and the selective recording of EMG signals from the muscles of interest. In spite of these limitations, however, the authors concluded that there was clear experimental evidence consistent with a pain–spasm–pain cycle.

Although muscle spasm is most commonly diagnosed in patients with acute LBP, most of the studies in the literature on muscle spasm involve chronic LBP patients. In general, these studies are equally divided between those that report increased EMG activity associated with muscle spasm (Kravitz *et al.*, 1981; Soderberg and Barr, 1983; Sherman, 1985) and those that do not (Collins *et al.*, 1982; Nouwen, and Bush, 1984; Cohen *et al.*, 1986; Miller *et al.*, 1987). Localized muscle abnormalities associated with long-loop inhibitory reflexes, have been offered as a possible mechanism for muscle spasm (De Andrade *et al.*, 1965; Garret *et al.*, 1989b; Hides *et al.*, 1994). Paraspinal muscles as well as some of the connective tissues in the region of the spine contain sensory nerve endings sensitive to changes in length, tension, position and movement which may be initiated by the presence of pain or other factors (Garret *et al.*, 1989b). In addition, some sensory endings respond to change in position by inhibiting muscle activity while others, possibly related to muscle spasm, increase muscle activity. In some studies, increased myoelectric activity has been observed at muscle sites corresponding to palpable abnormalities (Denslow and Clough, 1941; Elliot, 1944; Arroyo, 1966; England and Delbert, 1972; Fisher and Chang, 1985), whereas in other studies (Kraft *et al.*, 1968) no abnormal localized EMG findings were observed. One recent investigation has provided evidence, based on ultrasound scanning, that localized effects of muscle spasm are measurable (Hides *et al.*, 1994). Muscle wasting and 'rounded' muscles (measured by a shape ratio index computed from the muscle cross-sectional area) were present at symptomatic sites.

It is safe to say on the basis of reviewing the research literature that muscle spasm has still eluded proper characterization and further basic science investigations are needed to help clarify its presence and role in LBP. Research is particularly lacking in determining the effects of therapeutic modalities, such as exercise, heat, and spinal mobilization techniques, or the effects of medications, such as muscle relaxants or analgesics, on muscle spasm associated with LBP. The influence of ergonomic approaches to redesigning a work-site or modifying a job task has not been evaluated in terms of reducing muscle spasm or modifying abnormal muscle functioning. The current lack of research in these areas is truly remarkable considering that numerous treatment regimens currently in vogue are based on relieving symptoms associated with muscle spasm. In a recent workshop among a diverse group of LBP experts, the need to address these topics was recognized. In the report emanating from this workshop, the participants suggested that the first research step should be towards defining and documenting muscle spasm (Garrett *et al.*, 1989a). Of note, is the observation that surface EMG techniques were specifically mentioned as the most likely resources for accomplishing this important objective.

9.4 EMG STUDIES OF PARASPINAL MUSCLE FUNCTION DURING DYNAMIC TASKS

Although there is little agreement among researchers identifying which dynamic tasks are most important when evaluating back muscle function, most of the surface EMG studies described in the literature include a trunk flexion task, usually initiated from a standing posture. The interest in this task probably originated with the work of Floyd and Silver (1951, 1955) who studied the phenomenon of 'flexion–relaxation'. Flexion–relaxation refers to the observation that during forward flexion of the trunk, when paraspinal muscle activity is typically increasing in magnitude (as measured by the EMG signal), there is an eventual 'silent period', or period of significantly reduced paraspinal muscle activity, during the latter part of trunk flexion. It was hypothesized that this silent period results from reflex inhibition. However, most others have explained this phenomenon as being due to the passive resistance of either stretched muscles, ligaments, fascia, and/or facet joints that relieve the muscle of the need to contract actively (Farfan and Lamy, 1975; Gracovetsky *et al.*, 1977; Kippers and Parker, 1984; Schultz *et al.*, 1985). The interest in this phenomenon is related primarily to its implications for muscle functioning during lifting and other work activities that require a flexed posture.

The question of whether this phenomenon is absent in patients with LBP has prompted a number of surface EMG investigations among patients with LBP. Among the earliest of these investigations, Golding (1952) studied forward flexion in 120 patients and reported that 86 achieved the expected flexion–relaxation. Later studies by Floyd and Silver (1955) and Yashimoto *et al.*, (1978) confirmed these findings in a similar population of LBP patients. Contradictory findings have also been reported concerning the presence of a relaxation response (Chapman and Troup, 1970; Troup and Chapman, 1972). Wolf and Basmajian (1977) in their study of nine patients with chronic LBP, reported that muscle activity was lower than or the same as that in a healthy control population studied under static and dynamic conditions, including trunk flexion (Wolf and Basmajian, 1977; Wolf *et al.*, 1979). The results of this study have been questioned because no tests for significant differences were reported and some of the patients included in the study had a history of back surgery which could have altered the EMG signal (Miller, 1985). Nouwen *et al.* (1987) reported that all of the 20 patients they studied with LBP had significantly higher paraspinal muscle activity near full flexion than control subjects. Their subjects were tested during trunk flexion, extension, lateral bending, and rotation. They also reported no evidence of muscle imbalances on the basis of comparisons between left and right paraspinal EMG amplitudes. Others have explored the possibility of the flexion–relaxation phenomena as a useful clinical measure for LBP (Triano and Schultz, 1987). Results of the flexion–relaxation test from LBP patients and controls were compared to a disability rating scale. A positive relationship between the degree of disability and the loss of the flexion–relaxation phenomena was reported. All of the control subjects tested in this study exhibited the flexion–relaxation phenomena, however, this phenomena was absent in half of the patients tested. According to the results of this study, the test had excellent specificity but poor sensitivity.

Surface EMG studies that assess functional tasks have included a few evaluations of manual lifting, however they have for the most part been limited to normal healthy subjects rather than patients with LBP. Studies in normal healthy subjects have generally investigated the relationship between either lifting moments, posture, or load and EMG activity of paraspinal muscles (Seroussi and Pope, 1987; Scholtz, 1992). A number of other studies have evaluated different lifting strategies and its effect on muscle activity or coordination (Grieve, 1974; Andersson *et al.*, 1976a,b; Freivalds *et al.*, 1984; Scholtz, 1992) while others were undertaken to help validate biomechanical models to predict muscle load sharing (Bejjani *et al.*, 1984; Freivalds *et al.*, 1984; Jäger and Luttman, 1989). Many of these studies were limited to static or quasi-static conditions in which lifting was limited to a single plane of movement or to isometric conditions. This line of research is in its very early stages of development since real-life lifting tasks rarely involve just one axis of motion and are dynamic rather than static.

9.5 THE USE OF EMG SPECTRAL PARAMETERS TO DESCRIBE PARASPINAL MUSCLE FUNCTION

9.5.1 Muscle Fatigue and LBP

Studies in which surface-detected EMG signals from paraspinal muscles are analyzed to extract spectral parameters, such as the median or mean frequency, have contributed to our understanding of the role of muscle fatigue in LBP. Preliminary research findings indicate that muscle performance, as measured by spectral estimates of the EMG signal, may provide a more objective measure than purely mechanical indices (Biedermann *et al.*, 1991; Klein *et al.*, 1991; De Luca, 1993a,b; Roy *et al.*, 1995). The EMG spectral technique measures the shift in the EMG power spectrum associated with the biochemical events that occur during a sustained contraction. Spectral parameters of the

EMG signal are influenced by metabolic fatigue processes not cognitively perceived or voluntarily regulated by the subject when performing a sustained contraction, particularly when numerous muscle groups are being monitored (Basmajian and De Luca, 1985; De Luca, 1985). This aspect of the technique appears to provide the user with a more objective measure of muscle performance capability than techniques that rely on mechanical indices that can be volitionally regulated, such as torque or force measurements from back dynamometers. The second possible advantage of the technique is that it can enable the user to obtain localized measurements specific to a particular segment of the superficial paraspinal musculature. In this way, information describing the interaction between muscles associated with a work task can be measured, rather than modeling the back as a single extensor, as is the case for back dynamometer measurements. A third advantage is that the median frequency parameter is more reliable than the amplitude of the EMG signal (De Luca, 1985).

The current approach is based on the concept that by simultaneously monitoring the median frequency from multiple electrode sites, it is possible to evaluate the relative contributions of individual paraspinal muscle groups during a sustained extension of the trunk (De Luca, 1985, 1993b). This concept has been reviewed in detail in a recent position paper (De Luca, 1993b). Based upon the accepted notion that muscle dysfunction may follow injury, pain, or disuse, it is reasonable to expect that some muscles would compensate for these deficits, resulting in a relative alteration in their EMG activity during induced localized muscle fatigue. This concept is depicted in Figure 9.1.

The earliest applications of EMG-spectral techniques to back muscles were limited by the use of only a few EMG electrodes, the failure to isolate the trunk extensor muscles properly, and the reliance upon cumbersome methods of spectral analyses (Morioka, 1964; De Vries, 1968a,b; Jayasinghe *et al.*, 1978). Many of these initial limitations have been resolved by technical and methodological improvements (Roy *et al.*, 1989; Biedermann *et al.*, 1990, 1991; Klein *et al.*, 1991; Roy, 1992; De Luca, 1993b). The earliest studies of back muscle fatigue investigated the behavior of EMG spectral parameters during static, constant-force contractions of paraspinal muscles. Initial studies by Morioka (1964), Okada (1970), and Okada *et al.* (1970) reported an increase in the low frequency components of the EMG power spectrum while subjects performed static lifts of incremental loads. In one of these studies, subjects were asked to sustain the contractions until the point of muscle pain, at which time it was observed that the EMG signal characteristics changed. This was the first demonstration that back pain and fatigue resulted in a consistent change in muscle activation.

Andersson *et al.* (1979) contributed a major advancement to the application of EMG signal techniques in assessing paraspinal muscle function by (1) monitoring more paraspinal muscle sites (bilaterally in the thoracic and lumbar region), (2) carefully restraining the subject's posture during EMG signal

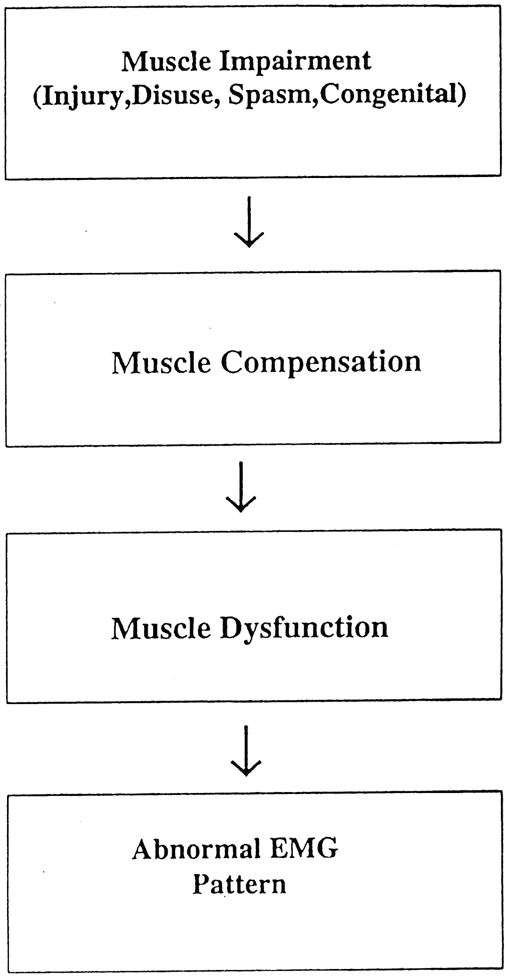

Figure 9.1 A diagram representing a proposed model of back muscle impairment that accounts for the changes to the surface EMG signals observed from lumbar paraspinal muscles. Muscle impairment from various types of LBP disorders result in the back muscles compensating for this impairment during a sustained contraction. Muscle compensation disturbs the normal functioning of back muscles which is measured as a change in EMG signal variables (either in amplitude or median frequency) detected from the lower back.

detection, and (3) measuring changes in EMG amplitude and spectral parameters concurrently during sustained contractions at different degrees of trunk flexion (from 10 to 50°). They observed significant EMG spectral shifts towards lower frequencies that were associated with increases in the EMG signal amplitude. Furthermore, they found that an increased level of EMG activity was always accompanied by a greater rate of decay of the EMG power spectrum.

Among the first to apply surface EMG techniques to compare back muscle fatigue in patients with LBP and controls, DeVries (1968a,b) showed that subjects who developed pain during a sustained trunk extension had a corresponding increase in EMG signal amplitude from the paraspinal muscles. In those subjects without pain, the EMG signal amplitude decreased. It was concluded by the authors that these differences in the characteristics of the EMG signal were indicative of the weakness and fatigue associated with LBP. Jayasinghe *et al.* (1978) conducted a similar study and confirmed these findings. Others have reported that patients with LBP develop more fatigue in their back muscles than controls, according to mechanical measures of endurance capacity (Jorgensen and Nicolaisen, 1987) and according to surface EMG spectral measurement (Roy *et al.*, 1989; Biedermann *et al.*, 1991; Klein *et al.*, 1991; De Luca, 1993b). Our group studied whether differences in fatigability between chronic LBP and control subjects were influenced by the force level of a sustained contraction and the muscle recording site (Roy *et al.*, 1989). Twelve patients with chronic LBP were compared to an equal number of control subjects. Median frequency measurements from six bilateral lumbar paraspinal muscles (the longissimus thoraces, iliocostalis lumborum and multifidus muscles at the L1, L2 and L5 interspinous lumbar levels) were analyzed during isometric trunk extension sustained at 40, 60, and 80% of MVC for a maximum of 1 min duration each. The median frequency slope (MF slope), a measure of the rate of change of the median frequency and an index of muscle fatigue (De Luca, 1985), was calculated for each EMG recording site using a linear regression interpolation procedure. The results (Figure 9.2) demonstrated that the MF slope was significantly higher (i.e. more negative) for patients compared to controls, but only for recordings from the multifidus and iliocostalis muscles corresponding to the 80% MVC contractions.

These findings demonstrated that median frequency measurements from back muscles are muscle specific and load dependent. Furthermore, they provided evidence that, to characterize paraspinal muscle function during sustained isometric tasks properly, several muscle sites are necessary. This recommendation may explain the poor reliability and conflicting data that have characterized previous attempts at studying back muscle function using only one or two electrode sites. The interpretation of these results from a physiological or biomechanical perspective was, however, less definitive. The higher fatigue rates in the LBP group may be explained by (1) either a greater proportion of type II muscle fibers (Jorgensen and Nicolaisen, 1987; Roy

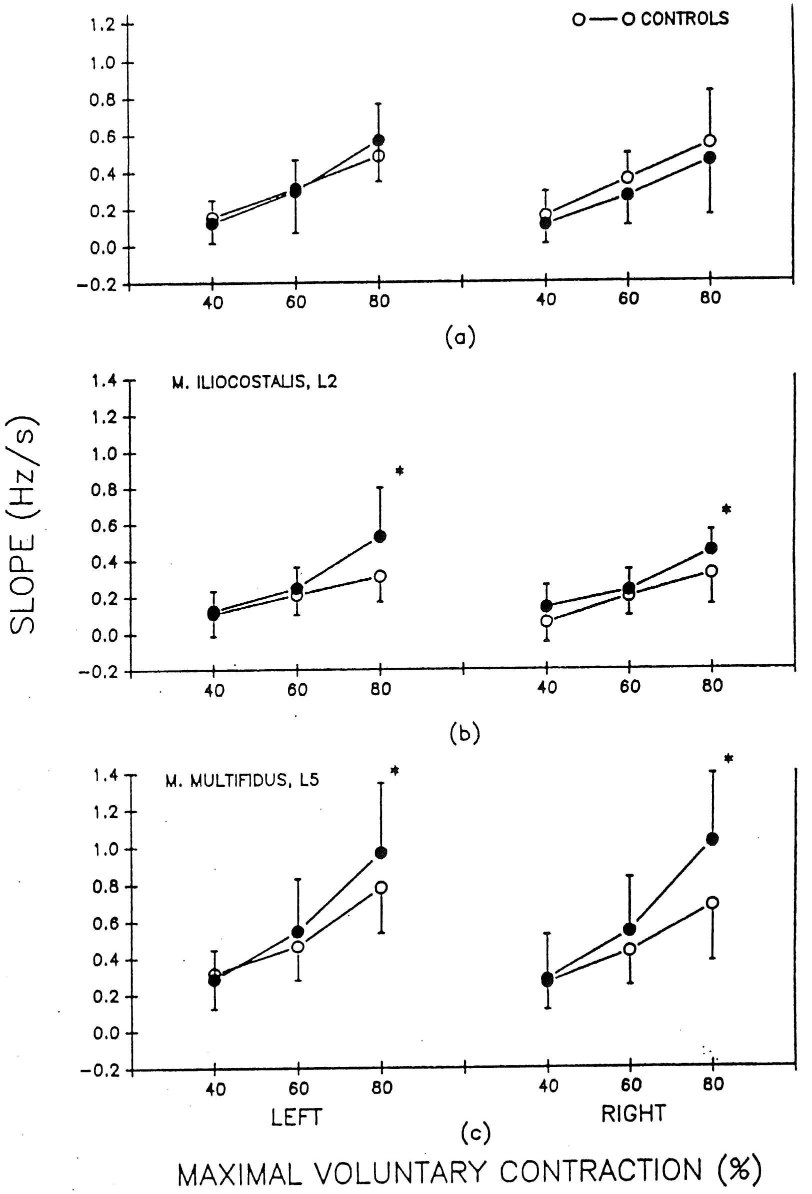

Figure 9.2 Mean values of the median frequency slope (Hz s^{-1}) for 12 patients with LBP (●) and 12 control subjects (○) tested at 40, 60, and 80% of MVC sustained for 60 s. Data is plotted separately for (a) the longissimus thoracis, (b) the iliocostalis lumborum, and (c) the multifidus muscles. In each figure, the results from the left and right side of the back are presented separately. $^*p < 0.05$ (with permission from Roy *et al.*, 1989).

et al., 1989, 1995; Biedermann *et al.*, 1991; Thompson *et al.*, 1992; Thompson and Biedermann, 1993), (2) a greater pre-contraction metabolite level resulting from persistent spasm (Armstrong, 1984; Roy *et al.*, 1989; Biedermann *et al.*, 1991), or (3) a redistribution of the loads among the various paraspinal muscles causing some muscles to fatigue more readily than normal (Roy *et al.*, 1989). The increase in the negative slope of the median frequency with increased force levels from 40 to 80% MVC is consistent with numerous similar studies from limb muscles which have argued that this effect results from an increased recruitment of type II fibers that are more glycolytic, and therefore contribute more metabolites to the muscle membrane environment (Basmajian and De Luca, 1985; De Luca, 1985).

Different strategies for utilizing EMG spectral measurements to evaluate paraspinal muscles were evaluated by Kondraske *et al.* (1987). Although their study did not include subjects with LBP, the issues raised are relevant to this application. They carried out a two-phase study in which phase I identified the most appropriate EMG measures of fatigue and phase II tested different normalization procedures for accommodating the effects of the absolute force level of the contraction on the median frequency. A test frame provided pelvic and lower limb stabilization and a visual feedback display was used to help produce isometric extension torques during standing. A number of relevant findings were reported and are summarized: (1) mean and median frequency results were comparable, (2) rate of spectral shift, although exponential, could be accurately measured by the slope of a linear regression line for a portion of the data, (3) maximum stabilization of the subjects posture and provision of force-feedback was highly recommended, and (4) target force levels based on percent body weight rather than % MVC was a more suitable method for normalizing muscle loads. Their last finding in this list raises an important question of whether it is appropriate to normalize contractions with respect to MVC when assessing paraspinal muscles. This question arises because the presence of LBP or fear of reinjury to the back might negatively influence the voluntary effort needed to produce a 'maximal' contraction. Biedermann (1990) has directly addressed this issue by implementing a technique in which subjects generate a constant load to the lower back by holding a specific absolute weight at arm's length for a prescribed duration. A reference frame was used to standardize the position of the subject's feet, pelvis, and spine. The reliability of the technique was evaluated in 31 subjects by having them perform the weight-holding test for 45 s and then repeating the test 5 days later (Thompson and Biedermann, 1993). The reliability of the EMG parameters from four bilateral lumbar sites was within an acceptable range ($r = 0.85$) according to calculations of a Pearson's correlation coefficient for the median frequency of the EMG signal. Similar reliability estimates have been reported for EMG parameters derived from contractions specified as a percentage of the MVC (Roy *et al.*, 1989). A further discussion of this issue is included later in this chapter where the influence of the MVC on classification techniques for muscle impairment is described.

9.6 APPLICATION OF EMG SPECTRAL TECHNIQUES TO LBP ASSESSMENT

9.6.1 Classification of Muscle Impairments

It has been suggested by several research groups that the analysis of paraspinal muscles using surface EMG spectral techniques may provide the clinician or occupational health professional with the following two requirements for a LBP evaluation procedure: (1) identification and classification of paraspinal muscle impairment and (2) monitoring changes of muscle impairment associated with treatment progression. With respect to the first requirement, it is often important to know more than if the back extensor muscles are functioning normally. Additional information is often needed to identify a specific type of impairment as well as the probability that the classification is correct. These additional features are important in maximizing the usefulness of the technique to planning treatment or modifying the work environment. Sometimes researchers overlook the requirement that a musculoskeletal assessment procedure should be of practical value for the intended user rather than just providing an abundance of objective data. One criterion of practicality is that the assessment results are interpretable to the user and are relevant to their particular area of interest. For example, a physical therapist should be able to use the EMG results to assist in the formulation of a back exercise program or to modify the physical demands of a particular work-site or job specification. Validated guidelines are still needed to bridge this gap between the data and how it should be interpreted to accomplish a particular objective. Techniques that produce volumes of objective data without suggesting a treatment plan are not ready for general use and should be considered only as investigative tools.

Although still in the early stages of development, there is evidence that surface EMG analysis techniques are effective in discriminating between LBP patients and control subjects. This indication is based in part on a series of four studies conducted using a device and technique referred to as a Back Analysis System (BAS®) (Roy *et al.*, 1989; Klein *et al.*, 1991; Roy, 1992; De Luca, 1993b), as well as from independent studies that have reached similar findings (Biedermann *et al.*, 1991; Thompson *et al.*, 1992). Details of the BAS system have been described previously (De Luca, 1993b); however the basic functional elements are depicted in Figure 9.3 and consist of (1) custom surface EMG electrodes having a specific architecture and electrical properties designed for the detection of EMG signals suitable for spectral analysis (De Luca *et al.*, 1979), (2) a muscle fatigue monitor which processes the EMG signals to obtain the EMG signal variables (Gilmore and De Luca, 1985, 1987), (3) a postural restraint apparatus which constrains the posture of the subject so that the measured force is related, as much as possible, to the force generated by the muscles being monitored, and (4) a software package to provide system calibration, monitor signal-quality, specify test configurations, organize the database, and analyze and present the results. The electrodes are

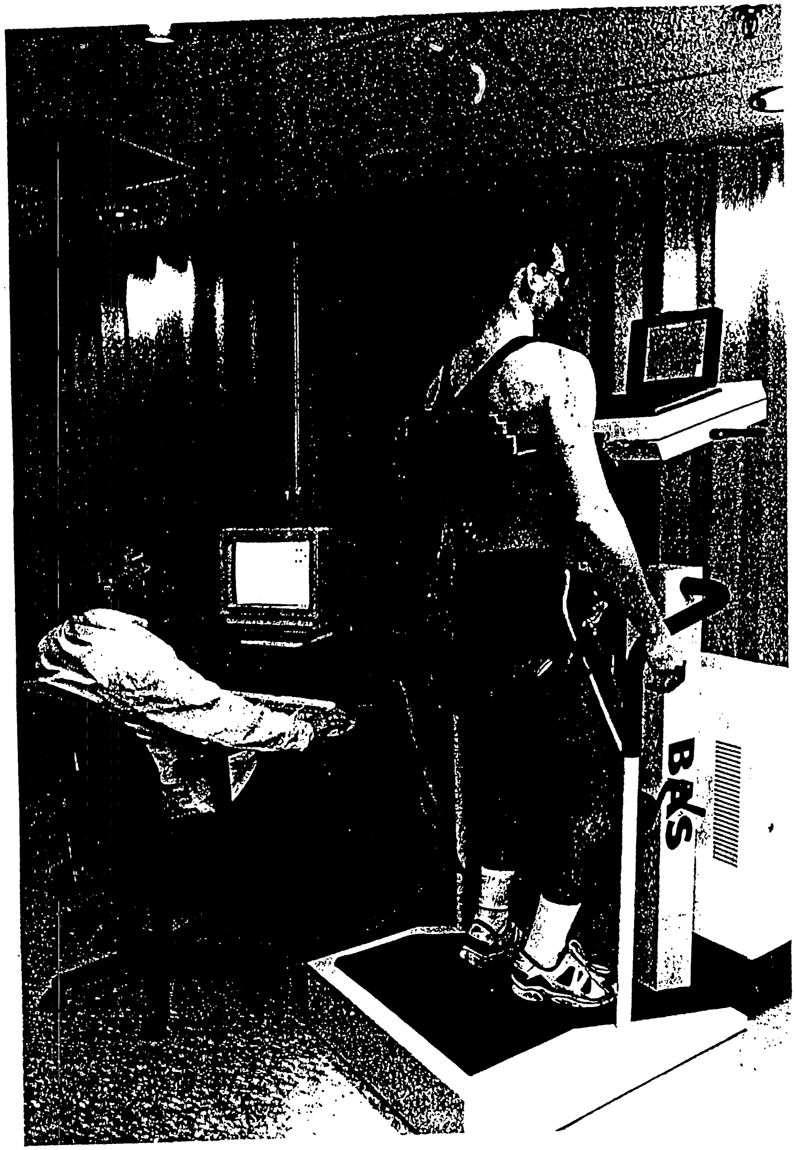

Figure 9.3 A photograph of a prototype Back Analysis System (BAS) used to acquire and process surface EMG signals and isometric trunk extension forces during various protocols designed to fatigue the lumbar paraspinal muscles. The subject is shown performing isometric trunk extension in an erect posture. The screen in front of the subject provides a visual display for feedback of the target force and the force they are producing during the task.

placed at six lumbar sites corresponding to specific superficial paraspinal muscle groups and the torso is immobilized to limit the extension task to an isometric contraction and to provide a means for standardizing the posture of the subject during the test. The restraint device also provides visual force feedback to limit contractions to constant force levels. These are important features to consider when conducting EMG spectral analysis because constant muscle length and tension are specified to insure signal stationarity (i.e. constant mean and variance) (Basmajian and De Luca, 1985; Merletti *et al.*, 1990). Studies in which EMG spectral parameters are derived from variable-force or dynamic contractions may be considered as methodologically flawed until more definitive analysis methods are available to identify stationary epochs within the data. Tests for EMG signal stationarity are under development (Bilodeau *et al.*, 1991; Franklin, 1993).

Most of our studies conducted to date on back muscles share similar protocols. A maximal voluntary contraction (MVC) is first obtained by selecting the highest force value from several attempts at producing a maximal trunk extension. One or more fatigue-inducing contractions are then sustained at a specified force level (typically 40, 60, or 80% MVC) and for a fixed time duration (typically 30 or 60 s). At least two median frequency parameters are calculated from each sustained contraction: (1) the median frequency slope (MF slope), defined as the coefficient of a linear regression fit by a least-squares procedure and (2) the initial median frequency (IMF), defined as the *y*-intercept of the linear regression used to derive MF slope. In some instances, the fatigue-inducing contraction is followed at exactly 1 min by a contraction of shorter duration (typically. 10 s) to derive a parameter to measure the amount of recovery of the median frequency (REC). Classification of subjects into 'LBP' and 'normal' groups are obtained by the use of a multivariate statistical procedure referred to as discriminant analysis (Zar, 1974). The procedure consists of developing a rule or 'discriminant function' based on the EMG median frequency measurements that best separates the subjects into their respective groups (i.e. the analysis maximizes the 'between-group variation' while minimizing the 'within-group variation'). Measurements from the LBP and control subjects (whose classifications are known *a priori*) comprise a 'learning set' to map the median frequency parameters from the six muscle sites into a single discriminant parameter which can then be used to make classification predictions. As a result, EMG measurements from future individuals whose LBP classification is not known *a priori*, can be predicted on the basis of the discriminant function from the learning set. The function is developed using a stepwise regression procedure to identify an optimal set of EMG parameters for discriminating 'normal' from 'LBP' groups. The stepwise regression procedure selects only those EMG variables that add to the discriminating ability of the function. Therefore, it is quite possible to start out with a dozen or more variables which can be reduced to a few discriminant variables for making the selection or classification. Another possible advantage of this technique is that in addition to providing a classification, the 'distance' of the discriminant function value from the cut-off point between one classification group and the other can also be plotted as Fisher *z*-scores. These scores can provide a measure of the strength of the classification prediction. Plots of *z*-scores are shown later in this section for clinical research results. A more detailed explanation of this procedure can be obtained in statistical textbooks that include multivariate regression analysis (Zar, 1974; Kleinbaum and Kupper, 1978).

The first of a series of case–control studies performed by our group evaluated male chronic LBP patients ($n = 12$; average duration of LBP = 5.2 years) and control subjects ($n = 12$) matched for age and height who had never experienced debilitating LBP (Roy *et al.*, 1989). Patients were not complaining of pain at the time of testing (i.e. they were in remission) and none had previous back surgery or radiological evidence of structural disorders of the spine. Tests were conducted at 40, 60, and 80% MVC. On the basis of the EMG parameters from the discriminant analysis functions, the test was able to identify the control subjects with similar high levels of accuracy (approximately 85%) for each of the three contraction levels (Table 9.1). The EMG variables selected by the discriminant procedure were primarily the initial median frequency from the L1 spinal level and the median frequency slope from the L2 and L5 spinal levels. These were the same parameters as those whose mean values were found to be significantly different between the LBP patients and controls (Figure 9.2). This study also demonstrated a higher percentage of correct classifications for analyses in which data from all electrode sites were included in the discriminant analysis rather than by treating muscle groups separately according to lumbar level. The results further support the recommendation that arrays of electrodes, rather than a few bilateral sites, provide the most accurate results for classification. The limited success and conflicting results of previous EMG studies may have been due in part to these factors. Earlier, three reasons were postulated for the altered fatigue characteristics of the lower back muscles.The results of this study excludes one of them – the one postulating a greater pre-contraction metabolite level resulting from persistent spasm.

Table 9.1 Results from discriminant analyses – all lumbar levels

Contractile level (% MVC)	Percent correct classification NLBP (n = 12)	LBP (n = 12)	Variables used in classification (in order)
40	92	82	(R)IMF, L1 (R)SLOPE, L2 (L)SLOPE, L2 (L)SLOPE, L1 (L)IMF, L2 (L)IMF, L1
60	67	75	(R)IMF, L1 (L)SLOPE, L1
80	84	91	(L)IMF, L1 (R)SLOPE, L5 (L)SLOPE, L5 (L)SLOPE, L2

(R), (L), right side, left side; L1, L2, L5, lumbar spinal levels; LBP, with low back pain; NLBP, without low back pain; IMF, initial median frequency; SLOPE, median frequency slope.

The successful implementation of the EMG signal procedures for chronic LBP subjects led us to the second in a series of investigations which utilized the technique to identify individuals with LBP ($n = 6$) within a population of elite athletes ($n = 24$) (Roy *et al.*, 1990). We were interested in determining whether athletes with LBP might still have muscular impairment associated with their disorder despite the fact that they were highly conditioned. The study addressed the larger question of whether different kinds of muscular disorders are present in LBP and whether they require separate discriminant functions. We speculated that there may be recognizable patterns of EMG signal disturbances among the various muscles being monitored for specific kinds of LBP disorders (e.g. acute versus chronic) or within specific populations of individuals (e.g. athletic versus sedentary). Twenty-three members of a men's collegiate varsity crew team ($n = 13$ port and $n = 10$ starboard rowers) were tested at 80% MVC × 30 s using the Back Analysis System. Recovery from fatigue was also included in the protocol and was analyzed as the percent recovery of median frequency at 1 min following the sustained contraction. This parameter, referred to as the median frequency recovery (REC), expressed the degree to which the median frequency returned to its baseline, pre-fatigued level as a result of the 1 min rest period. We speculated that the median frequency recovery parameter represented the ability of a muscle to recover from metabolite accumulation following strenuous exercise. The discriminant analysis resulted in 100% correct classification of the LBP rowers and 93% correct classification of non-LBP rowers (one false-positive classification). EMG variables selected by the classification function were primarily the median frequency recovery parameter from the L5 and L1 electrode locations. Interestingly, none of the parameters used to classify LBP and controls from our previous study on sedentary chronic LBP patients were selected by the discriminant analysis procedure to classify the rowers with LBP. This finding indicates that there are different muscle disorders associated with LBP for the sedentary and athletic populations studied. In the former group, the impairment was likely representative of deconditioning whereas in the latter, deconditioning and muscle disuse would be unlikely since these subjects continued their training and competitive rowing despite their LBP symptoms. The question remains, however, as to the nature of the muscle disorder represented by the EMG findings in the rower study. We have speculated that the differences in the median frequency recovery parameter may be related to the unique energy requirements of the sport of rowing. During competition, rowers quickly achieve a marked anaerobic response and must tolerate high levels of excessive lactate throughout the remainder of the race (Hagerman *et al.*, 1979). It is possible that the inefficient physiological removal of these high levels of lactate is a sequela of LBP in rowers. We also conducted a discriminant analysis between the port and starboard rowers in this study who load their back muscles asymmetrically by use of a single oar placed on either the port or starboard side of the hull. The test identified 100% of the port and starboard rowers correctly. The ability to identify muscle imbalances may have implications for ergonomic applications where chronic asymmetrical loading might also cause muscle imbalances.

A third study was conducted to compare EMG spectral methods of classifying LBP to standard clinical assessment procedures (Klein *et al.*, 1991). Twenty-five freshman sweep rowers were recruited for this study, eight of whom had a history of LBP (four chronic and four acute). None of the subjects reported pain during the test. Protocols similar to those described for previous studies using the Back Analysis System were conducted on all subjects. In addition, each subject was evaluated for trunk and spinal mobility. The clinical measurements consisted of maximal trunk extension strength and trunk range of motion (ROM) for forward, backward, and lateral bending, as well as trunk rotation. The discriminant analysis identified 88% (seven out of eight) of the patients with LBP and 100% (nine) of the subjects without LBP. In contrast, the conventional clinical tests were less accurate: identifying 57% (four out of seven) of the patients with LBP and 67% (10 out 15) of the subjects without LBP. The high sensitivity and specificity of the EMG procedure suggests that the technique may be superior to conventional clinical measures of trunk mobility and strength for LBP screening or identification of muscle impairment. No comparisons of this kind have been reported for populations of workers and therefore we cannot extrapolate these results to other populations.

The most recently published work from this series of investigations addressed many of the limitations of previous studies (Roy *et al.*, 1995). Most of the prior studies had been limited to evaluating relatively young, 'white-collar' males with non-specific spinal disorders. The yet to be confirmed applicability of the technique to the population at large, particularly among 'blue-collar' manual laborers at risk of LBP needed to be addressed. In addition, until this particular study, classification results had only been reported for subjects whose EMG data was included in the original formulation of the discriminant function. A total of 92 patients with chronic LBP and 52 control subjects with no history of debilitating LBP were studied. Many of the clinical characteristics of the patient population in this study were different from previous studies. Most of the patients had either a verified herniated disc or spinal surgery, conditions which were excluded in our previous studies. Secondly, we did not limit our selection of subjects in the present study to patients in remission from pain, as was also previously specified in other studies (Roy *et al.*, 1989). All of the patients tested described pain localized to the lumbar region and most were unable to produce a normal MVC. Patients were tested immediately prior to their entry into an occupational rehabilitation center where they participated in a full-time, multidisciplinary work hardening program for a 30 day period. Subjects were divided into a 'learning sample' and a 'holdout sample' of LBP and normal groups (Table 9.2). The learning sample was used to formulate the LBP discriminant function and then this function was used to classify the holdout sample. The discriminant function selected the initial median frequency and median frequency slope parameters from the L1 electrode site, and the initial median frequency from the three left lumbar sites to classify 85% of patients with LBP and 86% of control subjects for the learning set correctly (Figure 9.4).

Fisher discriminant function values or *z*-scores, representing the distance from the group classification cut-off point, are displayed for each of the LBP

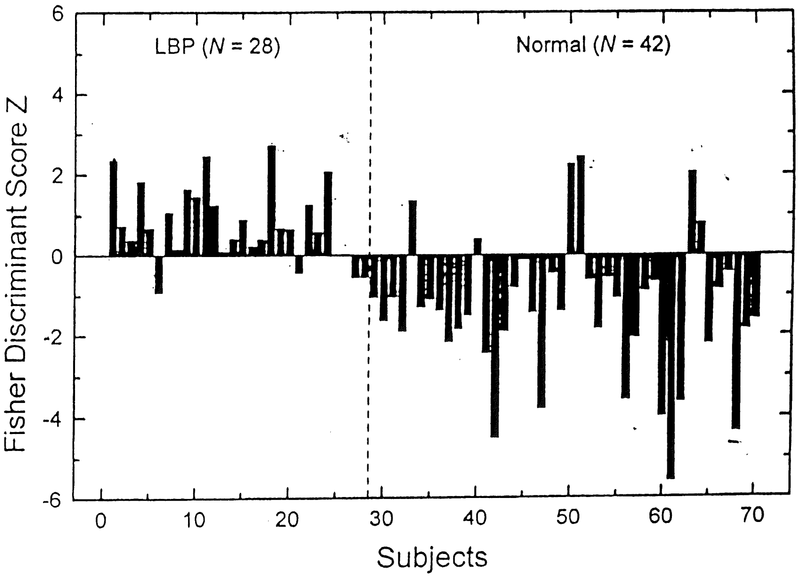

Figure 9.4 Fisher discriminant function scores (z-scores), a measure of the distance from the classification cutoff point, are presented for each of the LBP (n = 28) and control (n = 42) subjects that formed the 'learning set' for the discriminant function. A positive score indicates a LBP classification, a negative score indicates a normal classification. Subjects are divided along the x-axis according to those that are known *a priori* to be LBP or normal. Incorrect classifications are identified in the lower left quadrant for LBP subjects (four false-negative scores) and the upper right quadrant for normal subjects (six false-positive scores) (with permission from Roy *et al.*, 1995).

Table 9.2 Characteristics of subjects – mean values (SD)

	LBP (n = 28)	Normal (n = 42)	LBP (holdout) (n = 57)	Normal (holdout) (n = 6)
Age (years)	35.3 (8.9)	26.7 (5.2)	37.1 (8.9)	23.8 (2.5)
Height (m)	1.8 (0.1)	1.8 (0.1)	1.8 (0.1)	1.8 (0.1)
BMI (kg m^{-2}	27.0 (4.6)	23.0 (2.5)	27.4 (5.0)	25.7 (3.7)
Weight (kg)	84.2 (16.2)	70.5 (9.7)	86.4 (19.0)	81.4 (11.1)
MVC (lbs)	140.7 (57.0)	184.8 (73.0)	120.5 (70.5)	241.3 (77.5)
Surgery (%)	43	–	1	–
HNP (%)	75	–	27	–
Duration LBP (months)	26.3 (31.4)	–	15.2 (12.2)	–

LBP, low back pain; HNP, herniated disc; BMI, body mass index; MVC, maximal voluntary contraction.

control subjects. The four LBP subjects identified in the figure with a negative *z*-score represent false-negative classifications whereas the six normal subjects with a positive *z*-score represent false-positive classifications. The classification results were independent of the subject's ability to exert a maximal extension because the stepwise discriminant analysis procedure rejected an attempt to include MVC into the classification function. In other words, forcing MVC into the function did not change the accuracy of the classification. This implies that the discriminating power of the EMG spectral parameters was not simply a manifestation of the fact that patients with LBP had lower MVC values than the normal population.

The classification function performed as well among the holdout sample as it did for the learning sample with 88% of LBP patients and 100% of normal subjects correctly classified (Figure 9.5). The relatively high levels of correct classifications in this study cannot be explained as a consequence of the stepwise regression overfitting the model. The size of our sample population should have been adequate to avoid overfitting the data because it was approximately 14 times the number of EMG parameters used (Zar, 1974). The favorable classification results among the holdout sample further dispels the likelihood of overfitting and demonstrates that the test was highly sensitive and specific for a population that was not included in the initial learning set. Unfortunately, few if any procedures used to classify muscle function have demonstrated the sensitivity and specificity of their measures beyond those of the sample comprising the learning set (Newton and Waddell, 1993). Although there is no way of verifying this interpretation at this time, it has been suggested that the discriminant parameters based on median frequency measures differed between patients and controls as a result of a different pattern of muscle activation and load sharing between the different paraspinal muscles in response to pain or fear of reinjury (Roy *et al.*, 1989; Thompson *et al.*, 1992; De Luca, 1993b).

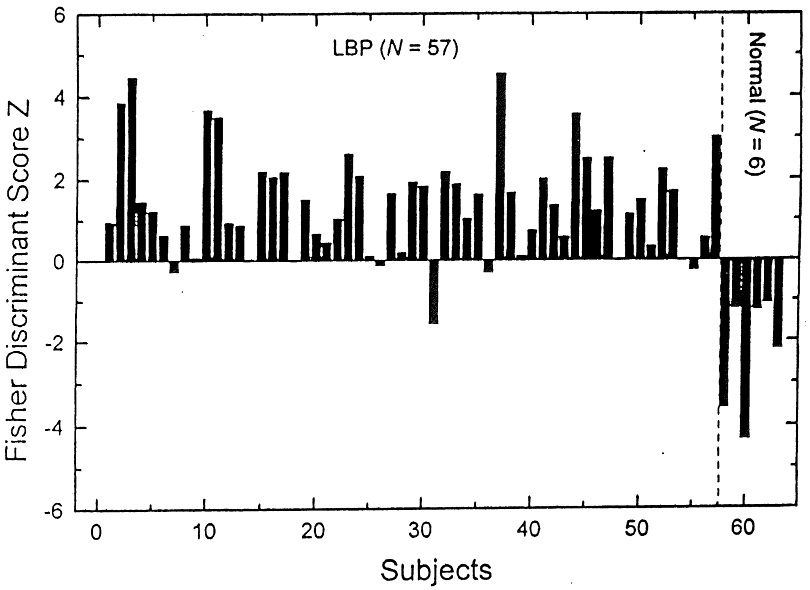

Figure 9.5 Fisher discriminant function scores (z-scores), a measure of the distance from the classification cut-off point, are presented for each of the LBP (*n* = 57) and control (*n* = 6) subjects that formed the 'holdout sample' for the discriminant function. A positive score indicates a LBP classification, a negative score indicates a normal classification. Subjects are divided along the *x*-axis according to those that are known a *priori* to be LBP or normal. Incorrect classifications are identified in the lower left quadrant for LBP subjects (five false-negative scores) and the upper right quadrant for normal subjects (zero false-positive scores) (with permission from Roy *et al.*, 1995).

Although few in number, other relevant reports in the literature describe the ability of EMG spectral techniques to identify and classify back muscle disorders. Biedermann *et al.* (1991) tested 22 healthy subjects and 24 patients with chronic LBP. Of particular interest was the method used to fatigue the back extensor muscles and the ability of median frequency parameters to distinguish between 'pain behaviors' in the LBP group. The technique employed a weightlifting procedure to produce a paraspinal contraction of constant isometric force and avoid the need to rely on an MVC determination. Each subject was asked to hold a barbell, which had two 5 lb weights attached symmetrically about its center, with both arms outstretched at 90° degrees of shoulder flexion. The subjects held the weight for a 45 s period while standing in a test reference frame which reliably positioned the feet, pelvis, and spine. Four surface electrodes were used to monitor EMG signals bilaterally from the iliocostalis lumborum muscle at the L2–L3 interspinous level and the multifidus muscle at the L4–L5 interspinous level. In addition to the 'normal' category, LBP subjects were divided into a physically-active or 'confronter' group, and a physically-passive 'avoider' group on the basis of their response to a pain behavior checklist (Zarkowska, 1981). It was postulated that these categories reflected the clinical observation that some patients remained very active despite their reported back problems, whereas others tended to avoid physical and social activities as much as possible to protect their painful condition. The discriminant analysis procedure resulted in 89% correct classification of the avoider LBP group (eight out of nine). There was considerable overlap however between the confronter LBP group and normals. These two populations were essentially categorized as one group. Only 8% (three out of 37) of the normals and confronters were misclassified as belonging to the avoider LBP group. Median frequency parameters similar to the median frequency slope and initial median frequency were selected as discriminant parameters, but only from multifidus muscle sites. Generally, the avoiders LBP group had greater spectral changes toward lower frequencies which were interpreted as an indication that physically passive LBP patients had more fatigable paraspinal muscles. This finding is consistent with earlier results on chronic LBP patients who had similar strength but higher fatigue as compared to controls (Jorgensen and Nicolaisen, 1987; Roy *et al.*, 1989).

9.6.2 Monitoring Treatment Progression

Independent reports by others lend support to the suggestion that the surface EMG technique can be useful as an objective, non-invasive measure of LBP treatment outcome. The physiological basis for this application of the technique is based in part on the effect that muscle adaptation has on muscle fiber conduction velocity and, hence, EMG power spectral parameters. Although the sensitivity of the technique to paraspinal muscle adaptations has not been demonstrated in a well-designed prospective study, there is sufficient experimental support to consider this likelihood. This evidence has been related to the following two mechanisms which have been shown to be sensitive to changes in muscle use: (1) conduction velocity and median frequency parameters are related to muscle fiber diameter, particularly in fast fibers (De Luca, 1985; Roy *et al.*, 1994) and (2) the conduction velocity and median frequency are related to intramuscular H^+ (De Luca, 1985; Brody *et al.*, 1991; Roy, 1993b) and extracellular K^+ (Juel, 1986), two metabolites that can change with muscle adaptation (Booth, 1987). Directed studies have also related muscle training and/or differences in muscle fiber type to conduction velocity and EMG spectral parameters (Sadoyama *et al.*, 1988; Thompson, *et al.*, 1992, Thompson and Biedermann, 1993; Roy *et al.*, 1994).

Retrospective and prospective EMG studies have been conducted to evaluate the influence of activity and training on back muscle function in normal and LBP subjects. Power spectrum analysis has been used in normal (pain-free) subjects to examine differences between those that are physically active from those that are sedentary (Biedermann *et al.*, 1991). Active subjects had a reduced fatigue rate, as measured by the change in the median frequency from the iliocostalis muscle during a weightlifting task. These same subjects had greater left–right side variability of the initial median frequency as well. However, the retrospective study design could not determine the sensitivity of the EMG spectral parameters to training or even whether these differences were the result of training or the result of pre-existing characteristics. A more recent prospective study has been reported (Moffroid *et al.*, 1993) examining the sensitivity of the EMG power spectrum analysis to the effects of a training program for paraspinal muscles. Healthy female subjects ($n = 28$) were randomly assigned to groups which (1) maintained their previous lifestyle or (2) completed a series of isometric back exercises twice daily, for 6 weeks. Subjects were tested before and after the intervention using a Sorenson test in which the endurance time and EMG median frequency from the L3 lumbar level were measured while the subject maintained a prone trunk extension with only the lower limbs and pelvis supported. The results indicated that while trained subjects showed a significant improvement in the endurance time, they did not change on any of the spectral parameters (initial median frequency and median frequency slope). A number of methodological limitations have been pointed out by others (Thompson *et al.*, 1992; Thompson and Biedermann, 1993) concerning the acquisition of the EMG signals in this study. Most of the criticism relates to the placement of the EMG electrodes which did not correspond to any specific muscle and did not take into consideration muscle fiber orientation. The interelectrode spacing of 25 mm was questioned as being too large to provide proper muscle localization. The authors of the study provided their own explanation for the lack of EMG sensitivity to training. They suggested that the lack of change in the initial median frequency and the median frequency slope could have been caused by the training program being too brief and not specific to reducing muscle fatigue. The training may have also improved the endurance of the hamstring and glutei muscles, which contribute significantly to back extension tasks such as the Sorenson test (Jones *et al.*, 1988; Pollock *et al.*, 1989).

In another training study, the EMG median frequency of the multifidus and iliocostalis muscles were compared to adaptive changes associated with physical training in normal subjects using a test–retest experimental design (Thompson *et al.*, 1992). Sedentary women were randomly assigned to a control group ($n = 24$) or a 1 h fitness class, three to five times per week for 12 weeks (exercise group, $n = 22$). In addition to monitoring the EMG median frequency from four lumbar paraspinal muscles during a 45 s weight-holding task, the investigators also measured several physical fitness parameters for aerobic capacity, back muscle strength, and back flexibility. Various anthropometric measures were also included. Only two EMG parameters meeting an acceptable level of reliability were included in the analysis. They were the initial median frequency (IMF) defined previously in this chapter and an adjusted fatigue parameter (FTG) defined as the decline in the median frequency over the trial, adjusted by arm length, because the fatigue of the back muscles during a constant force contraction is known to be affected by the distance of the weight from the body (Biedermann, 1990). Parameters first considered but eventually excluded from further analysis because of poor reliability were parameters measuring recovery of the initial median frequency after a second trial, and the absolute left–right difference in the initial median frequency from the contralateral back muscles. The results described significant improvements in aerobic capacity, back strength, and flexibility following training with no comparable changes in the control group. EMG power spectrum parameters were also responsive to training. For the exercise group, the FTG showed a significant reduction (approximately 35%) from pre- to post-test, being significantly lower than that of the control group at post-test. Interestingly, the same parameter from the iliocostalis muscle did not change with training.

The authors explained the differential response between muscle groups as possibly representing the different demands placed on these muscle groups by the specific exercises of the fitness class. The changes in the FTG associated with training were explained by improvement in the oxidative capacity and oxygenation of the muscle, which were confirmed indirectly. The analysis did not find a significant change in the initial median frequency with training, however the initial median frequency from the multifidus muscle decreased at a near significant level ($p = 0.06$). The observed change in the initial median frequency was explained on the basis of disuse atrophy producing smaller diameter muscle fibers and therefore correspondingly lower values of conduction velocity and median frequency. This finding and interpretation are consistent with previous results of our studies which compared patients with chronic LBP with controls (Roy *et al.*, 1989). In addition, the data were analyzed further to determine if there was a relation between changes in fitness parameters and changes in EMG median frequency parameters since both were responsive to training. However, the results did not identify a significant overall relationship between these two sets of parameters probably because both measures are indirect and the underlying physiological adaptations were specific to the muscles involved in the test.

In a similar study, without controls, a group of LBP patients participating in a back-care exercise and education program were assessed (Thompson *et al.*, 1992). The subjects were middle aged, non-obese males and females, employed or retired, with chronic LBP with episodic remissions and recurrences, sometimes necessitating time off from work. They completed EMG and fitness assessment as described above for the training/control study, before and after participating in 20 1 h classes over a 10 week period. The exercises consisted of progressive extension and flexion strengthening and flexibility exercises and low-intensity aerobic activities (mostly walking) at home. The results were a significant improvement in back flexibility but no significant improvement in aerobic capacity or lifting strength. Concomitantly, there was a substantial reduction in the median frequency fatigue parameter

(FTG) in both muscle groups following training. In fact these differences in the median frequency resulted in a reclassification of patients from 'inactive LBP patient' to 'normal control' on the basis of the discriminant function from a previous diagnostic study (Biedermann *et al.*, 1991). There was also a small, but non-significant, increase in the multifidus initial median frequency. Because of the small sample size, no analysis was conducted on the possible relationship between fitness and median frequency changes with training. These results confirm that EMG spectral measurements of back muscles are sensitive to training effects, not only in healthy subjects, but also in patients with LBP.

Mayer *et al.* (1989) used EMG spectral analysis for fatigue assessment in normal subjects and deconditioned patients. Ten industrial workers undergoing functional restoration for chronic disabling spinal disorders and 11 healthy volunteers were tested by monitoring the changes in the EMG mean frequency during a Roman Chair exercise. This exercise is similar to the Sorenson test described earlier in this chapter. Subjects were required to complete two successive sessions of ten trials where each trial consisted of 15 s of unsupported trunk extension followed by 10 s of rest. The slope of the decline in mean frequency was significantly greater (i.e. more negative) in LBP subjects at initial testing than either normal subjects or back pain subjects after reconditioning. These findings indicated that the EMG spectrum shifted further and recovered more slowly for LBP patients compared to normals, and that muscle reconditioning can result in a more normal fatigue response as measured by the EMG spectral parameter. The results of this study were less successful in demonstrating consistency between the spectral parameter estimate of fatigability and actual endurance. This unexplained discrepancy, as well as other issues raised by the authors relating to the validity of the EMG fatigue index and its reliability, were discussed in terms of the applicability of the technique as a clinical assessment procedure (Standridge *et al.*, 1988). The problems identified by these investigators could be related to the protocol they used. Repeated duty cycle contractions can be notoriously unstable in terms of EMG spectral estimates because of poor signal stationarity resulting from length and force changes in the muscle and significant disturbances to muscle blood flow (De Luca, 1985). During static isometric contractions constrained to a constant force level, the EMG signal is more stable. Although more work is needed, the relationship between changes in EMG spectral parameters and the loss of force-producing capability in muscles have been studied in lower back muscles. A recent study by Mannion and Dolan (1994) reported significant correlations between median frequency parameters and trunk extension endurance during static paraspinal muscle contractions.

Other studies have evaluated the usefulness of surface EMG procedures for evaluating work-related LBP in patients undergoing multidisciplinary rehabilitation (Roy *et al.*, 1995). Twenty eight-patients (24 males and four females) with a history of chronic LBP and clinical evidence of mechanical strain or sprain were tested using the Back Analysis System just prior to and immediately following their participation in a multidisciplinary functional restoration program for work-related back injuries. Twelve of the patients with LBP had prior back surgery for a decompression laminectomy, the average duration of LBP syndrome was 26.3 months, and all complained of debilitating LBP in the lumbar region. Subjects participated in the rehabilitation program for an average of 40 h per week according to a fixed schedule that included physical therapy, occupational therapy, circuit weight training, work-hardening, back pain school, and psychological counseling. Baseline EMG testing was conducted during trunk extension sustained at 40 and 80% MVC for 30 s. Although the MVC value was reassessed at follow-up, the sustained contractions requested at follow-up were specified at 40 and 80% of the baseline MVC. In this way, any EMG changes in fatigability would be independent of differences associated with muscle force. Data acquired before and after the rehabilitation program were analyzed using a repeated-measures, four-way ANOVA to study the influence of the following main effects on the initial median frequency and median frequency slope parameters: time (pre-and post-rehabilitation), % MVC (40 and 80%), lumbar level (L1, L2, and L5), and lumbar side (left and right). The ANOVA results indicated that the median frequency slope significantly changed ($p < 0.05$) in a manner consistent with improved muscle fatigability (i.e. the median frequency slope was less negative) in patients with LBP undergoing rehabilitation. Because no pain was reported by the patients and no change in the amplitude of the signal was observed following training, it was speculated that training resulted in a change in the muscle's production and/or elimination of metabolites during the contraction rather than a redistribution of muscle forces among the different muscle groups. Changes in the median frequency slope following rehabilitation were not significantly influenced by test protocol factors such as electrode location or the % MVC of the trial. The only main effect from the ANOVA analysis of the initial median frequency and median frequency recovery was between lumbar levels ($p < 0.05$). Similar findings have been explained on the basis of possible fiber type differences between the different erector spinae muscles (Biedermann *et al.*, 1991; Thompson *et al.*, 1992). Because the MF slope differed significantly between patients and normals ($p < 0.05$) as well as when comparing baseline to post-rehabilitation trials ($p < 0.05$), the ANOVA analysis for the MF slope was repeated with the baseline MVC as a co-variate. The results demonstrated a significant interactive effect for time (pre- and post-rehabilitation) and MVC ($p = 0.03$). This interactive effect is plotted in Figure 9.6 and demonstrates that patients with a low baseline MVC had the most 'improvement' in the median frequency slope. Interestingly, it was also found in this study that patients with a history of previous back surgery did not 'improve' their median frequency slopes as much as those without previous surgery. The surgical history in this instance was decompression laminectomies for herniated discs, all from posterior approaches in which muscle fibers could have been damaged.

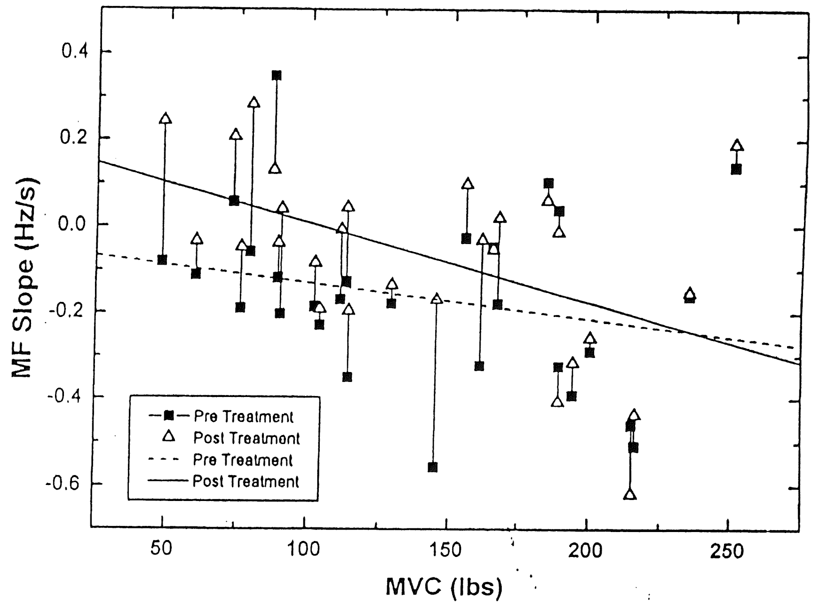

Figure 9.6 The interactive effect of baseline MVC and time (pre- and post-rehabilitation) on MF slope is depicted. The mean MF slope (all electrode sites and % MVC trials) for pre-rehabilitation [■] and post-rehabilitation [△] are connected for each individual patient. The MF slope is plotted according to the baseline MVC for each patient. Least-squares linear regressions are displayed separately for pre- and post-rehabilitation data points (with permission from Roy *et al.*, 1995).

Adaptive change following exercise, producing such effects as muscle hypertrophy and changes in muscle bioenergetics, have been associated with median frequency parameters (Thompson *et al.*, 1992; Roy, 1993a; Thompson and Biedermann, 1993), in back muscles as well as other muscle groups. Other than the study by Mayer *et al.* (1989) already mentioned, only one other independent group has reported changes in EMG spectral parameters in back muscles following exercise. Thompson *et al.* (1992) compared sedentary women without LBP participating in a 12 week fitness class to a second group consisting of LBP patients participating in a 10 week back-care exercise program. The results in both study groups indicated that the median frequency decreased by a lesser amount during an isotonic, isometric task when trials conducted at baseline were compared to similar trials at the end of training. The reduced decrement of median frequency during the fatigue-inducing task was evident in both the multifidus and iliocostalis muscles for the LBP group, whereas this effect was only present for the multifidus muscles in the non-LBP group. LBP patients also presented with a significant increase in the initial median frequency parameter following the training period. These results are fully consistent with our own results reported earlier (Roy *et al.*, 1995). Although this study documented that the intervention resulted in concurrent improvements in muscle strength, endurance and flexibility, we are still left without definitive evidence identifying a specific physiological adaptation with the changes in the EMG parameters. For this to be clarified, *in vitro* models will need to be conducted to clarify these points.

Although it can be appreciated from this brief overview of surface EMG signal analysis of paraspinal muscles that much has been gained by this relatively new science, much remains to be developed before we can fully realize the potential benefits of the described technique. Specialists in the field of ergonomics and their clinical colleagues in occupational and physical therapy have begun to incorporate some of these techniques in their research and/or clinical practice. Many more have likely considered its use but are hesitant because of their unfamiliarity with the technical and procedural aspects of the technique. The routine use of surface EMG techniques in clinical practice will be achieved when technological advances are combined with the guidelines set forth by clinical research.

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