

## CLINICAL INVESTIGATION

# Fatigue, recovery, and low back pain in varsity rowers

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### ABSTRACT

ROY, S. H., C. J. DE LUCA, L. SNYDER-MACKLER, M. S. EMLEY, R. L. CRENSHAW, and J. P. LYONS. Fatigue, recovery, and low back pain in varsity rowers. *Med. Sci. Sports Exerc.*, Vol. 22, No. 4, pp. 463-469, 1990. The purpose of this study was to determine whether surface electromyography (EMG) from the erector spinae muscles could correctly identify individuals with low back pain within a population of elite athletes. A similar technique had previously been successful in identifying low back pain patients within a non-athletic population. A Back Analysis System was used to compute the median frequency of the EMG power density spectrum to monitor metabolic changes in back muscles associated with muscle fatigue. Twenty-three members of a men's collegiate varsity crew team consisting of port ( $N = 13$ ) and starboard ( $N = 10$ ) rowers were tested in a laboratory during a fatigue-inducing isometric contraction sustained at a relatively high, constant force. Six of the rowers tested were further classified as having low back pain. A brief test contraction was repeated at a fixed interval following the fatiguing contraction to monitor recovery. A two-group discriminant analysis procedure correctly classified 100% of the rowers with low back pain and 93% of the rowers without back pain on the basis of the median frequency data. The median frequency parameters related to recovery were the best discriminators of back pain. A similar analysis correctly classified 100% of the port rowers and 100% of the starboard rowers on the basis of their spectral parameters. The best discriminating variables in this instance were the median frequency parameters relating to both fatigability and recovery. Results from this study demonstrate that low back pain and asymmetrical muscle function in rowers can be assessed on the basis of EMG spectral analysis.

ELECTROMYOGRAPHY, MUSCLE FATIGUE, RECOVERY,  
MEDIAN FREQUENCY, ROWING, LOW BACK PAIN

Rowing is considered to be among the most physically demanding of all endurance sports (9). The biomechanical demands of the rowing stroke and the rigorous nature of the associated training produce repeated forces of high magnitude to the lower back extensor muscles (13,15). These forces can be excessive and induce a back injury, particularly when fatigue impairs the contractile ability of the muscle (13,15). As

a result, many rowers suffer from recurring episodes of lower back pain (LBP) despite their high level of physical conditioning.

Recent studies indicate that nonspecific, nonstructural LBP can be associated with excessive back muscle fatigue (19). Advances in surface electromyography (EMG) have prompted a renewed interest in examining the fatigue properties of back muscles. Recently, an assessment tool called the Back Analysis System (BAS) was developed in our Center to objectively measure localized back muscle fatigue on the basis of EMG signal analysis (19). An integral component of this system is the Muscle Fatigue Monitor (MFM), a signal processing device that provides a computer-assisted method of quantifying changes in the EMG signal associated with muscle fatigue. The MFM tracks the median frequency (MF), or midpoint, of the EMG power density spectrum in real time (7). Localized muscular fatigue is measured as a decrease in the MF parameter during a sustained contraction (2,11,16). The biochemical processes that occur at the level of the muscle tissue result in the formation of acidic end products which decrease the conduction velocity of the muscle fiber action potential along its membrane (12). The resultant decrease in conduction velocity is associated with a compression of the EMG spectrum to lower frequencies, which, in turn, can be measured as a time-dependent decrease of the MF (5). Other factors such as the discharge properties and recruitment of motor units have also been proposed to account for the frequency shift of the EMG signal (2). The predictable decrease in the MF has been operantly defined to be an objective fatigue index (2). Consequently, muscle fatigue is modeled as a time-dependent process related to biochemical events rather than as the more popular method of identifying a single point in time wherein contractile failure occurs.

In the present study, we have continued the implementation of the EMG spectral analysis technique to determine whether this objective measure of muscle performance could effectively discriminate between LBP patients and a pain-free control group among an athletic population. Specifically, we tested the hypothesis that the EMG back analysis technique could identify painful and pain-free rowers on the basis of the EMG spectral parameters. If muscle function is abnormal in rowers with LBP and this abnormality can be objectively measured, then the technique may be of practical value as a screening tool or treatment outcome measure for LBP. Since rowers who use only one oar (sweep rowers) may have asymmetrical muscle development corresponding to their rowing side (port vs starboard), we also tested the hypothesis that EMG spectral parameters could discriminate the port from starboard rowers. This analysis would help to confirm whether the EMG parameters are also sensitive to the unilateral exercise effect of sweep rowing.

## METHODS

Twenty-three rowers from the Boston University men's varsity crew team were recruited for this study. All rowers competed in sweep crews of eight over a racing distance of 2000 m. Each rower signed a written informed consent prior to participation. All testing was conducted at the NeuroMuscular Research Center, Boston University, during the team's off-season months, October through December. Subjective LBP history, specific training regimen, physical descriptive data, and trunk range of motion (ROM) were recorded for each subject. In addition, the subjects completed an abbreviated McGill pain questionnaire to indicate the level of pain experienced on the day of testing (14). To be classified as having LBP, a subject must have reported a single or recurring incidence of LBP during the past year which interfered with activities of daily living (ADLs), including rowing or training activities. Six of the rowers were classified as having LBP. One had a grade II spondylolisthesis, whereas the remainder were classified as described by Snyder-Mackler (20) as having discogenic ( $N = 1$ ), muscular ( $N = 3$ ), and hypomobility/hypermobility ( $N = 3$ ) problems.

To determine electrode placement, motor points were first identified in the lumbar region of the back using low level (1–5 mA) pulsed electrical stimulation. Six active bipolar surface electrodes, similar to those described by De Luca et al. (3), were positioned bilaterally on the longissimus thoracis muscle at L1 spinal level, on the iliocostalis lumborum muscle at L2 spinal level, and on the multifidus muscle at L5 spinal level (Fig. 1). Care was taken not to place the EMG electrodes on the identified motor points to avoid unwanted signal effects related to the innervation zone of the muscle

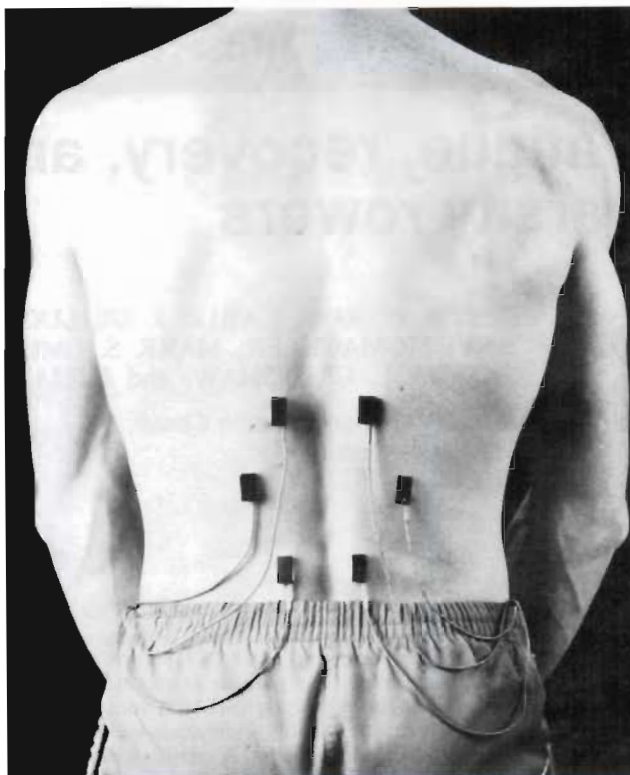


Figure 1—A typical location of six EMG surface electrodes is shown corresponding to the approximate bilateral locations of longissimus thoracis (L1), iliocostalis lumborum (L2), and multifidus (L5) muscles. (From Roy et al. (19), with permission.)

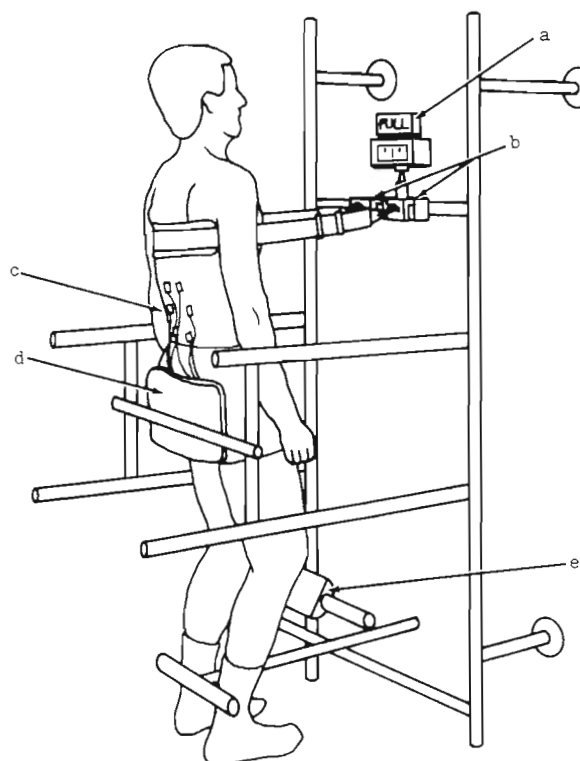


Figure 2—The postural restraint device and force acquisition system of the Back Analysis System (BAS). a: zero null meter for visual feedback of forces; b: two load cells to measure external extension force of trunk; c: six surface EMG electrodes; d: posterior ischial support (anterior support not shown); e: patellar tendon support.

(18). The electrodes were aligned so that the parallel detection surfaces were approximately perpendicular to the muscle fibers. Electrodes have a gain of 10 and a -3 DB bandwidth of 20-550 Hz, with a rolloff of 12 DB per octave.

Subjects were then positioned in the postural restraining device (Fig. 2). Specially contoured, adjustable front and rear restraining pads held the subject securely in a slight posterior pelvic tilt with the knees in approximately 20° flexion. The patellae and Achilles tendons rested on pads to provide points of leverage and partial weight bearing during the test contractions. A padded nylon harness was positioned across the scapular region of the back and attached to two Interface SM 500 force transducers (Interface Inc., Scottsdale, AZ) to record the net force generated during the isometric test contractions. The transducers have a dynamic range of 2224.6 N (500 lb) and a compliance of 0.28  $\mu\text{m} \cdot \text{N}^{-1}$ , and their output was amplified such that it was calibrated to 1 V = 444.8 N (100 lb). Differences in the force measurements from the two load cells provide a measure of the degree to which a test trial resulted in a symmetrical pull. Unequal force measurements from the load cells can result when the subject either leans to one side or rotates his trunk.

Each subject was given instructions for the proper technique of extending his trunk against the nylon strap to produce an isometric contraction of his back extensor muscles. The test procedure consisted of the following isometric contractions:

1. a 5 s maximal effort contraction to determine force output (MVC);
2. a 30 s contraction at 80% MVC to induce fatigue in the lower back extensor muscles; and

3. following 1 min of rest, a 5 s contraction at 80% MVC to monitor recovery from fatigue.

For the fatigue and recovery contractions, visual force feedback was provided by an analog null meter that was set to the appropriate MVC level to be maintained by the subject (Fig. 2).

The six channels of EMG signals were further amplified to achieve an output of approximately 1 V peak-to-peak. Data were recorded for further analysis on a multi-channel data recorder at a tape speed of 4.8  $\text{cm} \cdot \text{s}^{-1}$  to provide a bandwidth of 1.25 kHz. The EMG data were individually processed using the MFM to compute the MF of the signal. This parameter and the force data were further amplified and simultaneously digitized. A sampling rate of 100 Hz was selected to satisfy the Nyquist criterion since the fluctuations of the MF and force were below 40 Hz. The digitized MF records for each of the six electrode locations were simultaneously plotted as a function of time (Fig. 3). Several parameters were extracted from these data for further statistical analysis. They included the following:

1. the time rate of change of the MF (SLOPE); this was calculated as the slope of a least squares linear regression calculated for the MF data over 30 s;
2. the initial MF (IMF); this is equal to the y-intercept of the linear regression described above; and
3. the percent recovery of MF at 1 min (REC); this was calculated using the following formula:

$$\text{REC} = ((\text{IMF1} - \text{FMF}) / (\text{IMF} - \text{FMF})) \times 100,$$

where

IMF = initial MF of the fatiguing contraction,  
 FMF = final MF of the fatiguing contraction,

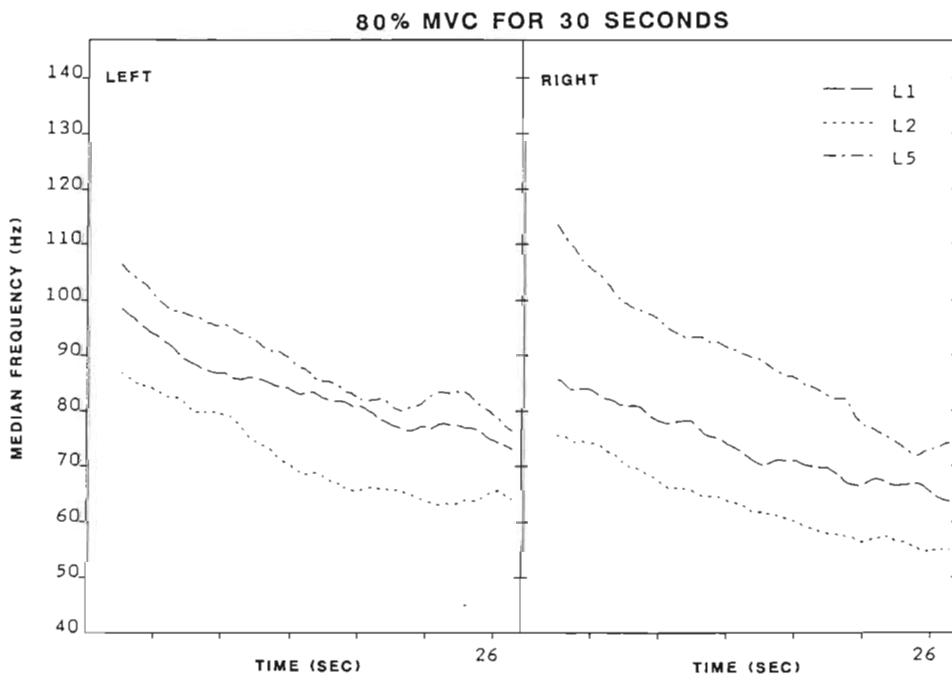


Figure 3—A typical median frequency plot for one subject as a function of contraction duration. The results for six concurrently active muscle sites are shown for a test conducted at 80% MVC for 30 s. Curves are arranged in groups of three, corresponding to the three lumbar electrode sites (L1, L2, L5) on the left and right sides of the back.



and

IMF1 = initial MF of the 5 s contraction at 1 min recovery.

A two-group stepwise discriminant analysis procedure was conducted to investigate the ability of the MF parameters to discriminate LBP from non-LBP groups. A similar analysis was also conducted for the port and starboard classifications. These analyses included the IMF, SLOPE, and REC parameters from the six electrode sites. All parameters were first pre-screened for multicollinearity by computing a correlation matrix and eliminating those variables having a correlation coefficient greater than 0.80. For more subtle patterns of correlation, no variable was entered into the classification function unless it could pass a tolerance limit of 0.01.

We also tested the hypothesis that a six-channel electrode configuration results in a better prediction of LBP than procedures relying on fewer electrode configurations. This test was implemented by conducting the discriminant analysis separately for each of the bilateral recordings at L1, L2, and L5 spinal levels. The percent correct classification from each of these analyses was then compared to similar calculations that combined data from all six electrode sites.

## RESULTS

Among the six rowers in the LBP group, three were port rowers and three were starboard rowers. Of the rowers in the non-LBP group, ten were port rowers and seven were starboard rowers. Three of the starboard rowers originally rowed from the port position, and they were therefore excluded from the discriminant analysis for port and starboard classification. Mean values of the physical descriptive data and MVC force output are presented in Table 1.

Preliminary tests for multicollinearity resulted in a maximum of eight variables entered into the classification function. The two-group discriminant analyses for LBP and non-LBP categories resulted in 100% correct classification of LBP rowers and 93% correct

TABLE 1. Descriptive profile of crew members.

Crew Team Group	Age (yr)	Ht (cm)	Wt (N)	MVC (N)
Port (N = 10)	20.8 (1.5)	188 (4.0)	827.3 (44.0)	1289.9 (371.9)
Starboard (N = 7)	20.0 (1.3)	188 (6.0)	809.5 (45.8)	1352.2 (337.2)
Port LBP (N = 3)	20.0 (1.0)	189 (8.8)	880.7 (109.4)	1659.1 (89.8)
Starboard LBP (N = 3)	19.6 (1.2)	186 (4.2)	840.7 (43.1)	1579.0 (403.4)
Group Means (N = 23)	20.3 (1.3)	188 (5.1)	831.8 (56.0)	1396.7 (350.5)

Values are means, with standard deviations in parentheses.

Ht = height; Wt = weight; MVC = maximal voluntary contraction.

TABLE 2. Results from discriminant analyses—LBP vs. non-LBP

Contractile Level (%MVC)	Percent Correct Classification		Variables Used in Classification (in Order)
	LBP (N = 5)	Non-LBP (N = 15)	
80%	100%	93%	(R)REC, L5 (L)REC, L5 (L)REC, L1 (R)REC, L1 (R)SLOPE, L1 (L)REC, L2

TABLE 3. Discriminant analyses—individual lumbar levels.

Lumbar Level (Groups)	Percent Correct Classification	Variables Used in Classification (in Order)
L2 (Port, Starboard) N = 11, N = 7	100% Port 86% Starboard	(R)REC (R)IMF (R)SLOPE
L5 (non-LBP, LBP) N = 17, N = 6	77% Non-LBP 83% LBP	(R)REC (L)REC

TABLE 4. Results from discriminant analyses—port vs starboard.

Contractile Level (%MVC)	Percent Correct Classification		Variables Used in Classification (in Order)
	Port (N = 11)	Starboard (N = 7)	
80%	100%	100%	(R)REC, L2 (R)SLOPE, L5 (R)IMF, L2 (R)REC, L1 (R)IMF, L5

classification of non-LBP rowers (Table 2). This corresponds to no false negative identifications and one false positive identification. Variables used in the classification function were five REC parameters and one SLOPE parameter from the right (R) and left (L) sides of the back. When the analysis was repeated using data from each of the lumbar levels separately, 83% of the LBP rowers and 77% of the non-LBP rowers were identified correctly from L5 data (Table 3). The variables used in the classification were (R)REC and (L)REC. All other analyses of the data from L1 and L2 electrode sites resulted in less than 70% correct classification of LBP and non-LBP groups and were therefore excluded from Table 3.

The two-group analysis between port and starboard rowers correctly classified 100% of the port rowers and 100% of the starboard rowers (Table 4). The variables entered into the classification function were all from the right side of the back and included REC, SLOPE, and IMF parameters in descending order of discriminating power.

The separate analyses of data from each lumbar spinal level resulted in a correct classification for 100% of the port rowers and 86% of the starboard rowers for data from the L2 electrode sites (Table 3). Contributing

variables, in descending order of discriminating power, were REC, IMF, and SLOPE, all from the right side of the back. Analyses of the data from L1 and L5 electrode sites resulted in less than 70% correct classification of port and starboard rowers and were therefore not included in Table 3.

Comparisons between the mean left and right REC data at L2 revealed directly opposite values for port and starboard groups. The left side of the port rowers and the right side of the starboard rowers had full recovery, whereas their contralateral sides were only partially recovered.

## DISCUSSION

The results of this study support the validity of using an EMG-based back analysis system to identify back muscle characteristics associated with LBP and rowing. All of the rowers with LBP were correctly identified by the procedure based solely on the EMG spectral parameters. This is a strong argument for the usefulness of muscle fatigue and recovery measurements as markers for clinical LBP.

To our knowledge, this is the first study in which the sensitivity and selectivity of EMG spectral parameters to LBP have been quantified in an athletic population. This result supports the findings of an earlier work (19) in which a similar technique successfully identified non-athletes with and without LBP. In this previous study, 91% of the subjects with LBP were correctly identified on the basis of the MF parameters. Among these non-athletes, IMF and SLOPE were the strongest discriminating variables for LBP. Among rowers, they were minimally involved in the classification function. This difference may be a reflection of the continued high activity and performance level maintained by rowers, even when LBP is present. (All of our subjects were actively training at the time of data collection.) In contrast, the non-athletic patients with LBP from the previous study were not actively participating in a rigorous conditioning program. Their differences in IMF and SLOPE parameters were most likely indicative of muscle disuse. Collectively, the results of these two studies suggest that physical conditioning may be an important factor in determining whether EMG fatigue indices are normal in an individual with LBP. A prospective study is needed to determine whether physical conditioning can actually attenuate abnormal EMG fatigue indices in individuals with LBP and, more importantly, whether these changes can result in fewer incidences of LBP and disability.

Our results to date have demonstrated that the EMG technique is able to correctly identify persons with LBP from two very different populations. The same cannot be said for static strength measurements (as determined

by the MVC value), which were not appreciably different for LBP and pain-free subjects in both of these studies. This is a compelling example of the advantage of this method over more conventional techniques that assess trunk strength.

The two-group discriminant analysis for LBP indicated that REC data from both sides of the back were used to identify individuals with LBP. Five of the six available REC parameters were included in the analysis, indicating that REC is a highly independent variable with strong discriminating power for the identification of subjects with low back pain. The recovery data from L5 (the best single discriminating level) show a difference in the pattern of left and right side recovery between rowers with and without LBP. Within the LBP group, recovery on the left side of the back seemed to be less efficient than recovery on the right side. It is interesting to note that four of the six individuals with LBP complained of pain localized to the left side of the back.

There was one false positive result for LBP. It is possible that this rower may be predisposed to LBP even though it was not manifested prior to testing. We will be conducting a follow-up study of this subject and the other misclassified subjects from previous studies to assess the effectiveness of the technique in screening individuals predisposed to LBP.

The fact that recovery was such a strong discriminator for LBP in this population may be a reflection of the unique energy requirements of the sport of rowing. Hagerman et al. (8,9) suggest that the style of pacing during competitive rowing results in an inefficient approach to energy expenditure. Rowers begin the 200 m race with an immediate, vigorous sprint through the first 30–40 s, averaging 40–50 strokes·min<sup>-1</sup>. Stroke cadence is then decreased to 34–38 strokes·min<sup>-1</sup> and is maintained until the final sprint, when the stroke cadence is again increased and held for approximately 1 min until the finish line is reached. Hagerman et al. argue that the physiological effect of this type of pacing is that rowers incur the largest portion of their very high oxygen deficit during the first 30–90 s of their race. Therefore, rowers quickly achieve a marked anaerobic response and must tolerate high levels of excessive lactate throughout the remainder of the race. It is possible that the inefficient physiological removal of these high lactate levels is a sequela of LBP in rowers. Armstrong (1) presented a model of LBP that offers a possible mechanism for this association. He proposed that involuntary muscle contractions (spasms) restrict circulation and result in an accumulation of metabolites that stimulate nerve endings, resulting in pain and further spasm. Consequently, there may be a greater need in rowers with LBP to emphasize recovery from fatigue in their training regimens.

The differences between port and starboard rowers



may be explained by differences in the use of the right and left sides of the back during the execution of the rowing stroke. An effective rowing stroke requires highly conditioned trunk extensors for stabilization and power production during the drive phase of the rowing stroke (8,17). Thus, trunk extensors may develop asymmetrically as a consequence of rowing from either the port or starboard position (6). This may explain why the discriminant analysis for individual lumbar levels resulted in only the L2 data producing high percentages of correct classification. The L2 electrode site is primarily over the iliocostalis lumborum muscle, which is particularly well situated anatomically to be selectively active during the combined rotation and extension of the trunk immediately after the "catch" phase of the rowing stroke when the upper trunk is rotated toward the oar.

Unlike the discriminant analysis for LBP, the discriminant analysis for identifying port and starboard rowers introduced all three MF parameters into the classification function. Since the distinction between port and starboard rowers is related to asymmetrical functioning of the trunk muscles, it is reasonable that the presence of consistent differences between contralateral MF parameters enabled the classification function to identify the two groups. This imbalance is manifested in both the fatigue and recovery conditions tested since all three MF parameters from one side were included as discriminating variables for port and starboard classification. The only other study to test the sensitivity of EMG spectral parameters to asymmetrical muscle function was a recent investigation of hand dominance (4). It was reported that the MF of the first dorsal interosseus muscle of the hand was significantly different in the non-dominant hand than in the dominant hand. Similar comparisons of MF measurements between the left and right hands in ambidextrous subjects demonstrated no significant differences. This result is consistent with our finding that starboard rowers had greater percent recovery on the right side of the back, and port rowers had greater percent recovery on the left side of the back. The physiological basis for these differences may be related to the fact that in-

creased use of a muscle, particularly during repetitive tasks, results in a more rapid turnover of metabolites (10).

The results of this study also demonstrated that multi-channel electrode configurations were better identifiers of LBP and rowing side than procedures relying on fewer electrode configurations. We reported similar results for our studies among non-athletes (19). These findings suggest that the back extensor muscles cannot be assessed properly by relying on only one or two sites for EMG signal detection. This factor may explain the poor reliability and conflicting data that have characterized previous attempts at studying back muscle fatigue by surface EMG.

In summary, the results of this study have verified the usefulness of a surface EMG measurement technique to identify changes in back muscles that are characteristic of LBP in rowers. Our results pertaining to the identification of port and starboard rowers further suggest that this technique is capable of identifying the adaptation of back muscles to repetitive asymmetrical loading. The technique may be useful to athletic trainers and other health professionals for evaluating the muscular component of LBP in their patients. Identification of muscle characteristics related to fatigue and recovery may also be useful in developing prophylactic and remedial back exercise programs.

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When this research was conducted, Ronda L. Crenshaw and Juliann P. Lyons were graduate students at Sargent College of Allied Health Professions at Boston University.

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