Research Report

Comparison of Spinal Mobility and Isometric Trunk Extensor Forces with Electromyographic Spectral Analysis in Identifying Low Back Pain

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This study compared conventional clinical measurements with electromyographic (EMG) spectral measurements for identification of individuals with low back pain (LBP). Twenty freshman sweep rowers were subjects for this study. Range-of-motion (ROM) measurements were taken for forward bending (FB), backward bending (BB) (double inclinometers), lateral bending (LB) (tape measure), and rotation (double-arm goniometer). Intratester reliability for ROM was also assessed. The Back Analysis System was used to determine static trunk extensor strength (ie, maximal voluntary contraction [MVC]) and to compute EMG spectral parameters from a paraspinal multi-electrode array. A two-group stepwise discriminant-analysis procedure for the ROM and MVC variables correctly identified 57% of the rowers with LBP and 63% of the rowers without LBP. A similar discriminant-analysis procedure for EMG spectral parameters correctly identified either 88% of the rowers with LBP and 100% of the rowers without LBP or 100% of the rowers with LBP and 88% of the rowers with LBP, depending on whether EMG measurements of recovery were calculated at 1 minute or at 2 minutes into the recovery period. Sensitivity (66%) and specificity (71%) results from the more traditional tests suggest that these techniques may be of limited usefulness for LBP screening or diagnosis. [Klein AB, Snyder-Mackler L, Roy SH, DeLuca CJ. Comparison of spinal mobility and isometric trunk extensor forces with electromyographic spectral analysis in identifying low back pain. Phys Ther. 1991;71:445–454.]

Key Words: *Electromyography; Muscle performance, measurement; Pain; Spine; Tests and measurements, range of motion.*

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Each year, 5% of American adults experience an episode of low back pain (LBP).[1] Despite this high prevalence, LBP is poorly understood. Although studies have shown early evaluation and treatment significantly reduce the occurrence of low back injury, identification has been problematic.[1,2] Objective treatment outcome measures are needed to develop more effective intervention.

Traditionally, joint motion and muscle strength have been used to characterize individuals with LBP.[1,3] For the purpose of this article, *strength* is op-

erationally defined as the maximum force or torque generated by a muscle or muscle groups at a specified velocity.[4] Mayer et al[5] reported a significant difference in spinal mobility between healthy subjects and subjects with a history of LBP. Physical therapists have used spinal mobility as an objective clinical assessment of spinal function and back pain severity.[3,6] Spinal mobility tasks, such as forward bending (FB) (flexion), backward bending (BB) (extension), and lateral bending (LB), have been used clinically to assess dysfunction, to evaluate progress with rehabilitation, and ultimately to determine discharge from physical therapy and return to work.[3,5,7,8]

Low back extensor muscle strength has also been used as an indicator of low back dysfunction. Studies have revealed that isometric and isokinetic trunk extensor muscle strength (measured as force or torque) is the most severely affected variable in tests conducted on patients with LBP.[9–13] Frymoyer and Cats-Baril[1] concluded that a successful rehabilitation program was associated with improvement of various markers of trunk extensor muscle performance. Smidt et al[13] compared percentages of maximum isometric torque in patients with LBP with those of healthy subjects. They found that the patients with LBP were consistently weaker than the healthy subjects. Despite numerous methods of measuring trunk extensor strength,[9,12,14] only a few authors[7,9,13] have reported reliability measurements and none have determined the amount of stabilization required to isolate back extensor assessment. Other studies[8,12] have found no significant difference in measured torque- or force-generating capability of the trunk extensors between subjects with and without LBP.

Recent advances in electromyography (EMG) indicate that there is an identifiable muscular component to chronic LBP.[15,16] Individuals with LBP were correctly identified solely on the basis of EMG spectral parameters. These studies used the Back Analysis System (BAS)* to assess muscle fatigue characterized by EMG spectral changes. This technique analyzes EMG in the frequency domain: the EMG power-density spectrum. This signal waveform undergoes a predictable change in its shape as a fatiguing contraction is sustained. This phenomenon can be measured as a shift in the EMG power-density spectrum to lower frequencies (compression) as the propagation velocity of the EMG signal is reduced by the accumulation of metabolites (acidic by-products of muscle contraction).[17,18] The compression of the EMG power-density spectrum has been more conveniently measured by monitoring the median frequency (MF) or midpoint of the EMG power-density spectrum. The Muscle Fatigue Monitor (MFM),[1] an integral component of the BAS, tracks the MF of the EMG power-density spectrum recorded during a sustained isometric contraction.[18] Roy et al[15] used the BAS to compare lumbar muscle fatigue in subjects with and without LBP. They found spectral shifts in the EMG signal differed between the two groups. The MF in the erector spinae muscles of the subjects with LBP showed a greater rate of decay and therefore a greater rate of fatigue than in the pain-free controls.

Roy and colleagues[15,16] evaluated fatigue in the low back extensor muscles of athletic and nonathletic populations to discriminate between subjects with and without LBP. Subjects with LBP and a pain-free control group were correctly identified using the differences in muscle performance as measured by EMG spectral analysis. As a result, they were able to begin to clinically validate the use of spectral estimates of muscle fatigue as indicators of LBP in both a nonathletic population and an elite athletic population of varsity sweep rowers with a high incidence of LBP. No studies have used spinal mobility or trunk extensor strength variables to similarly characterize individuals with and without LBP. The literature to date has merely focused on the clinical differences between these populations with respect to these traditional variables.

The purpose of this study was to compare the ability of traditional tests of spinal mobility and trunk extensor strength to identify athletic individuals with LBP using EMG spectral analysis. Intratester reliability of the range-of-motion (ROM) techniques was also examined.

Method

Subjects

Twenty-five members of the Boston University men's freshman sweep crew team volunteered for this study. Eight of the 25 subjects had 1 to 9 years of rowing experience ($\bar{X}$=4.1, SD=2.3) prior to this study. Descriptive profiles of the subjects are presented in Table 1. All rowers were in the first month of training for the fall season. The rowers who had rowed previously had had no organized training for the previous 2 months. The remaining subjects had participated in many different activities during the summer, none of which included rowing. The fall training regimen consisted of running or cycling, weight training, and ergometer workouts.

Each rower was given an introduction to the purpose of the study and a description of the testing protocol. A consent form was read and signed by each subject prior to testing. Testing was conducted at the NeuroMuscular Research Center at Boston University and at the Boston University Boat House.

Subjective LBP history, the specific training regimen, and physical descriptive data are a regular part of our BAS testing protocol and were obtained from each rower. In addition, rowers who were experiencing LBP on the day of testing or who reported a history of LBP completed an abbreviated McGill Pain Questionnaire to indicate the intensity and quality of

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Table 1. *Descriptive Profile of Subjects*

Group[a]	Age (y)		Height (cm)		Weight (kg)		MVC[b] (kg)		Rowing Experience (y)	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Non-LBP (n=17)	18.1	0.6	188.6	4.7	82.5	6.3	117.8	19.1	0.9	1.5
LBP (n=8)	18.8	1.0	189.3	2.7	82.4	7.5	114.8	24.2	2.4	3.3
Total sample (N=25)	18.3	0.8	188.8	4.1	82.5	6.5	116.9	20.4	1.3	2.3

[a]LBP=low back pain.

[b]MVC=maximal voluntary contraction.

pain experienced on the day of testing.[19] This questionnaire is also a part of our back testing protocol. Although not all of these data were used in our study, we believe we should report that we used our entire test battery in order for readers to judge whether this factor affected our results.

Rowers were classified as having LBP according to the following operational definition: report of a single or recurring incidence of lumbar LBP during the past year that interfered with activities of daily living, including rowing or training activities. This information was obtained from the LBP history.

Procedure

Experiment 1. All ROM measurements were taken twice (consecutively) to assess reliability. An intraclass correlation coefficient (ICC) was calculated to determine the amount of agreement and the difference between the ROM trials (Tab. 2). The ICC is derived from a repeated-measures analysis of variance (ANOVA) and examines variance and agreement between sets of numbers. The ICC formula (2,1), as described by Shrout and Fleiss,[20] was chosen, because both trials (judges) evaluated the same population of subjects (targets). The ICC is a measure of correlation that takes variance into account. The amount of measurement error between the two trials is calculated by subtracting the ICC value from 1.00 and multiplying by 100 to obtain the percentage of error between the trials. In our testing protocol, two measurements of each motion are taken sequentially and ROM testing is *always* performed in the following order: FB, BB, left lateral bending (LLB), right lateral bending (RLB), left trunk rotation (LROT), and right trunk rotation (RROT). Readers should be cautioned that our reliability results may not be reproduced if the tests are performed in a different order.

Lumbar spine ROM for FB and BB were measured using inclinometers.[†] The rower assumed a standing position with the cervical, thoracic, and lumbar spines in 0 degrees of lateral flexion and rotation. The spinous processes at L-1 and S-1, determined by palpation, served as landmarks for placement of the inclinometers. The inclinometers were placed on the landmarks and "zeroed" before motion occurred (Fig. 1A). The rower performed FB by bending forward as far as he could (Fig. 1B). The rower was instructed to keep his knees extended throughout the movement. Once full FB was achieved and each inclinometer was read, the rower returned to the starting position. The difference between the readings on the two inclinometers was the FB ROM measurement (r=.89).

During the BB movement, the rower was instructed to place his hands on his posterior ilia to stabilize the pelvis. The inclinometers were placed on L-1 and S-1 and were "zeroed" prior to performance of the BB movement. The rower was asked to bend backward as far as he could. Once full BB movement was completed, each inclinometer was read and the rower returned to the starting position. The difference between the readings on the two inclinometers was the BB ROM measurement (r=.82).

Standard goniometric methods were followed for LB and rotation measurements.[19] The starting position for LB was standing with the cervical, thoracic, and lumbar spines in neutral (0°). The rower was asked to bend to one side, maintaining his knees in full extension and his hips and shoulders forward, to limit rotation or other aberrant motions during the movement. The rower then returned to the starting position. The distance between the tip of the middle finger and the floor was measured (in centimeters) in standing (start position) and in fully attained LB using a tape measure (Fig. 2). The difference between these two measurements was the LB ROM measurement for that side. Right lateral bending (r=.80) and LLB (r=.71) were measured.

A double-arm, full-circle goniometer[‡] was used to measure trunk rotation (ROT) to left and right. For ROT, the rower was positioned in sitting, with his feet on the floor to stabilize the pelvis. A stool without a back support was used to allow for full, free movement into rotation. The cervical, thoracic, and lumbar spines were in neutral (0°). The axis of rotation of the goniometer was centered over the rower's cranium. The arms of the goniometer were aligned with the acromion processes of the rower (Fig. 3A).

[†]Chattanooga Group Inc, 4717 Adams Rd, Hixson, TN 37343-0489.

[‡]Jamar plastic goniometer (12.5 in), Asimow Engineering Co, 1414 S Beverly Glen Blvd, Los Angeles, CA 90024.

Table 2. *Descriptive Data for Range-of-Motion Trials and Intraclass Correlation Coefficients*

Group[a]	Variable[b] FB(°) $\bar{X}$	FB(°) SD	BB (°) $\bar{X}$	BB (°) SD	RLB (cm) $\bar{X}$	RLB (cm) SD	LLB (cm) $\bar{X}$	LLB (cm) SD	RROT (°) $\bar{X}$	RROT (°) SD	LROT (°) $\bar{X}$	LROT (°) SD
Non-LBP (n=16)	51.3	15.9	23.5	13.2	23.3	6.2	23.8	4.0	73.4	16.7	75.4	16.9
LBP (n=7)	56.0	20.7	19.1	8.2	23.6	5.4	23.7	4.5	66.1	12.2	73.6	14.9
Total sample (N=23)	52.7	17.1	22.2	11.9	23.4	5.9	23.8	4.1	71.2	15.5	74.8	16.0
r	.89		.82		.80		.71		.90		.91	

[a]LBP=low back pain.

[b]FB=forward bending, BB=backward bending, RLB=right lateral bending, LLB=left lateral bending, RROT=right trunk rotation, LROT=left trunk rotation.

The rower was asked to turn as far as he could without flexing, extending, or laterally bending. Once full ROT was achieved, the moving goniometer arm was aligned with the rower's iliac crest (ie, iliac tubercle) (Fig. 3B). This angle was defined as the ROT ROM measurement (r=.90 [RROT], r=.91 [LROT]).

The test for determination of the maximal voluntary contraction (MVC) of the lumbar muscles has been fully described in previous reports.[15,16] The subject was positioned in the postural restraining device of the BAS (Fig. 4). Specially contoured, adjustable front and rear restraining pads were positioned at the level of the anterior and posterior superior iliac spines. These pads held the subject in a slight posterior pelvic tilt, with the knees in approximately 20 degrees of flexion. Three posterior straps were tightened to stabilize the pelvis. The patellar tendons rested on pads to provide points of leverage and partial weight bearing during the test contractions. The subject was positioned in approximately 10 degrees of FB using a nylon harness across the scapular region of the back. This harness was attached to two Interface SM 500 force transducers[§] to record net external force generated during the isometric test contractions. The transducers have a dynamic range of 227.3 kg (500 lb) and a compliance of 2.7 μm/kg and were amplified such that their output was calibrated to 1 V=45.5 kg (100 lb). The difference in the force computed from the two load cells provided feedback to the experimenter and subject to ensure that the pull was symmetrical.

Each subject was given instructions for the proper technique for extending his trunk against the nylon strap to produce an isometric contraction of his back extensor muscles. After several practice sessions, the subject was instructed to perform a short-duration (5-second) maximal-effort contraction to determine the MVC of his back extensor muscles. The subject's MVC was determined by calculating the average force over a 3-second window during each contraction. Two trials were consecutively performed, after allowing for a brief rest (30–60 seconds). Maximal voluntary contraction values calculated from the BAS using this technique in our laboratory have a reliability coefficient of .96 (ICC[2,1]).

Experiment 2. After the trunk ROM measurements were taken, motor points were identified in the lumbar region of the back using low-level (1-5 mA) pulsed electrical stimulation,[‖] as described previously.[15,16] The longissimus thoracis muscle at the L-1 spinal level, the iliocostalis lumborum muscle at the L-2 spinal level, and the multifidus muscle at the L-5 spinal level were identified bilaterally and marked with a skin pencil. These motor points were used to determine electrode placement. Electrodes were placed away from the motor point to avoid unwanted signal effects related to the innervation zone of the muscle.[22] Six active bipolar surface electrodes described previously[17] were positioned so that the parallel detection surfaces were perpendicular to the muscle fibers (Fig. 5). The electrodes have a gain of 10 and a 3-dB bandwidth of 20 to 550 Hz, with a roll-off of 12 dB/octave and parallel detection surfaces 1 cm long and 1 cm apart.

The subject was positioned in the BAS, and MVC testing was completed as described in experiment 1. After a 5-minute rest period, low back extensor activity was recorded using the surface-detected EMG signal for the following isometric contractions:

1. A long-duration (30-second) contraction, at 80% of MVC, was performed to induce fatigue in the low back extensor muscles.

2. A series of short-duration (10-second) contractions, at 80% of MVC, were performed at 1 minute, 2 minutes, 5 minutes, 10 minutes, and 15 minutes into the recovery period following the fatiguing contraction. These contractions were performed to monitor the recovery of spectral parameters to their baseline (ie, prefatigue) values.

For the fatigue and recovery contractions, visual force feedback was provided by a cross-shaped cursor and target rectangle displayed on a video monitor. The cursor moved

[§]Interface Inc, 7401 E Butherhus Dr, Scottsdale, AZ 85260.

[‖]Rich-Mar Corp, PO Box 879, Inola, OK 74036-0879.

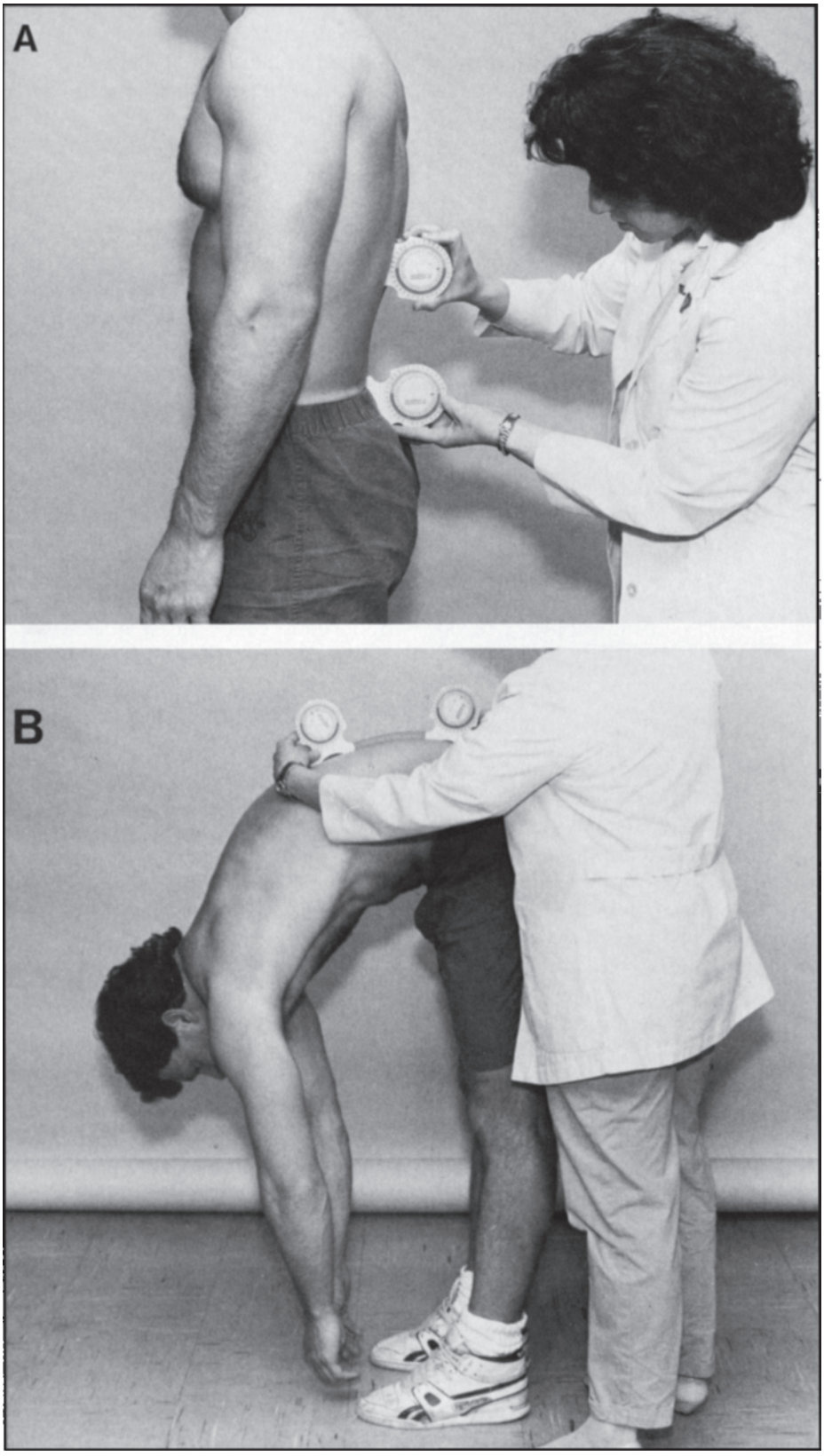

Figure 1. *Placement of double inclinometers: (A) starting position for forward-bending and backward-bending measurements; (B) position for fully attained forward-bending measurement.*

proportionally to the sum of the forces detected by the two transducers. The subject was instructed to maintain the cursor in the center of the rectangle while sustaining the isometric contraction.

Data Processing and Analysis

A two-group stepwise discriminant analysis[23] was performed using ROM and MVC variables. This analysis determined how well these variables discriminated rowers with LBP from those without LBP. All parameters were initially screened for multicollinearity by computing a correlation matrix. All variables with a Pearson Product-Moment Correlation Coefficient of greater than .80 were eliminated from the analysis. In order to be entered into the classification function, a variable also had to pass a tolerance limit of .01. (Tolerance, in this case, is generally equivalent to a probability value.)

The sensitivity and specificity of this test were then compared with the results of the EMG spectral parameters recorded as described in experiment 2. *Sensitivity* was defined as the number of correctly identified rowers without LBP divided by the total number of rowers without LBP. *Specificity* was defined as the number of rowers who were incorrectly identified as not having LBP divided by the total number of rowers with LBP. The data from the six EMG channels were recorded at a tape speed of 4.8 cm/s to provide a bandwidth of 1.25 kHz. This procedure allowed further amplification of the six EMG signals to achieve an output of approximately 1 V peak to peak. The MFM was used to process the data separately to compute the MF of each signal. The MF and force data were further amplified and simultaneously digitized. The MF and force data were sampled at 100 Hz, well above the minimum rate defined by the Nyquist criterion.[24] The digitized MF records for each of the six electrode locations were simultaneously plotted as a function of time (Fig. 6). Three parameters were further calculated from these data for statistical analysis:

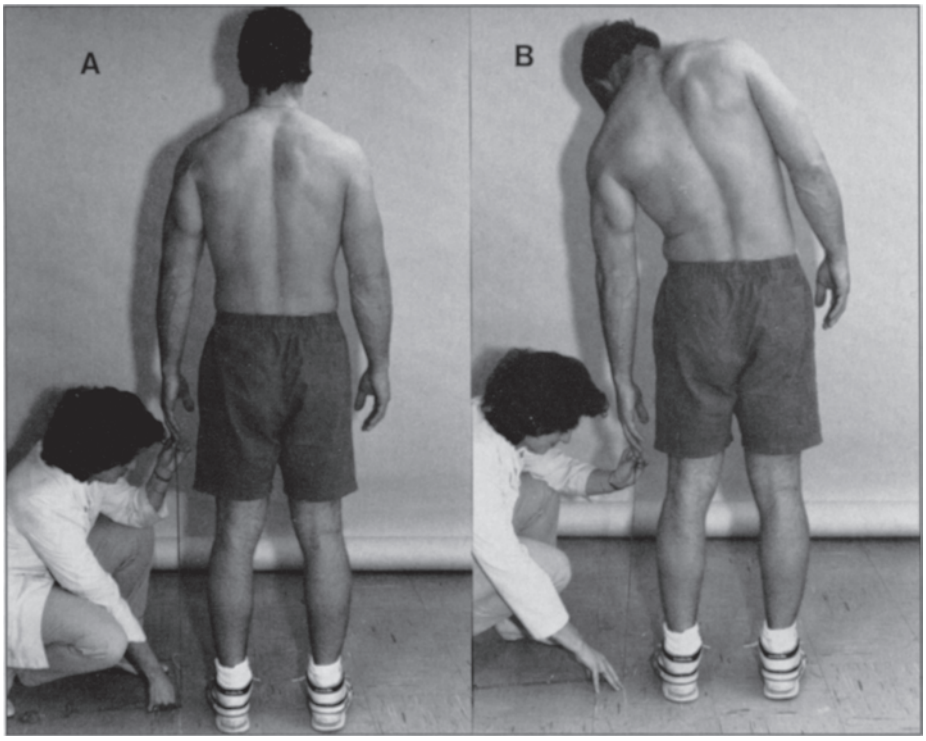

Figure 2. *Starting position for lateral-bending measurement (A); position for fully attained lateral-bending measurement (B).*

1. *SLOPE,* defined as the time rate of change of the MF. This parameter was calculated as the slope of least-squares linear regression calculated for the MF data over 30 seconds.

2. *Initial MF (IMF),* defined as the y-intercept of the linear regression described as SLOPE.

3. *REC,* defined as the percentage of recovery of the MF at each recovery time. The REC was calculated using the following equation:

$$REC = [(IMF1 - FMF)/(IMF - FMF)] \times 100$$

where IMF represents the initial MF of the fatiguing contraction, FMF represents the final MF of the fatiguing contraction, and IMF1 represents the initial MF of the 10-second contraction at each recovery time. The RECs were defined as follows: REC 1=recovery after 1 minute, REC 2=recovery after 2 minutes, REC 3=recovery after 5 minutes, REC 4=recovery after 10 minutes, and REC 5=recovery after 15 minutes.

A two-group stepwise discriminant-analysis procedure as described in experiment 1, was conducted separately for data from the fatigue trial and a single recovery trial. This analysis was repeated and compared for each of the recovery trials to determine the optimal MF parameters in classifying rowers with and without LBP. The dependent variables were the IMF, SLOPE, and REC parameters from the six electrode sites.

Results

The descriptive ROM data are presented in Tab. 2. The results of the discriminant analysis for the ROM and MVC variables are displayed in Tab. 3. Seven ROM/MVC variables were entered into this analysis. Sixty-three percent (63%) of the rowers without LBP were correctly identified. Of the total number of rowers with LBP, discriminant analysis resulted in correct classification of 57%. The RROT variable was the only variable to meet the preanalysis criteria for collinearity and tolerance and thus was the only variable entered by the program into this analysis.

One subject without LBP was not included in the spectral-parameter analyses, because no data were recorded from his right L-2 electrode. Thus, the number of subjects without LBP was reduced to 16 for this analysis. Two rowers were eliminated from single spectral-parameter analyses because of missing data; in both cases, data were missing from only one electrode site during a single recovery trial.

The discriminant-analysis results for each of the five analyses are summarized in Tab. 4. Thirty EMG variables were entered into each analysis. The analyses that included earlier recovery contractions (REC 1 and REC 2) resulted in higher percentages of correct classifications than any of the subsequent analyses. The variable that was the strongest discriminator in these two analyses was the calculated recovery from the right L-5 electrode.

Table 3. *Range-of-Motion and Maximal-Voluntary-Contraction Discriminant-Analyses Results*

Group[a]	Correct Classification (%)	Variable Used in Classification
LBP (n=7)	57	RROT[b]
Non-LBP (n=15)	63	RROT

[a]LBP=low back pain. (Note: 1 subject with LBP and 1 subject without LBP were eliminated from this analysis because no data were recorded.)

[b]RROT=right trunk rotation.

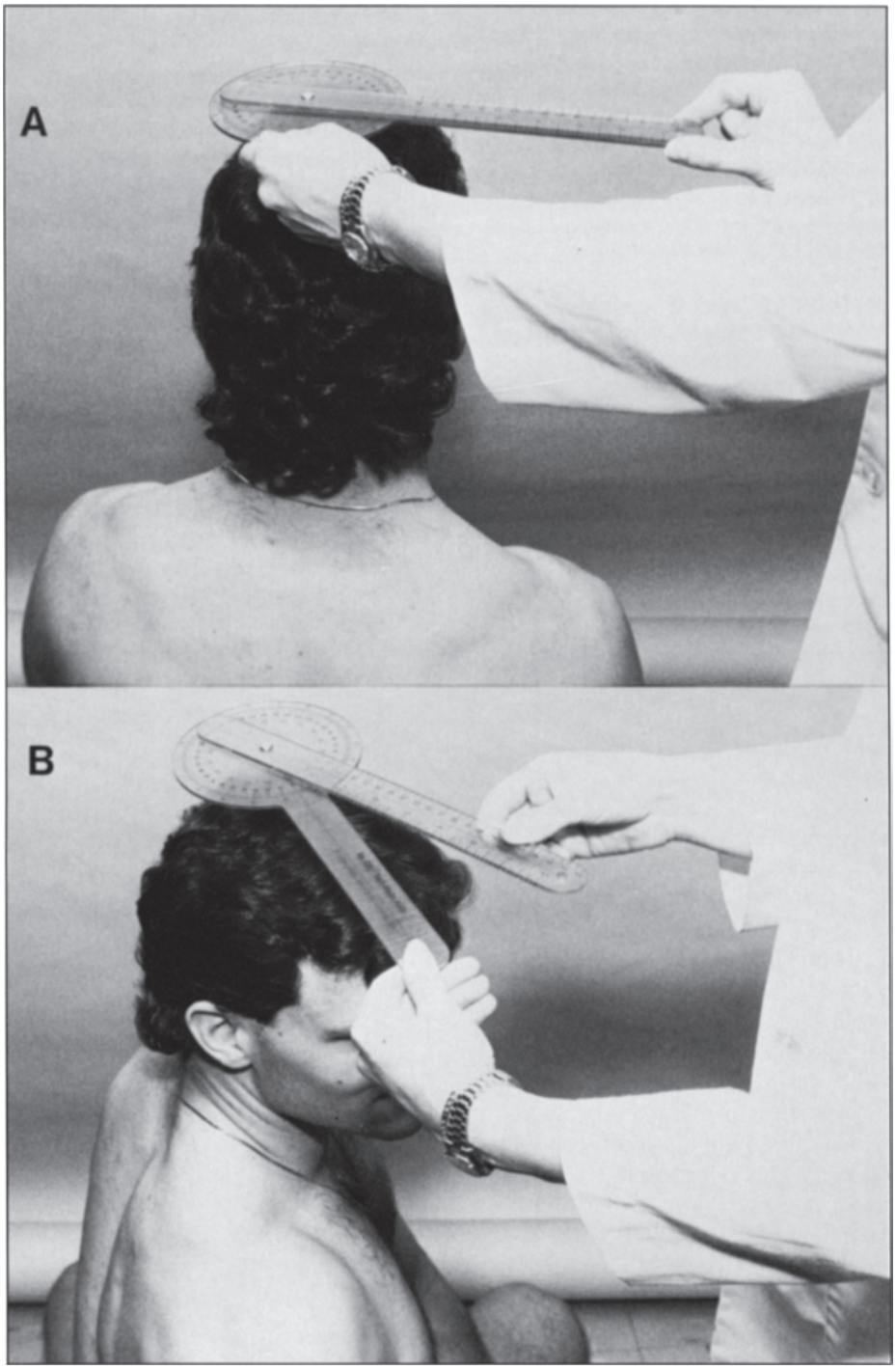

Figure 3. *Starting position for trunk-rotation measurement (A); position for fully attained trunk-rotation measurement (B).*

The ROM and MVC analysis showed the lowest sensitivity (66%) and specificity (71%). Analysis 1 (including recovery at 1 minute) revealed EMG spectral parameters to be 100% sensitive and 88% specific. Analysis 2 (including recovery at 2 minutes) revealed EMG spectral parameters to be 88% sensitive and 100% specific. The sensitivity and specificity results are presented in Table 5.

Discussion

Physical therapists have relied on their basic evaluation techniques to identify dysfunction. The findings of this study showed that the commonly used evaluative techniques of spinal mobility measurement and muscle strength testing could not correctly identify subjects with and without LBP. Right trunk rotation was the only variable entered into the discriminant analysis, based on its statistical ability to meet the preanalysis criteria. Surprisingly, MVC was shown to be a poor discriminating variable and was the first variable removed from the analysis. This analysis resulted in six false-positive results for LBP and three false-negative results for the absence of LBP. Clinically, these findings imply that, although ROM and MVC may be helpful markers of progress in a patient's rehabilitation, they are not identifying characteristics for individuals with LBP.

Experiment 2 showed that EMG spectral analysis (for recovery at 1 and 2 minutes) could correctly identify each group of rowers within acceptable limits. The best classification results were from data that included REC parameters from those trials. Of the variables introduced into the classification function for LBP, the best

Figure 4. *Position of subject in the Back Analysis System.*

Table 4. *Discriminant-Analysis Results for Recovery*

Recovery Time[a]	Correct Classification (%)		Variable Used in Classification (In Order)[d]
	LBP[b] (n=8)	Non-LBP[c] (n=16)	
1 min	88	100	(R)REC, L-5 (L)SLOPE, L-2 (R)SLOPE, L-5 (L)REC, L-2 (R)SLOPE, L-2 (L)IMF, L-5 (L)SLOPE, L-5
2 min	100	88	(R)REC, L-5 (R)SLOPE, L-5 (R)SLOPE, L-2 (R)REC, L-1 (L)SLOPE, L-2 (L)REC, L-5

[a]Contractile level=80% of maximal voluntary contraction.

[b]LBP=low back pain.

[c]One rower without LBP was eliminated from these analyses because of lack of data from his right L-2 electrode.

[d]REC=percentage of recovery of median frequency at each recovery time; SLOPE=time rate of change of median frequency; IMF=initial median frequency, or y-intercept of SLOPE.

single discriminating variable for LBP was the right REC variable from the L-5 level. This finding corroborates the results of Roy et al,[16] who concluded that REC was the highly discriminating variable in identifying LBP and L-5 was the strongest discriminating lumbar level, as determined by its use in the statistical analysis.

This result may be related to the fact that lower lumbar muscles generate proportionately more tension than upper lumbar muscles. Muscle fatigue in subjects with LBP, therefore, will more likely be manifested at these higher force levels. Yettram et al[24] demonstrated that, during standing or slight FB, the lower lumbar musculature sustains greater forces than the upper lumbar musculature, resulting in a difference in force distribution. Lower lumbar muscles also have a larger cross-sectional area with greater force-generating capacity than upper lumbar muscles.

In similar tests conducted on nonathletes, IMF and SLOPE parameters correctly identified subjects with LBP[15]; however, the design of that study did not include REC contractions. The IMF and SLOPE variables were also used to classify LBP in freshman rowers, possibly reflecting the predominance of untrained, nonathletic individuals in this population. The discriminating power of the SLOPE parameter may be related to the observation that there were higher slope values among nonathletes with LBP than among subjects without LBP. This finding may represent proportionately higher loads in these muscle groups for subjects with LBP compared with subjects without LBP as a result of compensatory mechanisms related to pain. Increased contractile force level may result in an increased rate of accumulation of metabolites, which can be measured as an increased MF SLOPE.[25,26] The physiologic adaptation in rowers with LBP could be the result of excessive extensor muscle fatigue associated with high precontraction metabolite levels. There may also be an altered recruitment of the extensor muscles during sustained muscle contraction secondary to persistent muscle spasm and prolonged muscle tension.[27] As the MF decreases in response to the prolonged muscle contraction, REC is dependent on the change in the MF and the muscle's ability to respond to this change. Recovery is also dependent on the rate at which the vascular network can remove metabolites from the muscle.

Despite precautions taken with electrode placement in this study, the EMG activity recorded may have included some signal contribution from neighboring muscles (cross talk). As the force level increases with a sustained muscular contraction, the EMG detection may include activity from neighboring muscles. For this reason, results cannot be extrapolated to differences in specific muscle groups, but rather only to different muscle sites.

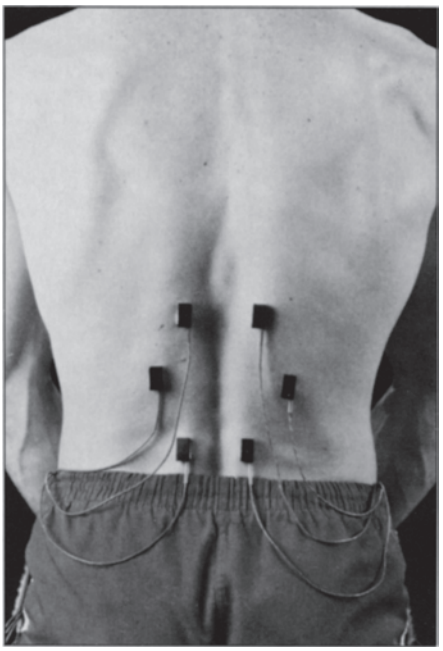

Figure 5. *Six electromyographic surface electrode placements for bilateral locations of longissimus thoracis (L-1), iliocostalis lumborum (L-2), and multifidus (L-5) muscles.*

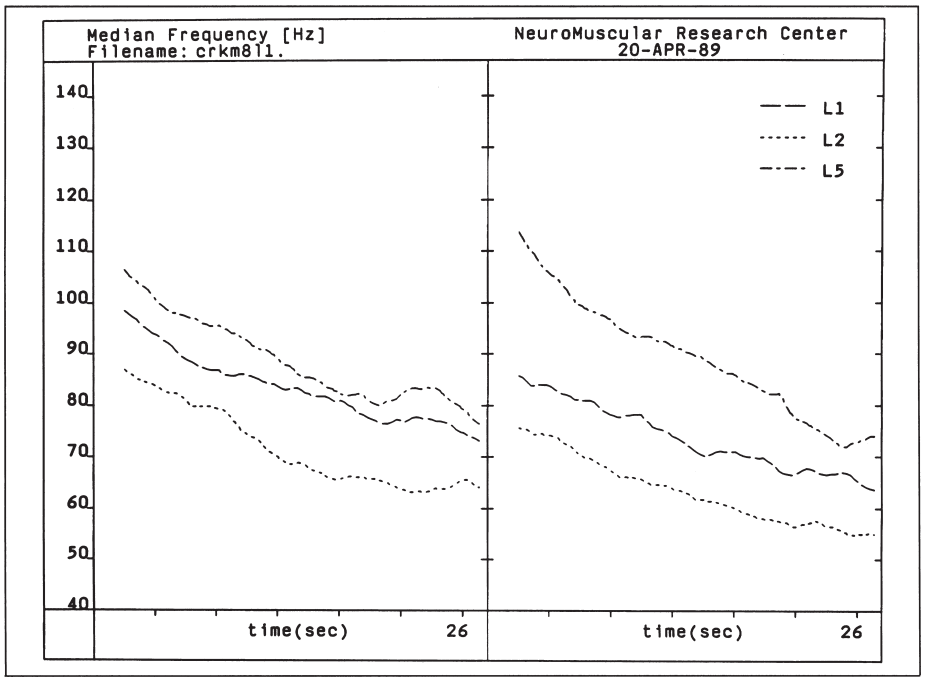

Figure 6. *Median-frequency plots as a function of contraction for six lumbar muscles tested at 80% of maximal voluntary contraction. Curves are arranged in groups of three, corresponding to left- and right-sided muscles.*

Sensitivity and specificity are used to describe the value of clinical tests. The physical therapist may use clinical tests to aid in diagnosis. The clinical screening test must be highly sensitive in order to identify everyone who has the problem, but should not necessarily be highly specific. This sensitivity allows the clinician to identify all individuals who *may* have a problem. Once identified, other evaluative techniques can be used to separate true-positive results from false-positive results. Although good screening tests are usually highly sensitive, but not always specific, good diagnostic tests should be both highly sensitive and highly specific. That is, they should identify all (or a large percentage) of the people with the disease, but not misidentify those without the disease. The results of the ROM-MVC analysis in this study showed neither case was true. These measures proved to be neither sensitive (six false-positive results) nor specific (seven false-negative results) in identifying rowers with LBP; they are neither good diagnostic nor good screening parameters for this patient population. Readers should be cautioned that probabilistic statements may not be made from sensitivity and specificity calculations.

Electromyographic spectral analysis was shown again to be a highly sensitive and highly specific diagnostic test.[15,16] Analysis 1 resulted in no false-positive results for LBP and only one false-negative result. The better screening test would be analysis 2, in which there were no false-negative results, but two false-positive results. The two false-positive results could perhaps be attributed to identifying rowers who are at risk for LBP. These individuals could be further evaluated or followed to verify or refute this possibility. Although this study examined a small, select population, these results confirm the previous findings of Roy and colleagues[15,16] in their tests of similar populations.

Clinically, this study demonstrated that spinal mobility and isometric trunk strength cannot be used to identify individuals with LBP. Spinal mobility measures, with the exception of LLB, can be used to reliably assess changes in lumbar motions. Research is being undertaken to determine the reliability of the isometric trunk extensor strength measurement by the BAS system, as well as the amount of

Table 5. *Analysis of Sensitivity and Specificity*

Method[a]	Test Result	Group[b] Non-LBP	Group[b] LBP	Sensitivity (%)	Specificity (%)
ROM/MVC	positive	6	4		
(n=23)	negative	10	3	66	71
REC 1	positive	0	7		
(n=24)	negative	16	1	100	88
REC 2	positive	2	8		
(n=24)	negative	14	0	88	100
REC 3	positive	3	7		
(n=24)	negative	13	1	81	88
REC 4	positive	4	6		
(n=22)	negative	11	1	86	60
REC 5	positive	4	3		
(n=24)	negative	12	5	38	75

[a]ROM/MVC=range-of-motion/maximal-voluntary-contraction testing, REC 1=recovery after 1 minute, REC 2=recovery after 2 minutes, REC 3=recovery after 5 minutes, REC 4=recovery after 10 minutes, REC 5=recovery after 15 minutes.

[b]LBP=low back pain.

stabilization required to maximize reliability.

Conclusion

The results of this study support the use of EMG spectral parameters, in particular REC, as discriminators of individuals with LBP. Despite the reliability of the ROM and MVC measurements, these tests were poor diagnostic and screening tools for LBP in this study.

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References

1 Frymoyer JW, Cats-Baril W. Predictors of low back pain disability. *Clin Orthop.* 1987;221:89–98.

2 Kelsey JL, White AA III. Epidemiology and impact on low back pain. *Spine.* 1980;5:133–142.

3 Marras WS, Wongsam PE. Flexion and velocity of the normal and impaired lumbar spine. *Arch Phys Med Rehabil.* 1986;67:213–217.

4 Knuttgen HG, Kraemer WJ. Terminology and measurement in exercise performance. *Journal of Applied Sport Science Research.* 1987;1:1–10.

5 Mayer TG, Tencer AF, Kristoferson J, Mooney V. Use of noninvasive techniques for quantification of spinal range-of-motion in normal subjects and chronic low back dysfunction patients. *Spine.* 1984;9:588–595.

6 Mellion G. PT for chronic low back pain: correlation between spinal mobility and treatment outcome. *Scand J Rehabil Med.* 1985; 17:163–166.

7 Lankhurst GJ, van de Stadt RJ, Vogelaar TW, et al. Objectivity and repeatability of measurements in low back pain. *Scand J Rehabil Med.* 1982;14:21–26.

8 Million R, Hall W, Haavik Nilsen K, et al. Assessment of the progress of the back pain patient. *Spine.* 1982;7:204–212.

9 Addison R, Schultz A. Trunk strength in patients seeking hospitalization for chronic low back pain disorders. *Spine.* 1980;5:539–544.

10 Biering-Sorenson F. Physical measurements as risk indicators for low back trouble over a one-year period. *Spine.* 1984;9:106–119.

11 Larson CB. Pathomechanics of backache. *J Iowa Med Soc.* 1961;51:643–650.

12 McNeill T, Warwick D, Anderson C, Schultz A. Trunk strengths in attempted flexion, extension and lateral bending in healthy subjects and patients with low back disorders. *Spine.* 1980;5:529–538.

13 Smidt G, Herring T, Amundsen L, et al. Assessment of abdominal and back extensor function: a quantitative approach and results for chronic low back patients. *Spine.* 1983; 8:211–219.

14 Seidel H, Beyer H, Brauer D. Electromyographic evaluation of back muscle fatigue with repeated sustained contractions of different strengths. *Eur J Appl Physiol.* 1987;56:592–602.

15 Roy SH, DeLuca CJ, Casavant DA. Lumbar muscle fatigue and chronic low back pain. *Spine.* 1989;14:992–1001.

16 Roy SH, DeLuca CJ, Snyder-Mackler L, et al. Fatigue, recovery and low back pain in elite rowers. *Med Sci Sports Exerc.* 1990;22:463–469.

17 DeLuca CJ. Myoelectric manifestations of localized fatigue in humans. *Crit Rev Biomed Eng.* 1985;11:251–279.

18 Gilmore DL, DeLuca CJ. Muscle fatigue monitor (MFM): second generation. *IEEE Trans Biomed Eng.* 1985;32:75–78.

19 Melzack R. The McGill questionnaire: major properties and scoring methods. *Pain.* 1975;1:277–299.

20 Shrout PE, Fleiss JL. Intraclass correlation: uses in assessing rater reliability. *Psychol Bull.* 1979;86:420–428.

21 Norkin CC, White DJ. *Measurement of Motion: A Guide to Goniometry.* Philadelphia, Pa: FA Davis Co; 1985:62, 129–131.

22 Roy SH, DeLuca CJ, Schneider J. Effects of electrode placement location on myoelectric conduction velocity and median frequency estimates. *J Appl Physiol.* 1986;61:1510–1517.

23 Dixon WJ, ed. *BMDP Statistical Software.* Berkeley, Calif: University of California Press; 1981.

24 Yettram AL, Bai BA, Jackman MJ. Equilibrium analysis for the forces in the human spinal column and its musculature. *Spine.* 1980;5:402–411.

25 Hermansen L, Vaage O. Lactate disappearance and glycogen synthesis in human muscles after maximal exercise. *Am J Physiol.* 1977; 233:E422–E429.

26 Sejersted OM, Vollestad NK. Biomechanical correlates of fatigue: a brief overview. *Eur J Appl Physiol.* 1988;57:336–347.

27 Armstrong RB: Mechanisms of exercise-induced delayed onset muscular soreness: a brief overview. *Med Sci Sports Exerc.* 1984;6:529–538.