

Muscle Activation During Exercises to Improve Trunk Stability in Men With Low Back Pain

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ABSTRACT. Hubley-Kozey CL, Vezina MJ. Muscle activation during exercises to improve trunk stability in men with low back pain. *Arch Phys Med Rehabil* 2002;83:1100-8.

Objectives: To evaluate the relative activation amplitudes from 3 abdominal and 2 trunk extensor muscle sites of persons with low back pain (LBP) performing the pelvic-tilt, the abdominal-hollowing, and level 1 of the trunk stability test (TST) exercises and to compare the activation amplitudes among muscle sites and exercises.

Design: A prospective, comparative, repeated-measures design.

Setting: Motion analysis research laboratory.

Participants: Fourteen men with LBP (mean duration, 8y; mean age \pm standard deviation, 39 \pm 5y).

Interventions: Subjects performed 3 exercises in random order while surface electromyograms were recorded from 5 muscle sites: lower and upper rectus abdominus, external oblique, erector spinae, and multifidus. The exercises were divided into 2 phases: a movement phase and a stabilization phase. The root-mean-square (RMS) electromyographic amplitude for each phase was calculated and normalized to the highest RMS amplitude from a series of 4 exercises, which attempted to elicit maximal voluntary isometric contractions (MVICs) for each muscle. A 2-factor, repeated-measures analysis of variance (ANOVA) tested the muscle by exercise interaction and the 2 main effects for each phase separately.

Main Outcome Measures: Normalized RMS amplitude was the main dependent variable. The ensemble-average profiles for each muscle were calculated to examine the phasing of activation throughout the exercises.

Results: The ANOVA revealed a statistically significant muscle-by-exercise interaction ($P < .05$) for both phases, which showed that the 3 exercises; recruited the 5 muscle sites using different patterns of relative amplitudes. The external oblique muscle site was activated to higher amplitudes than the other 4 muscle sites for all 3 exercises; the highest normalized RMS activity occurred at the external oblique during the pelvic tilt (32% MVIC). The phasic patterns among the 5 muscle sites were not consistent for the TST but were consistent among the 5 sites for the other 2 exercises.

Conclusions: None of the exercises recruited the abdominal muscles to intensities deemed adequate for strengthening. The TST challenges the coordination of muscle activity during the

leg-loading task (stabilization phase) as evidenced by changes in amplitudes over the total exercise time for the external oblique site, but not the other 4 sites. All 3 exercises could be used as initial exercises in a dynamic stability progression when low-recruitment amplitudes of specific muscles were the objective but not for strengthening.

Key Words: Electromyography; Exercise therapy; Low back pain; Muscles; Rehabilitation.

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DYNAMIC STABILITY EXERCISES have become an accepted option in the management of low back pain (LBP) over the past decade.¹⁻⁶ Although passive and active structures aid in trunk stabilization,⁷ the active muscle forces play a significant role to counteract external perturbations associated with fundamental movements, and these forces are controlled by the nervous system.⁷ McGill⁸ provides an excellent overview of the need for the trunk muscles to act in a synchronous manner to maintain stability, suggesting that even 1 muscle producing an inappropriate contraction (force) could result in the necessary force to disrupt stability. The link between mechanical instability of the lumbar spine and LBP disorders,⁹ and the association of LBP with muscle dysfunction,¹⁰ supports the concept of dynamic trunk-stability training. The dynamic-stability approaches include building muscle strength and endurance and using neuromuscular control strategies required to maintain dynamic trunk stability. These strategies include (1) selective recruitment of specific muscles and (2) synergistic coactivation.^{1,2,8,9,11} The goal is to improve the muscular responsiveness needed to stabilize the spine against perturbations associated with movement and activities of daily living.

The present study focused on 3 exercises commonly prescribed in the management of LBP: the pelvic tilt,^{6,11} abdominal hollowing,^{11,12} and trunk stability test (TST) level 1.³ The latter 2 emphasize the importance of a neutral spinal position and are claimed to recruit abdominal and trunk muscles in a manner consistent with dynamic stability training, lumbopelvic stability in particular.¹⁻⁵ To date, there are no measures other than electromyography to substantiate that certain exercises elicit specific muscle activation patterns. A recent electromyography study of healthy subjects¹³ performing the 3 study exercises provided evidence that supported some and refuted other previous claims associated with the pelvic-tilt^{11,14} and the abdominal-hollowing exercises.^{11,12} The first electromyographic data on the TST were also presented in this study.¹³ Previous claims made about the TST had been based on anatomical and kinesiological principles and 2 electromyography studies of leg-lifting exercises.^{15,16} The study¹³ did not support conclusions that the external oblique muscle was selectively recruited for the abdominal hollowing compared with the pelvic tilt but did support that trunk extensor coactivity occurred during the TST exercise and that the TST challenged the neuromuscular system to produce coordinated coactivity among muscle sites while maintaining lumbopelvic stability.

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This study¹³ also showed that none of the 3 exercises recruited any of the muscle sites examined to levels deemed necessary for eliciting a strengthening response.

In a recent comprehensive review,¹⁰ compelling evidence was presented that neuromuscular dysfunction is associated with LBP, with changes in muscular strength and endurance of the trunk muscles, and changes in activation amplitudes and synergistic muscle activation patterns reported for a variety of movement patterns. Few studies, however, have examined muscle activation in persons with LBP as they performed therapeutic exercises. Of relevance to the present study are 2 studies: one on the pelvic tilt¹⁴ and one on the abdominal-hollowing exercise.¹⁷ First, high paraspinal activity was reported for subjects with LBP performing the pelvic tilt.¹⁴ This study¹⁴ compared raw electromyographic amplitudes. A recent review¹⁸ illuminated that drawing comparative conclusions based on raw electromyographic data is a flawed approach because of the volume-conducting differences among subjects and muscles. The second study¹⁷ revealed no significant differences in rectus abdominus or internal oblique activity during the abdominal hollowing for LBP subjects compared with healthy controls but did find that the ratio of oblique activity to rectus abdominus activity differed between the groups. O'Sullivan et al¹⁷ concluded that comparing ratios was a better method of highlighting altered patterns of synergistic activity. Once again, the normalization technique used in their study is in question. The electromyographic amplitudes were normalized to a double leg-lifting task,¹⁷ which produces submaximal activation and nonlinear relative amplitudes from different abdominal sites,¹⁶ making it difficult to make between-subject and muscle comparisons. The third exercise examined in the present study, the TST, has been correlated with measures of muscle function,¹⁹ but no electromyography studies on persons with LBP have been reported. Although the neuromuscular patterns of healthy subjects for various therapeutic exercises provide valuable baseline data on activation amplitudes from specific muscles, little is known about LBP subjects and the muscle activity associated with the 3 study exercises.

The present study sought to quantify and compare the activation amplitudes from specific muscle sites recorded from subjects with chronic LBP and to assess whether these exercises recruit specific muscles in a manner consistent with the goals of dynamic stability exercises.^{1,2} As in our previous study on healthy subjects,¹³ we sought to determine the potential for each exercise to improve muscular strength, to selectively recruit the external oblique muscle and the 2 segments of the rectus abdominus muscle, and to coactivate the trunk extensors and abdominals. Our specific objectives were 2-fold: (1) to measure the relative activation amplitudes from 3 abdominal and 2 trunk extensor muscle sites as persons with LBP performed the pelvic-tilt, abdominal-hollowing, and TST exercises and (2) to compare the activation amplitudes among muscle sites and exercises. The main dependent variable was relative activation amplitude, which we measured by surface electromyography, normalized to maximal voluntary isometric contraction amplitudes (MVICs). We hypothesized that we would find differences in the relative activation amplitudes in 3 areas: (1) differences for the 5 muscle sites among the 3 exercises; (2) differences among the 5 muscle sites, showing selective recruitment of abdominal sites and minimal coactivation; and (3) differences among the 3 exercises, showing different neuromuscular demands for each exercise.

In addition to the quantitative analysis of activation amplitudes, the electromyographic profiles for each exercise were examined to determine whether the patterns of activity

throughout the exercise provided evidence of synergistic coactivation of agonist and antagonist muscles.

METHODS

Participants

Fifteen men between the ages of 20 and 50 years who had chronic LBP were recruited. Women were excluded so results could be compared with a previous study¹³ on normal subjects. Chronic LBP was defined as "pain between the lower ribs and gluteal folds, with minimal radiation to the thigh and never below the knee, present for a minimum of seven weeks."²⁰ Subjects were recruited through advertisements posted at a military base, throughout various departments of the hospital, the gymnasium, and on the Internet. Subjects were excluded if they had nerve root pain, neurologic signs and symptoms, complications such as tumor or infection, previous spinal surgery, spinal fracture, or structural deformity such as scoliosis or spondylolisthesis. Complications were determined by questionnaire and a physical assessment performed by an orthopedic physiotherapist (CB, see Acknowledgments).

The study was approved by the Faculty of Health Professions Ethics Committee, Dalhousie University. During the initial session, subjects provided written informed consent. A postural assessment was conducted by a physiotherapist with 15 years of orthopedic clinical experience (MJV). Subjects were then graded using the trunk-raising forward exercise²¹ to assess objectively minimal muscle function for descriptive purposes only.^{13,16} Subjects were instructed on how to perform the 3 study exercises, were provided with a written description of the exercises, and were asked to practice the 3 exercises (10 times each on 3 separate days between the initial session and the test session).

The test session took place approximately 2 weeks later. Age (y), mass (kg), height (cm), number of practice sessions from the initial session, and physical activity level¹⁶ were recorded. To quantify the pain and disability associated with their LBP at the time of testing, subjects completed the Roland-Morris Disability Scale,²² including the pain scale. To indicate level of disability during everyday activities, they completed the Oswestry Low Back Pain Disability Questionnaire.²³ The Roland-Morris Scale is sensitive to changes in functional status of patients with minor disability²⁴ and correlated with a 6-point pain scale.²² Subjects were excluded if they were unable to perform 1 or more of the 3 exercises correctly on the test day or if their pain prevented them from performing the exercises.

Surface Electromyographic Data Acquisition

The skin was prepared by shaving excess hair and rubbing the skin with an alcohol-water solution to reduce impedance (ratio of skin/amplifier impedance, <.10%).²⁵ Surface electrode (Meditrace Ag/AgCl, 10-mm pellet)^a pairs were placed in a bipolar configuration over the 5 muscle sites. They were aligned with the muscle fibers at an interelectrode distance of 2cm. A reference electrode was placed over the right iliac crest. The 5 muscle sites on the right side were (1) the lower rectus abdominus (LRA), (2) the upper rectus abdominus (URA), (3) the external oblique, (4) the erector spinae, and (5) the multifidus. Details of electrode placement and validation by comparison to manual muscle testing is described in detail elsewhere.¹³

The raw surface electromyographic signals were preamplified (500×) then further amplified (bandpass at 10–1000Hz; CMRR=115dB [at 60Hz], input impedance, ≈10GΩ) using 5 channels of an AMT-8^b electromyography system. The raw

electromyographic signals and an event marker (a step voltage change) were digitized at 1000 samples per second by using a Tecmar Lab Master^c analog-to-digital conversion board (12-bit resolution). The event marker was used to divide the study exercises into 2 phases: the movement phase and the stabilization phase.¹³ The gain on each channel was adjusted to ensure a high signal amplitude, and each channel was calibrated by recording a 166Hz sinewave with a 0.6-mV peak-to-peak amplitude to calculate the true gain. No recordings were made within 10 minutes of electrode placement to ensure that skin temperature and impedance were stable. Baseline activity was recorded for 0.5 seconds while the subject completely relaxed in the supine position. The root-mean-square (RMS) amplitude of the noise on all channels was less than 5 μ V. Electromyographic signals were recorded from 3 abdominal and 2 back extensor muscle sites while subjects performed the normalization exercises and the 3 study exercises.

Normalization Exercises

Before performing the study exercises, subjects performed 4 different exercises intended to elicit maximal activity for normalization purposes. The exercises were selected according to criteria from previous reliability and validity studies of activation amplitudes^{26,27} and to minimize high compressive forces,²⁸ thus reducing the subjects' risk of injury. The exercises included (1) restrained sit-up in which the subject produced a maximal effort against a restraining strap across the chest^{13,26,27}; (2) trunk rotation to the left in which the seated subject, secured by straps across the hips and chest, produced a maximal rotation without trunk flexion^{5,13,26}; (3) isometric abdominal contraction in which the subject, lying supine with no restraints, maximally contracted the abdominals without moving^{13,16,26}; and (4) resisted back extension in which the subject, lying prone with feet and chest secured, maximally extended against the straps.^{13,26,29} The order of these normalization exercises was randomized, and each exercise was repeated at least twice. The electromyographic data were collected for 4 seconds for all trials, and subjects were given a 2-minute rest between trials. Verbal encouragement ("push, push, push") was given by the tester for all normalization trials. The study exercises were conducted after the normalization procedures.

Study Exercises

The pelvic-tilt, abdominal-hollowing, and TST exercises were randomly assigned, and each exercise was repeated 5 times. All 6 potential orders of presentation were represented

by the randomization. A short rest, of approximately 1 minute, was given between each trial. We found no significant order or trial effects in our earlier study on healthy subjects.¹³ Verbal instructions were consistent with a previous study.¹³ The starting position was similar for all 3 exercises. Subjects lay supine on an exercise table, knees flexed, and feet flat; hips were flexed to 70° as measured by a standard goniometer. For the pelvic tilt, subjects were instructed to "tighten their abdominals, roll their pelvis backward and flatten their low back so that it came in contact with the exercise table and hold that position until the end of the 4-second exercise."^{11,13,21} For the abdominal-hollowing exercise, the subjects were instructed to "tighten their abdominals and bring their navel up and in toward the spine and maintain this position until the end of the 4-second exercise."¹¹⁻¹³ For the TST exercise, the subjects were instructed to tighten their abdominals similar to the abdominal hollowing and then subjects were to lift their right foot off the exercise table until the thigh was vertical and the hip angle was 90°; the left leg was then lifted to the same position, then the legs were lowered one at a time in the same order.^{3,13,19} The total exercise from the "Go" command to the end of the exercise took 4 seconds. It was divided into 2 phases by 1 examiner who used the event marker to indicate the end of phase 1. Phase 1 was defined as the phase in which the movement of the trunk into the stable position took place. Phase 2 was the phase in which the low back and the pelvis were stabilized. This stabilizing phase began at the end of phase 1 and continued until the end of the data collection when the subject was asked to relax.¹³

Data Processing

The electromyographic amplitudes (in millivolts) were calculated by using the calibration, system bias, and subject-bias files. The RMS amplitudes for the normalization trials (RMSmvcj) and the test trials (RMSij) were calculated by using Fortran programs based on numeric recipes algorithms.¹³ The RMSij for each trial *i*, for each muscle *j*, for phases 1 and 2 were calculated separately, then were normalized to the RMSmvcj to yield a normalized RMS amplitude for each muscle *j* and trial (NRMSij) in %MVIC.³⁰

To examine temporal phasing of the muscle activity, the raw electromyographic signals were full-wave rectified, then low-pass filtered at 6Hz by using a second-order recursive Butterworth filter to yield a linear enveloped profile.³¹ The 4 seconds of data were time normalized to 100% by using a linear interpolation algorithm and then amplitude normalized to the appropriate MVIC trial. Ensemble-average patterns for each

Table 1: NRMS Amplitude in Percentage of MVIC for Each Muscle, for Each Exercise in Phases 1 and 2

Muscle sites	Exercises					
	Pelvic Tilt (N=14)		Abdominal Hollowing (N=14)		TST Level 1 (N=14)	
	Phase 1	Phase 2	Phase 1	Phase 2	Phase 1	Phase 2
LRA (%)	13.4±9.3*	12.4±8.9*	4.6±3.3*	5.0±2.5*	8.3±5.5*	8.6±4.7*
URA (%)	11.7±6.0*	12.9±8.2*	5.7±2.7*	6.2±3.0*	7.2±4.1*	8.5±4.5*
EO (%)	31.9±17.9	29.7±15.7	15.2±12.6	13.9±9.7	22.0±18.7	19.5±11.4
ES (%)	6.3±3.8*†	6.5±4.1*†	5.9±4.0*	6.4±3.9*	9.4±5.6*	9.7±5.9*
MT (%)	4.2±3.6*†	4.6±3.5*†	4.6±3.9*	5.1±3.7*	5.3±4.1*	7.1±4.7*

NOTE. Values are mean ± SD. Pairwise comparisons among muscles are statistically significant at the .0008 level (exceed the critical value of 3.24 for 104 *df*).

Abbreviations: EO, external oblique; ES, erector spinae; MT, multifidus.

* Significantly different from the EO.

† Significantly different from both the LRA and the URA.

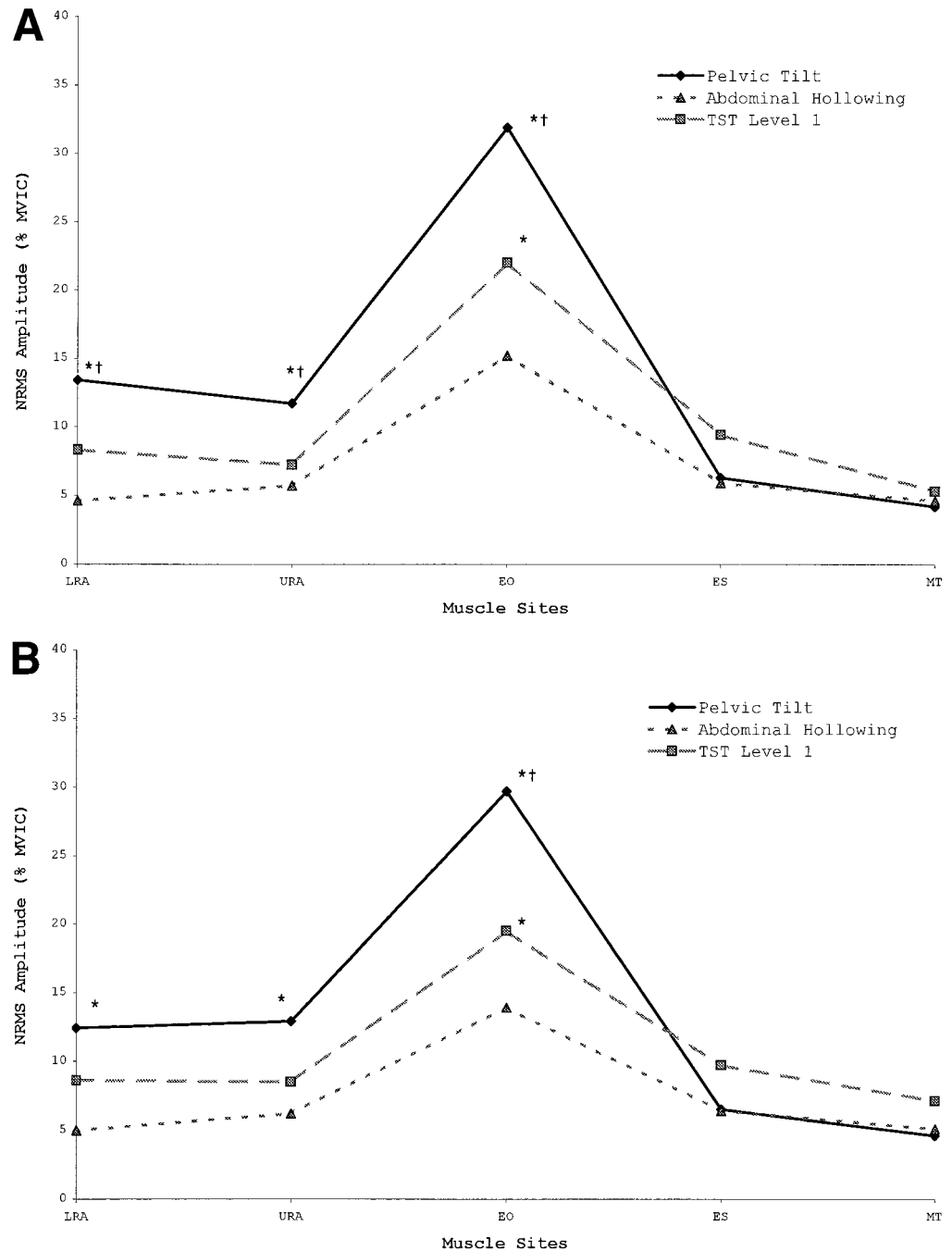


Fig 1. Interaction plots for muscle by exercise for (A) phase 1 and (B) phase 2. These interactions were statistically significant ($P < .05$). The between-exercise significant differences ($P < .0016$) are indicated on the plot for each muscle site. *Significantly different from abdominal hollowing; † significantly different from TST. Critical $t_{1,04} = 3.02$.

muscle for each exercise were calculated for the sample and the coefficients of variation (CVs) were determined.³

Statistical Analysis

Means and standard deviations (SDs) for age, height, mass, number of years with LBP, the disability scale, and the number of practice sessions before testing, and training sessions per week were calculated for descriptive purposes. Trial effects for the NRMS_{ij} amplitudes were tested by using repeated-measures analysis of variance (ANOVA) models before testing the 3 main hypotheses. In the absence of a trial effect, the mean

NRMS_{ij} amplitude for the 5 trials for each muscle for each exercise was calculated by using Excel, version 7.0,^d and was included as the main dependent variable.

Two separate 2-factor (muscle, exercise), repeated-measures ANOVA models were used to test the muscle-by-exercise interaction, and the muscle and exercise main effects for phases 1 and 2, separately ($\alpha = .05$). The statistical analyses were performed by using Minitab^e statistical software package, release 11Xtra. Bonferonni post hoc analyses were performed on all appropriate significant effects, and α was adjusted accordingly.

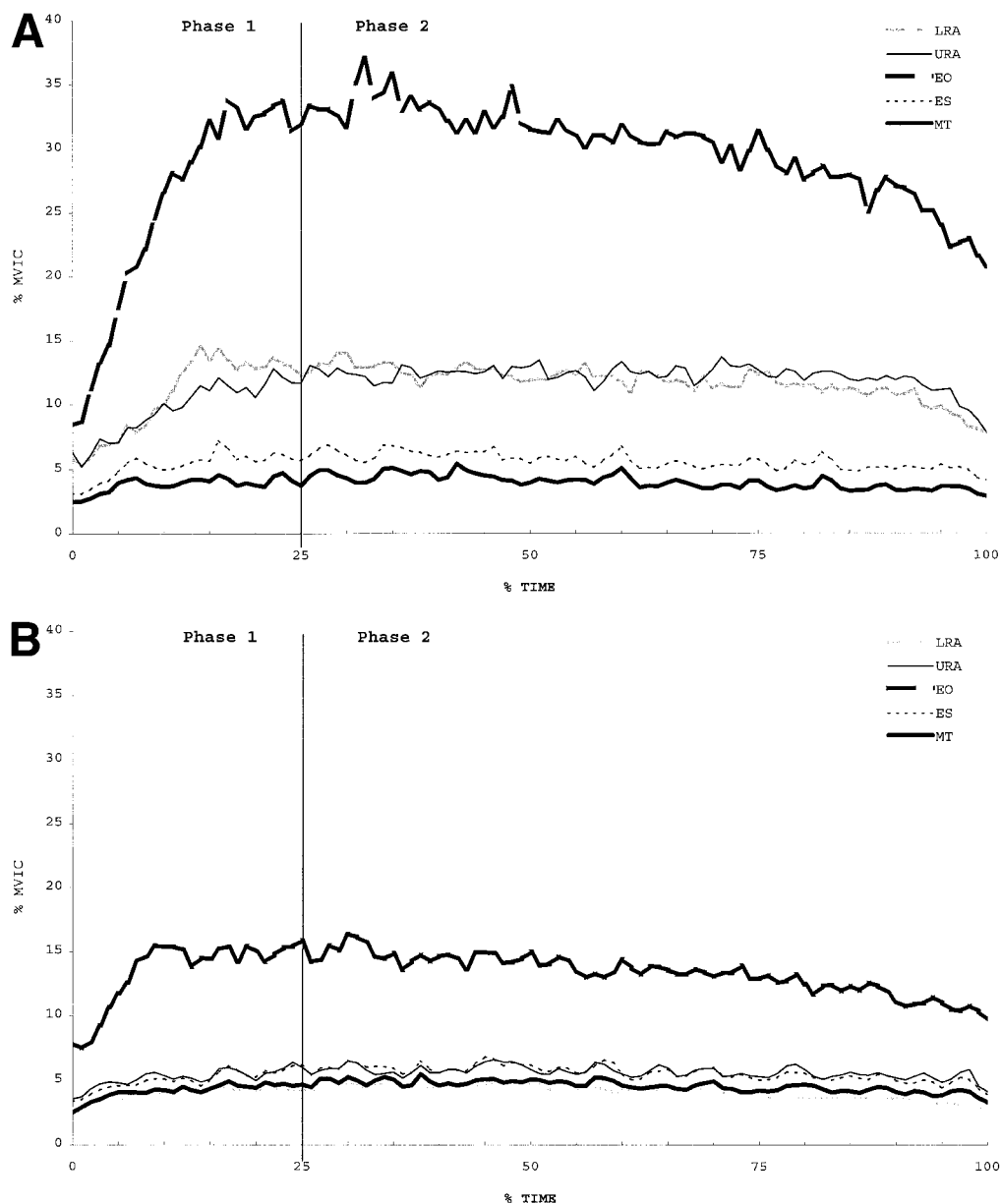


Fig 2. Ensemble-average curves (N=14) showing percentage of total exercise time that each muscle was activated. CVs for the LRA, URA, external oblique, erector spinae, and multifidus, respectively, are (A) pelvic tilt: 70%, 51%, 51%, 60%, and 86%; (B) abdominal hollowing: 72%, 47%, 83%, 68%, and 84%;

RESULTS

Fifteen subjects volunteered and were initially screened; one could not be tested because of his high disability rating and high discomfort on the test day. Fourteen men (age, 39 ± 5 y; mass, 87.4 ± 15 kg; height, 177.4 ± 5 cm) completed the study. The mean number of years reported for having LBP was 7.7 ± 4.8 , and the range was from 1 to 15 years. All subjects had received physiotherapy during the course of their LBP, but none had previously performed stabilization exercises. The mean Roland-Morris Disability Scale score was 4.3 ± 3.4 , with a range from 0 (1 subject), indicative of no disability, to 12, or moderate disability. The scale indicated the persons' perceived disability on test day. The pain scale range was from 1 to 3, with 7 subjects reporting 1 (mild pain), 6 reporting 2 (moderate), and 1 reporting 3 (quite bad). The mean Oswestry questionnaire score was 19.4 ± 13.9 . Subjects had a consistent number of practice sessions: the mean number reported between the

initial session and the test session was $3.4 \pm .76$. The mean number of training sessions per week, indicative of subjects' physical activity level was 2.9 ± 2 . Seven of the 14 subjects (50%) were unable to perform the trunk-raising forward test for minimal abdominal strength on test day.

There were no difference ($P > .05$) in NRMS amplitude across trials; therefore, the mean NRMS amplitude of the 5 trials for each subject for each exercise was the main dependent measure used to test the 3 hypotheses. The sample means \pm SDs for the NRMS are in table 1 for phases 1 and 2. The ANOVA revealed a statistically significant ($P > .05$) muscle site-by-exercise interaction for both phase 1 and phase 2 (fig 1). Subsequently, the effects of exercise were tested by fixing muscle site, and the effects of muscle site were tested by fixing exercise. We used the Bonferroni *t* test and corrected α ($\alpha = .0008$ for comparing among muscles, $\alpha = .0016$ for comparing among exercises).

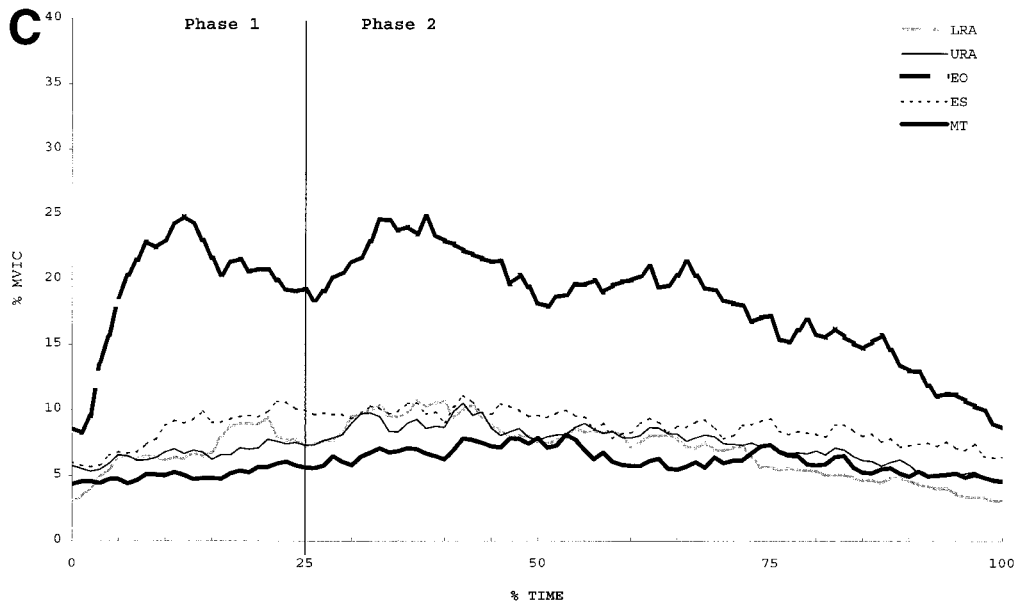


Fig 2. (Continued) (C) TST: 66%, 57%, 85%, 60%, and 77%.

Statistically significant differences ($P > .0008$) in NRMS amplitudes were found among muscle sites within each exercise (table 1). The external oblique was activated at a significantly higher ($P > .0008$) relative amplitude than the other 4 muscle sites for all 3 exercises and for both phases. The LRA and URA did not differ significantly ($P > .0008$) from each other for any of the exercises, but both rectus abdominus sites did differ significantly from the 2 back extensor sites for the pelvic-tilt exercise only. No other between-muscle differences were statistically significant.

The significant differences among exercises are shown on figures 1A and 1B for phase 1 and phase 2, respectively. The pelvic-tilt NRMS amplitude for the external oblique was significantly higher ($P > .0016$) than either the abdominal-hollowing or the TST exercises for both phases; the TST external oblique activation also was higher than the abdominal hollowing for both phases. The 2 rectus abdominus NRMS amplitudes for the pelvic tilt were significantly higher than the abdominal-hollowing exercises ($P > .0016$) for both phases but only for phase 1 compared with the TST.

The ensemble-average electromyographic profiles for the 5 muscles and the 3 exercises are in figure 2. The patterns for the pelvic-tilt and the abdominal-hollowing exercises were similar. For all 5 muscle sites, they exhibited an initial increase in activity, particularly for the external oblique muscle site, very little variation in amplitude over most of the exercise, and a decrease in activity toward the end of phase 2. The TST profiles showed an initial increase in activity during phase 1 for all muscle sites except the multifidus. The amplitude of the external oblique muscle site increased and decreased throughout the exercise in synchrony with the leg-lifting and lowering tasks. The other 4 muscle sites did not increase and decrease in a synchronous manner with respect to the external oblique or with respect to each other. No statistical tests were performed on these curves. The CVs for the ensemble-average profiles indicated large between-subject variability in the activation amplitudes used to perform the 3 exercises.

DISCUSSION

The recruitment amplitudes and patterns indicated that some muscle sites were recruited in a manner consistent with the objectives of dynamic lumbopelvic-stability exercises. Although some of the present findings were similar to those reported for normal healthy subjects,¹³ notable differences existed both in the quantitative amplitude data and in the ensemble-average profiles.

The LBP subjects in the present study represented a relatively heterogeneous group with respect to mass, height, and the amount of physical activity in which they participated on a regular basis. A higher percentage of our subjects could not complete the minimal abdominal test (50%) compared with percentages reported for normal healthy samples (25%).^{13,16} This was expected because muscle dysfunction has been shown to be present in persons with LBP.¹⁰ As indicated by the disability rating, most subjects reported a low to moderate level of disability on test day, but this finding should not be interpreted to mean that they are this disabled at all times. The Roland-Morris Disability Scale is sensitive to change in persons with low disability,²⁴ and in the present study it was used to describe the level of disability of the sample on test day. The highest disability rating was 12, a rating that has been previously associated with a "quite bad pain" rating on a 6-point scale.²² However, this subject reported a moderate level of pain. Similar to the disability rating, the pain scale indicated mostly mild to moderate pain on test day with only 1 subject reporting "quite bad pain." It should be noted that this subject did not have the highest Roland-Morris measure but did have the highest score on the Oswestry scale. On the Oswestry scale, all subjects reported some disability in managing everyday activities because of their pain, with the mean indicative of mild to moderate disability, although 2 subjects scored in the severe disability category.²³ The results must be interpreted within this context. All subjects were classified as chronic because they reported having LBP longer than the minimum of 7 weeks defined by the Quebec Task Force on Spinal Disorders.²⁰ Because diagnostic classification of LBP continues to

provide challenges and debate, we adhered to specified descriptive measures, definitions, and exclusion criteria in an effort to provide a clear description of the population from which our sample was drawn. The study sample was deemed appropriate because there is support for exercise as an effective therapeutic option for persons with chronic LBP, whereas minimal evidence exists that it is effective in the acute phase.³² The patterns reported in the present study represent patterns from men with mostly mild to moderate disability and pain levels and should not be extrapolated to those who have severe pain and disability.

All subjects reported practicing the exercises on 3 or more occasions, and there was minimal variation in the number of practice sessions among subjects (<.80 of a session). Because all subjects correctly performed the study exercises on test day and there was no significant trial effect, 3 practice sessions were deemed sufficient for the subjects to learn the tasks, with minimal neuromuscular variation between trials. Subsequently, the differences in the quantitative comparisons and the qualitative evaluation of the ensemble-average profiles between exercises were not attributed to learning, consistent with findings for subjects who had no LBP.¹³

Comparisons of the NRMS Amplitudes

LBP subjects used different patterns of recruitment amplitudes (see fig 1) to perform the 3 study exercises, providing evidence that the neuromuscular demands differed for each exercise. In the movement phase (phase 1), we observed several interesting relationships: amplitudes measured during the pelvic tilt were higher than those for either the abdominal-hollowing exercise or the TST, showing that the instruction to "tighten the abdominals, roll the pelvis backward and flatten the low back" elicits higher activation from the abdominal muscle sites than "tighten the abdominals and bring the navel up and in toward the spine and maintain this position." Our findings were consistent with those reported in a study¹³ of healthy subjects who performed the abdominal-hollowing exercise with similar instructions, however, those researchers reported no significant differences for the 2 rectus abdominus sites between the pelvic-tilt and the abdominal-hollowing maneuvers for the TST (phase 1). The present data on LBP subjects also show that—compared with the pelvic-tilt maneuver—the abdominal-hollowing maneuver was not better able to selectively recruit the external oblique. Both exercises produced significantly higher external oblique activity than rectus abdominus activity. Although our finding was consistent with that reported for healthy subjects,¹³ it contrasts with earlier claims that the pelvic-tilt maneuver targets the LRA and not the external oblique muscles.¹¹ The difference may be explained by the normalization procedure followed by Richardson et al,¹¹ who used a single trunk-rotation exercise for normalization,¹¹ an exercise shown to produce high external oblique and low LRA activity.²⁶ We found that external oblique amplitudes were significantly higher than rectus abdominus amplitudes during the abdominal-hollowing exercise. Another study¹⁷ of patients whose pain levels were similar to our subjects' had a different result: they found no difference between the internal oblique and rectus abdominus amplitudes. The large between-subject variability they reported¹⁷ can explain why the difference in muscle activation was not statistically significant even though the internal oblique amplitude was almost twice as high as that for the rectus abdominus. Subjects included in their study also had evidence of spondylolisthesis and spondylolysis (which causes intervertebral instability and may elicit different muscle activation), whereas the former was an exclusion in the present study.

Of particular interest were the findings related to the abdominal-hollowing exercise and the TST. The abdominal-hollowing task for both exercises was the same in phase 1, but the leg-lifting perturbation during phase 2 of the TST provided an additional challenge to trunk stability. The LBP subjects did not elicit a preparatory contraction of the rectus abdominus preceding the external leg-lifting perturbation during phase 1 nor did they exhibit higher rectus abdominus activity to assist with trunk stabilization during phase 2 of the TST, both of which were reported for healthy subjects.¹³ Also, in both phases of the TST, external oblique activation was higher than that recorded during the abdominal-hollowing exercise, whereas for healthy subjects higher external oblique activity was reported¹³ only during phase 2 (ie, in response to the increased challenge associated with the leg-lifting task). Our present findings contradict the previous evidence that persons with LBP are unable to isolate the oblique muscles to the same extent as normal subjects during the abdominal-hollowing maneuver¹⁷ and the clinical claims that the rectus abdominus tends to substitute for the obliques during attempts to preferentially activate them.⁵ Our findings support the theory that LBP patients' abdominal muscle recruitment strategies differ from those of healthy persons, particularly with respect to the role of the rectus abdominus during both the movement and stabilization phases of the TST exercise.

Many exercises are advocated for improving dynamic trunk stability,^{1-6,11,12,33} and recent electromyography studies using standardized methods^{13,33-35} have attempted to provide the quantitative empirical evidence to improve our understanding of the muscle activity during these exercises. Knowing which muscles are targeted during specific exercises and whether LBP subjects recruit muscles differently than do healthy persons is imperative for evidence-based decision making and exercise prescription. Different normalization procedures, or lack thereof, have made between-study comparisons and interpretation of results difficult. Although the value of normalizing electromyographic amplitudes to maximal voluntary isometric efforts has been extensively debated, there is evidence that evaluating the percentage of maximum that a muscle is recruited on a specific day has a physiologic meaning,²⁵ and its value in making between-muscle comparisons is shown.³⁶⁻³⁸ Many recent studies have presented data normalized to maximum voluntary amplitudes,^{12,13,33-35} and current guidelines for using surface electromyography in the assessment and treatment of low back dysfunction recommends the use of a maximal effort for normalization purposes.³⁶ Pain or other inhibitory mechanisms may prevent LBP patients from achieving true maximum activation. Nevertheless, because none of the 3 exercises recruited the 5 muscle sites to intensities above 30% of their maximal voluntary effort, these exercises would not be considered appropriate for eliciting a strength training effect.³⁵ Because strength deficits have been associated with LBP,¹⁰ we expected that LBP subjects would recruit their abdominal muscles to a high percentage of MVIC for the TST in response to the leg-lifting challenge. The data, however, suggest that the demand on the neuromuscular system is low for LBP subjects.

All 3 exercises had trunk extensor activity greater than 4% MVIC. Amplitudes as low as 3% to 5% MVIC are effective for improving trunk stability.⁹ Although erector spinae activity in the TST tended to be higher than that in either the pelvic tilt or abdominal hollowing, this trend was not statistically significant. It was, however, significant in normal subjects during phase 1 of the TST.¹³ The present study found that none of the exercises were more effective than any other for recruiting higher extensor activity. Trunk-extensor coactivation has been considered important for trunk stabilization during leg-lifting

tasks.⁶ This finding requires further exploration before definitive conclusions can be drawn as to whether LBP patients are unable to coactivate back extensors during leg-lifting. In the present study, the percentage of MVIC for erector spinae during the pelvic tilt was similar to the amplitudes reported for healthy subjects¹³ but contrasted with earlier reports¹⁴ of high erector spinae activity in LBP subjects performing the pelvic tilt. The muscle spasm theory was used to explain higher paraspinal activity in persons with LBP¹⁴; however, controversy exists regarding muscle spasm and muscle deficiency theories associated with back extensors and LBP.¹⁰ Although our present data indicated low trunk extensor activity for all 3 exercises, the sample was of low disability and all had learned to cope with their chronic condition. Further examination of the role of the trunk extensors during therapeutic exercises in other LBP populations is needed to ascertain whether specific exercises would benefit or harm persons who have associated muscle spasm or muscle deficiencies of the paraspinal muscles.

Qualitative Assessment of Electromyographic Profiles

The activation patterns for the 5 muscle sites for the pelvic-tilt and the abdominal-hollowing exercises were similar with the exception of the steep initial increase for the external oblique muscles. Figure 2 clearly shows a gradual drop in abdominal activity and minimal change in trunk extensor activity throughout performance of the phase 2 for the 2 exercises. It is difficult, therefore, to ascertain whether the muscles were coactivated in a coordinated manner. In contrast, the TST profile shows an initial increase for the external oblique during phase 1, followed by a decrease and then small increases in external oblique activity associated with the leg-lifting (just after 25% time) and leg-lowering tasks (approximately 50% time). The profiles for the other 4 muscles show minimal change throughout the stabilization phase and thus do not support coordination of coactivation among the 5 muscle sites examined. A similar trend to that described above for the external oblique was reported for healthy subjects for the external oblique muscles during the TST, however, the trend was also found for the LRA, URA, and erector spinae muscle sites, a finding that supports coordination of activity among these 4 sites.¹³ Synergistic coactivation of agonist and antagonist muscles is an important concept associated with dynamic stability,^{8,10} and quantitative comparisons of the profiles are needed to substantiate whether 1 exercise challenges this coordination better than another. Ensemble averaging provides a mean profile. This approach may mask subtle differences in muscle activation patterns and may compromise our ability to detect intermittent activity. More objective are statistical pattern recognition techniques such as principal component analysis. This approach may help us better classify and diagnose dynamic stability problems. Assessing the electromyographic profiles through quantitative analysis should improve our ability to measure the effectiveness of different therapies aimed at improving coordination of muscle coactivation.

Clinical Implications

The results showed that the exercises differed from each other and that some objectives associated with dynamic stability training were being met in each exercise. Results from persons with no LBP¹³ indicate that neuromuscular strategies are different in persons with LBP, and this was most evident with respect to the TST. Quantitative comparisons and further study of the TST in particular are necessary to determine whether training with this exercise will change muscle activation patterns and ultimately improve dynamic stability. All 3 exercises could be used as initial exercises in a dynamic sta-

bility progression when low-recruitment amplitudes of specific muscles is the objective, but not for strengthening.

CONCLUSION

This surface electromyography study of 14 LBP subjects revealed differences in relative activation amplitudes among exercises and among muscle sites, providing evidence that the 3 exercises differed with respect to patterns of muscle recruitment amplitudes. None of the 3 study exercises recruited the abdominal muscle sites to intensities deemed effective for eliciting a strengthening response, although the variability among subjects suggests that some may have reached intensities that would be appropriate for promoting a strengthening or endurance response with repetition. All 3 exercises selectively recruited the external oblique muscles to higher amplitudes than the LRA and URA sites, and all had low amplitudes of antagonist coactivation. The electromyographic profiles also support the conclusion that the neuromuscular demands differed among the exercises. The TST exercise showed qualitative differences in the electromyographic profiles among the 5 muscle sites, indicative of a lack of coordination of activity and thus a challenge to the neuromuscular control of the trunk for this sample of subjects with LBP.

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