Muscle Activation in Therapeutic Exercises to Improve Trunk Stability

M. Johanne Vezina, MSc, Cheryl L. Hubley-Kozey, PhD

ABSTRACT. Vezina MJ, Hubley-Kozey CL. Muscle activation in therapeutic exercises to improve trunk stability. Arch Phys Med Rehabil 2000;81:1370-9.

Objective: To evaluate the relative activation amplitudes from 3 abdominal and 2 trunk extensor muscle sites in healthy subjects performing the pelvic tilt, abdominal hollowing, and level 1 of the trunk stability test (TST level 1) exercises and to compare the activation amplitudes among muscle sites and exercises.

Design: Prospective comparative study.

Setting: Motion Analysis Research Center, Dalhousie University, Canada.

Participants: Twenty-four healthy men (mean age, 30 ± 8.1yr [SD]) without low back pain.

Interventions: Subjects performed 3 exercises in a balanced order, repeating each exercise 5 times while surface electromyography (EMG) was recorded from the 5 muscle sites. Exercises were divided into 2 phases: movement and stabilization. The root-mean-square amplitude of the EMG for each phase was calculated and normalized to the maximal voluntary isometric contraction (MVIC) amplitude for each muscle. A 2-factor repeated-measures analysis of variance (ANOVA) tested the muscle by exercise interaction and the main effects for each phase separately.

Main Outcome Measures: Normalized activation amplitude was the main dependent variable. Ensemble-average curves were calculated to examine the phasing of activation.

Results: ANOVA showed a statistically significant interaction ($p < .05$) for both phases, indicating the 3 exercises recruited the 5 muscle sites using different patterns of relative activation. The external oblique (EO) muscle site was activated to higher amplitudes than the other 4 sites in all 3 exercises for both phases. The highest activity was recorded from the EO during the pelvic tilt, just more than 25% of MVIC. The only exercise to recruit the erector spinae to significantly higher amplitudes than the multifidus site was the TST level 1.

Conclusions: Study exercises were not interchangeable for the patterns of trunk muscle activation amplitudes. The exercises did not recruit the abdominal muscles to adequate levels for strengthening for this healthy sample; however, all 5 muscle sites were activated, forming the basis of a stabilizing exercise approach.

EXERCISE AS A THERAPEUTIC APPROACH to the prevention, treatment, and management of low back pain (LBP) has received increasing support over the past decade.[1,2] However, controversy exists in the literature about improved outcomes associated with specific interventions, and most LBP episodes have recovered within 6 weeks regardless of treatment.[3] A recent focus has been on exercises to restore dynamic stability to the trunk[4-7] because spinal instability has been linked to the development of low back dysfunction.[1,8] Dynamic instability of the spine has been associated with insufficient strength and endurance of the trunk stabilizing muscles and inappropriate recruitment of the trunk and abdominal muscles.[1] Therefore, dynamic stability exercises should improve the muscular responsiveness needed to stabilize the spine against perturbations associated with movement and activities of daily living,[9,10] emphasizing proper sequencing of muscle activation, coactivating synergistic muscles, and restoring muscle strength and endurance to key trunk stabilizers.[11]

Although many therapeutic exercises are used to manage low back dysfunction, this study focuses on exercises of abdominal musculature, particularly those exercises performed in the supine position. The 3 exercises examined were the pelvic tilt,[12-14] abdominal hollowing,[7,14,15] and level 1 of the trunk stability test (TST level 1).[2,16] The latter has been used as an initial progression to assess trunk musculature ability to maintain trunk stability[16] and as a therapeutic exercise.[2,17] Claims, many unsubstantiated, indicate some exercises are more beneficial than others for recruiting the trunk musculature in a manner that would improve trunk stability. The 3 exercises were chosen to compare approaches developed in the past decade with the more traditional pelvic tilt exercise, acknowledging the many unanswered questions about activation patterns associated with the pelvic tilt.[18]

The aim of this study was to quantify and compare the activation amplitudes of specific muscle sites and to use this information to assess the potential of each exercise to recruit specific muscles in a manner consistent with the objectives of dynamic stability exercises.[11] First, we sought to determine the amplitude of activity produced during the exercises relative to the maximum voluntary amplitude to assess each exercise's potential to improve abdominal strength and endurance. Surface electromyography (EMG), reported as a percentage of maximum, has been used to assess potential training effects of therapeutic exercises for back extensor muscles.[4] Second, we examined the selective recruitment of the oblique abdominals because the obliques are considered important trunk stabilizers,[6,19,20] particularly for sagittal plane movements. Third, we examined the possibility that different segments of the rectus abdominus (RA) can be isolated while the 3 exercises are performed because selective recruitment reportedly occurs within the different levels of the RA, although this is controver-

sial.[21-24] The final objective was to use the relative activation amplitudes to assess back extensor coactivation, a neuromuscular control strategy important to maintain trunk stability.[25] In particular, the intersegmental multifidus (MT) muscle had a greater role in stability than such superficial trunk extensors as the erector spinae (ES) muscle.[26]

Our specific objectives were to measure the relative activation amplitudes from 3 abdominal and 2 trunk extensor muscle sites of healthy subjects performing the pelvic tilt, abdominal hollowing, and TST level 1 exercises and to compare the activation amplitudes among muscle sites and exercises. The main dependent variable was relative activation amplitude measured by surface EMG, normalized to maximal voluntary isometric contraction (MVIC) amplitudes. We hypothesized that: (1) the patterns of recruitment amplitudes for the 5 muscle sites are different among the 3 exercises; (2) the relative activation amplitudes among the 5 muscle sites are different, showing selective recruitment of abdominal sites and minimal coactivitation; and (3) the relative activation amplitudes among the 3 exercises are different, showing that the neuromuscular demands of each exercise are different.

METHODS

Subjects

Twenty-four healthy men aged 20 to 54 years, without known neuromuscular, orthopedic, or cardiovascular conditions, volunteered to participate in the study. Subjects were recruited through advertisements posted at a military base in various departments, at the base hospital and gymnasium, and on the Internet. The study was restricted to men to reduce variability associated with sex. Subjects with a history of LBP, spinal deformities, or previous spinal surgery were excluded.

During an initial session, subjects were informed of the project, and written consent was obtained, with the approval of the Faculty of Graduate Studies and Health Professions Ethics Committees of Dalhousie University (Halifax, NS, Canada). A postural assessment was conducted by a physiotherapist (MJV.) with 15 years' orthopedic clinical experience to ensure that subjects had no structural spinal deformity. Subjects were graded for minimal abdominal strength using the trunk raising forward exercise[27] to provide an objective assessment of minimal muscle function and to compare percentages from this sample with results from a previous study of abdominal muscle exercise progressions.[28] No inclusion or exclusion criteria were based on participation in an abdominal exercise or other exercise program, and no subjects had previously performed the study exercises. Subjects were instructed how to perform the 3 study exercises and asked to practice them 10 times each on 3 separate days. They were given a written description of the exercises and asked to report the number of practice sessions between the initial session and test session.

The test session occurred 1 to 2 weeks later, and EMG data were collected. The subjects' age (years), mass (kilograms), height (centimeters), number of practice sessions from the initial session, and physical activity level were recorded. Physical activity level was defined as the average number of training sessions weekly, including at least 30 minutes of cardiovascular fitness.[28] Subjects were excluded if they were unable to perform 1 or more of the 3 exercises on test day. EMG signals were recorded from 3 abdominal and 2 trunk extensor sites during the performance of a series of normalization exercises and the 3 study exercises.

Surface EMG Data Acquisition

Five channels of an 8-channel surface EMG system[a] were used. The raw EMG signals were preamplified (500 times) then further amplified (bandpass, 10–1000Hz; common mode rejection ratio, 115dB (at 60Hz); input impedance, $\sim 10\text{G}\Omega$). The raw EMG signals and an event marker (step voltage change) were digitized at 1000 samples/second using a Tecmar Lab Master analog to digital conversion board[b] (12-bit resolution) and a general basic program[c] on a personal computer. Because of the minimal signal energy in surface EMG at frequencies as high as 500 Hz,[29] a sampling rate of 1000Hz was used. Data were recorded onto a hard disk and transferred to floppy disks for offline processing. The event marker was used to divide the exercises into 2 phases.

Before the subjects arrived, EMG system bias and noise were recorded for 0.5 seconds. Surface electrode (Meditrace silver/silver chloride [10mm] pellet[d]) pairs were placed in a bipolar configuration over the 5 muscle sites in line with the muscle fibers, at a distance of 2cm center to center. Skin preparation included shaving excess hair and rubbing the skin with an alcohol-water solution to reduce skin impedance magnitude (ratio of skin–amplifier impedance $< 0.1\%$). The 5 sites on the right side were: (1) the lower RA (LRA), centered on the muscle belly midway between the pubis and umbilicus[28]; (2) upper RA (URA), centered on the muscle belly between the sternum and umbilicus[28]; (3) external oblique (EO), 15cm lateral to the umbilicus[8]; (4) ES, 6cm lateral to L1-L2 spinous process[30]; and (5) MT, 2cm lateral to L4-L5 spinous processes[4,8] (fig 1). Potential exists for cross-talk from other muscles; however, electrode sites were validated using manual muscle testing to isolate each component.[31] It is difficult to isolate the lateral ES and the more medial MT sites; however, these sites were previously monitored and differences were shown between the 2 sites.[30] A recent study showed high correlations between indwelling and surface recordings for the MT site.[4] Slight modifications and adjustments for anatomic variations among subjects were made by palpation by the physiotherapist. A reference electrode was placed over the right iliac crest.

The gains on each channel were adjusted to ensure a high signal amplitude, and actual gain for each channel was calculated by recording a 166-Hz sine wave with a 0.6-mV peak-to-peak amplitude. No recordings were made within 10 minutes of electrode placement to ensure a stable temperature and impedance.[32] Subject were asked to relax completely in the supine position; this baseline activity was recorded for 0.5 seconds and used as the subject bias activation amplitude and to assess total noise. Noise on all channels was less than 5μV; thus, a high signal to noise ratio was achieved.

Normalization Exercises

Before the test trials, subjects performed 6 different normalization procedures, 4 for the abdominal and 2 for the trunk extensor groups, in an attempt to elicit a maximal effort. The exercises were: (1) restrained sit-up effort, in which subjects produced maximal effort against a restraining strap across the chest, intended to elicit high URA and LRA activity[33,34]; (2) hanging supine, in which subjects lowered the trunk to the horizontal until they were leaning over the edge of the plinth with the trunk horizontal and the umbilicus in line with the edge of the plinth, intended to elicit high LRA and EO activity[33,34]; (3) trunk rotation to the left, in which subjects were seated, secured by straps across the hips and chest, and required to produce maximal rotation without trunk flexion, intended to produce high EO activity[37,34]; (4) isometric abdominal contrac-
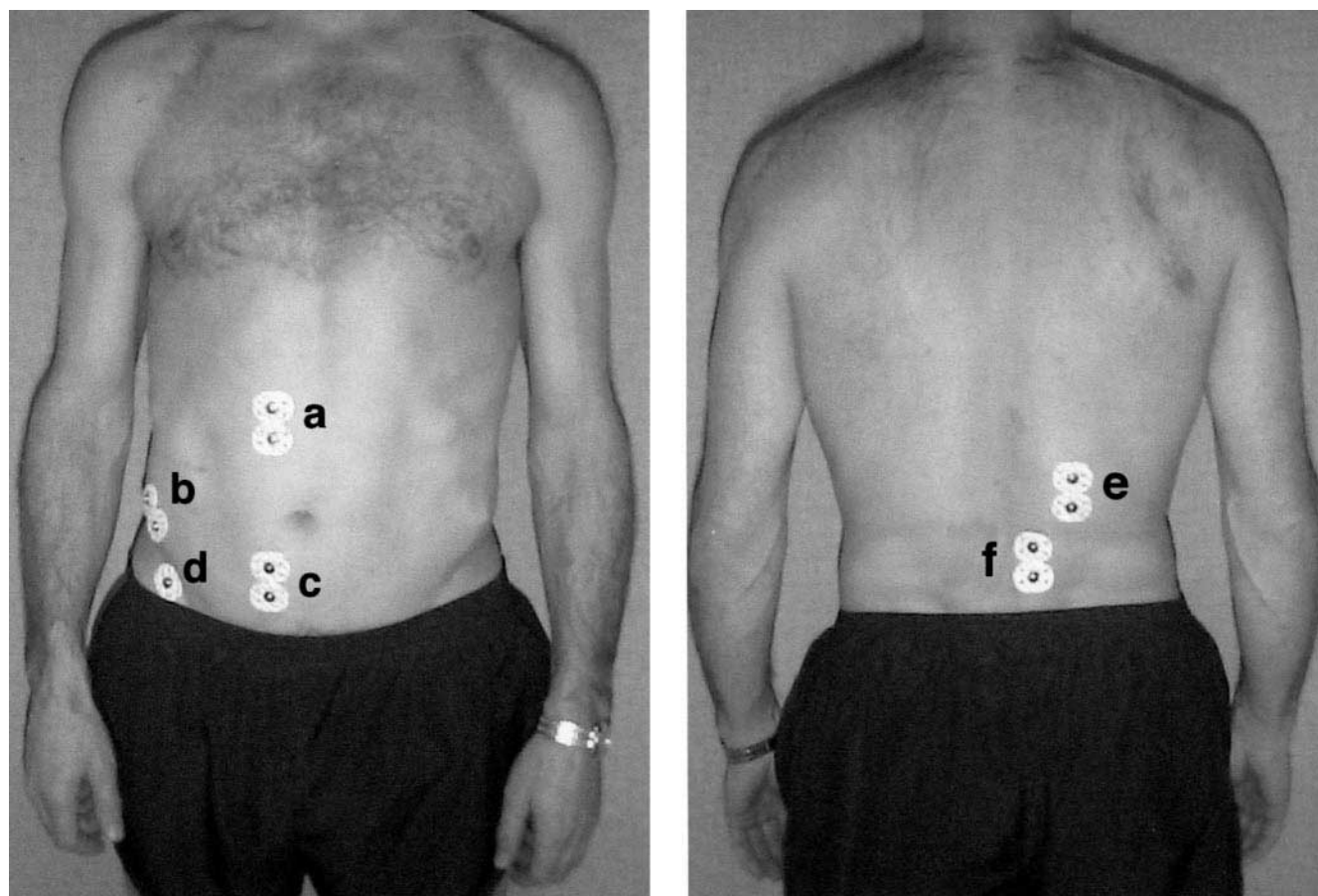
Fig 1. Electrode placements for (a) URA, (b) EO, (c) LRA, (d) reference electrode, (e) ES, and (f) MT. See text for description.

tion with no resistance, with subjects lying supine without restraints and maximally contracting the abdominals without moving, intended to produce high activity from all abdominal muscles[28,34]; (5) hanging prone, in which subjects lay prone and extended to and held a horizontal trunk position[34,35]; and (6) resisted back extension, in which subjects' feet and chest were secured while lying prone and they were asked to extend against the straps.[34,36] Exercises 5 and 6 were intended to elicit maximal activity from the 2 trunk extensor sites. The order of the abdominal and trunk extensor normalization procedures was randomized, and each exercise was repeated at least twice. EMG data were collected for 4 seconds for all trials, and subjects were given a 2-minute rest between trials. The tester gave verbal encouragement: ''push, push, push'' for all normalization trials except hanging supine and hanging prone, in which the subject maintained the static horizontal position. The study exercises followed normalization procedures.

Study Exercises

The pelvic tilt, abdominal hollowing, and TST level 1 exercises were randomly assigned and balanced to test order effects. Subjects performed 5 successive trials of each exercise, with a short rest of approximately 1 minute between each trial. Verbal instructions were consistent for every subject for every trial. The 3 exercises and verbal commands are described next.

Pelvic tilt exercise. Subjects lay supine on an exercise table with knees flexed and feet flat, hips flexed to 70° as measured by a goniometer. They were instructed to tighten their abdominals, roll their pelvis backward, flatten their low back so it came

in contact with the exercise table,[7,27] and maintain this position until the end of the 4-second exercise.

Abdominal hollowing exercises. Subjects lay supine on a exercise table with knees flexed and feet flat, hips flexed to 70° as measured by a goniometer. They were instructed to tighten their abdominals, bring their navel up and in toward the spine, and maintain this position until the end of the 4-second exercise. The exercise performance was closely monitored to ensure that subjects were not tilting the pelvis backward or inhaling and elevating the rib cage to make the abdomen look flat.[2,7]

TST level 1 exercise. Subjects lay supine with hips and knees bent and feet flat on the exercise table and placed their fingertips on each side of the abdomen just above the pelvis and below the rib cage. They were instructed to tighten their abdominals, bring their navel up and in toward the spine, and hold this position until the end of the 4-second exercise. Once the spine was stabilized, subjects lifted their right foot off the exercise table until the thigh was vertical and the hip angle was 90°.[2,16,34] The left leg was then lifted to the same position. Legs were lowered 1 at a time to the starting position in the same order. Trials in which the back arched during the second phase of the exercise were discarded, and the exercise trial was repeated, emphasizing the need to keep the stomach up and in and maintain the pelvis stable while lifting the legs.[2]

From beginning to end, the exercise took 4 seconds and was divided into 2 phases by an event marker indicating the end of phase 1. Phase 1 included movement of the trunk into the stable position. For pelvic tilt phase 1, it was from the ''Go'' command

until the time the pelvis was tilted and the back flattened. For the abdominal hollowing and TST level 1 exercises, phase 1 was from the "Go" command until the abdomen was flattened or hollowed as defined by Richardson et al.[2] During phase 2, the low back and pelvis were stabilized, after which subjects were told to relax. A single examiner determined all testing positions and phases.

Data Processing

The EMG digitized signals were converted to millivolts using a Fortran program that used the calibration, system bias, and subject bias files to correct the data for DC offsets and biases and to calculate the amplitude of the EMG signal recorded at the skin electrode interface. The programs incorporated numeric recipe algorithms.[37] Root-mean-square (RMS) amplitudes were calculated for the normalization trials by a computer algorithm that determined the 500 consecutive samples (0.5sec) of raw EMG data within the 4-second sample, with the highest RMS amplitude for each normalization exercise[34,38] for each muscle. $RMSmvic_j$ was determined to be the RMS amplitude for muscle j with the highest amplitude, regardless of the normalization procedure from which it was obtained.[33,38]

For the test trials, a computer program separated the 2 phases based on the event marker and RMS_{ij} for each trial i and each muscle j; phases 1 and 2 were calculated separately. RMS_{ij} data were then normalized to the $RMSmvic_j$ using the following equation:

$$NRMS_{ij} = RMS_{ij} * 100\%$$
$$RMSmvic_j$$

where $NRMS_{ij}$ is the normalized value for muscle j and for trial i. $NRMS_{ij}$ values for both phases were the main dependent variables of the study.

To examine EMG patterns over time, raw signals were full-wave rectified, then low-pass filtered at 6Hz using a second-order recursive Butterworth filter to yield a linear enveloped profile.[31,39] The 4 seconds of data were first time normalized to 100% using a linear interpolation algorithm and then amplitude normalized to the MVIC trial. Ensemble-average patterns for each muscle for each exercise were calculated for the sample ($n = 24$), and coefficients of variation were determined.[39]

Statistical Analysis

Descriptive statistics were calculated including mean ± standard deviation (SD) for age, height, and mass. Median and range for number of training and practice sessions weekly and number of subjects able to perform the basic abdominal testing

were reported. Homogeneity of variance was tested using the Levene test,[40] and trial effects and order effects were tested using a repeated-measures analysis of variance (ANOVA) model before testing the 3 main hypothesis. In the absence of a trial effect, the mean $NRMS_j$ value for the 5 trials for each muscle was calculated using Excel version 7.0[e] and was the main dependent variable. Sample means ± SDs for $NRMS_j$ for each muscle for each exercise were calculated using Excel.

Two separate 2-factor (muscle, exercise) repeated-measures ANOVA models were used to test each hypothesis for phases 1 and 2 separately ($\alpha = .05$). Statistical analyses were performed using Minitab statistical software package, version 11Xtra.[f] Bonferonni post hoc analyses were performed on all appropriate significant effects. To achieve an overall family error rate of 5%, α was adjusted for a 2-sided t-test ($.05/2 = .025$) and multiple comparisons. When comparing muscles, α was adjusted for 30 comparisons, $.025/30 = .0008$, and when comparing exercises, α was adjusted for 15 comparisons, $.025/15 = .0016$. Age, mass, height, minimal abdominal strength, number of practice sessions, and number of training sessions were examined using stepwise regression procedures to determine if any variables or subset of variables were potential covariates ($\alpha = .05$).

RESULTS

Twenty-eight subjects were initially screened; 2 could not be tested because of hardware problems, and 2 could not perform the abdominal hollowing exercise on the test day. Twenty-four men (age, 32 ± 8.1yr; mass, 83 ± 7.7kg; height, 175.7 ± 6.8 cm) completed the study. There was a median of 3 practice sessions between the initial screening session and test session, and a median of 3 training sessions per week, indicative of their physical activity level. Six of the 24 subjects (25%) were unable to perform the trunk raising forward test for abdominal strength. None of the covariates was statistically significant ($p > .05$).

Mean times to complete phase 1 of each exercise were 1.1 ± .40 seconds for pelvic tilt, 1.1 ± .26 seconds for abdominal hollowing, and 1.0 ± .27 seconds for TST level 1 exercises. The homogeneity of variance assumption was violated ($p < .05$), and data were transformed using an arc sine transform of the normalized data. The F test was not statistically significant for the transformed data ($p > .05$); therefore, the homogeneity of variance assumption was valid and ANOVAs were performed on the transformed data. There were no differences ($p > .05$) in NRMS amplitude across trials or for order. Therefore, the mean NRMS for the 5 trials for each subject for each exercise was the main dependent measure used to test the 3 hypotheses. Table 1 shows means ± SDs for NRMS for phases 1 and 2. ANOVA showed a statistically significant ($p < .05$) muscle site by

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

| Muscle Sites | Exercises | | | | | |
| | Pelvic Tilt | | Hollowing | | TST Level 1 | |
	Phase 1	Phase 2	Phase 1	Phase 2	Phase 1	Phase 2
LRA (%)	13.2 ± 7.7*	12.2 ± 6.4*	6.1 ± 3.3*	6.3 ± 3.5*	11.3 ± 6.2*	12 ± 6.9*
URA (%)	14.9 ± 7.2*	15.9 ± 7.2*	6.7 ± 3.6*	7.3 ± 3.7*	12.2 ± 7.1*	14 ± 8.2*
EO (%)	28.3 ± 17.5	26.3 ± 16.3	18.9 ± 11.5	18.1 ± 9.8	22.2 ± 13.7	21.9 ± 15.9
ES (%)	6.5 ± 3[†]*	7.3 ± 3.9*[†]	6.6 ± 3*	7.4 ± 3.6*	10 ± 8*	10.2 ± 7.9*
MT (%)	4.1 ± 2.7*[†]	5.6 ± 5*[†]	3.7 ± 1.8*	4.1 ± 1.9*	4.7 ± 3.7*[†‡]	5.6 ± 5*[†‡]

Values expressed as mean ± SD. Pairwise comparisons among muscles statistically significant at the .0008 level (critical value of 3.19 for 184 *df*).
* Significantly different from EO.
† Significantly different from LRA and URA.
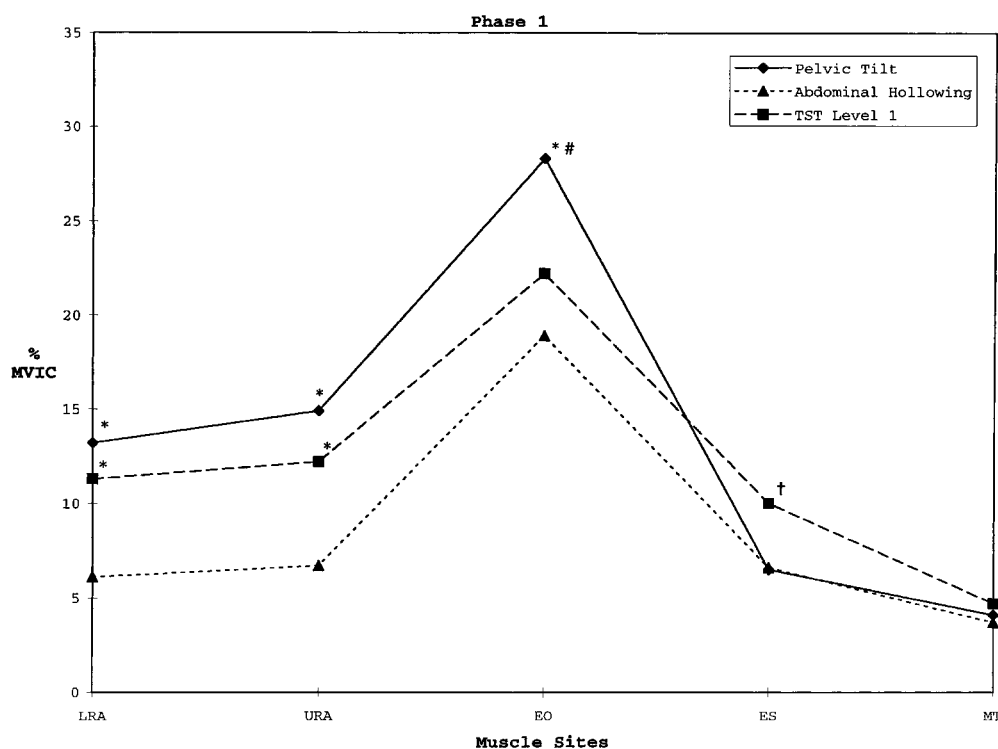‡ Significantly different from ES.

Phase 1

Fig 2. Interaction plot for muscle by exercise for phase 1. Interaction was statistically significant ($p < .05$). The between-exercise significant differences ($p < .0016$) are indicated for each muscle site. *Significant difference from abdominal hollowing. #Significant difference from TST level 1. †Significant difference from pelvic tilt. Critical $t = 2.97$ for 184 df.

exercise interaction for both phase 1 and phase 2 (figs 2, 3). Subsequently, effects of exercise were tested by fixing muscle site, and effects of muscle site were tested by fixing exercise using the Bonferroni t test.

Statistically significant differences ($p < .0008$) in NRMS amplitudes were found among muscle sites within each exercise (table 1). The EO was activated at a significantly higher ($p < .0008$) level than the other 4 muscle sites for all 3 exercises for both phases. The LRA and URA were not significantly different ($p > .0008$) from each other for the exercises. TST level 1 was the only exercise in which ES activity was significantly higher than MT activity, which occurred for both phases.

The multiple comparisons among exercises within muscles sites are shown in figures 2 and 3 for phase 1 and phase 2,
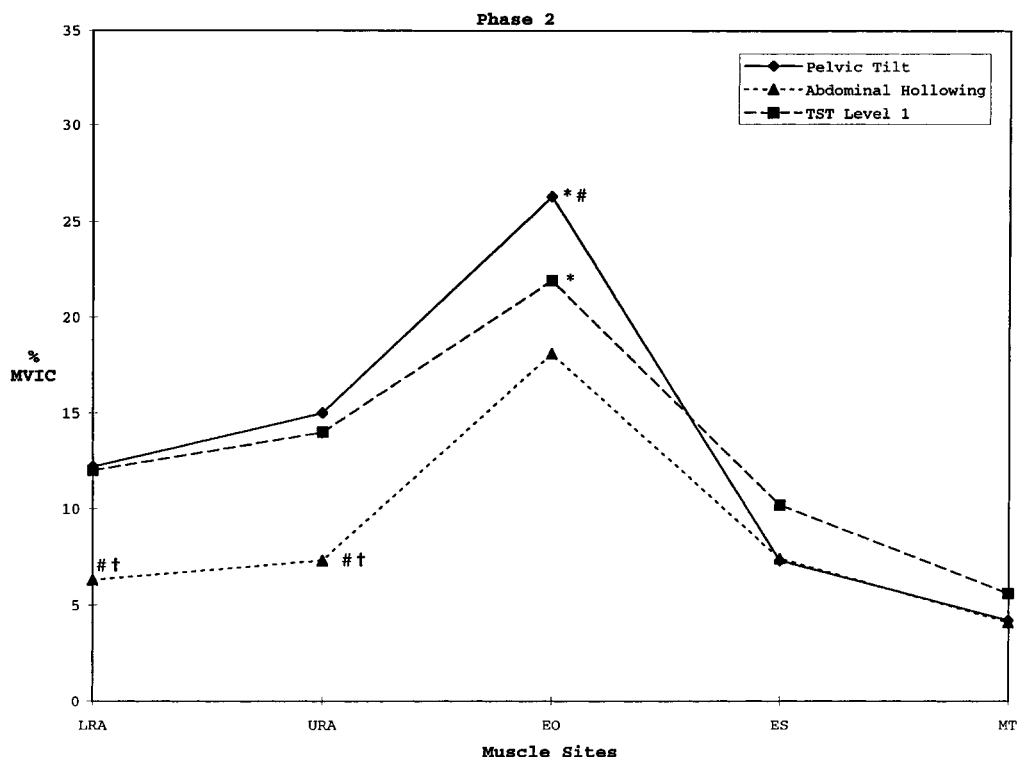
Phase 2

Fig 3. Interaction plot for muscle by exercise for phase 2. Interaction was statistically significant ($p < .05$). Between-exercise significant differences ($p < .0016$) are indicated for each muscle site. *Significant difference from abdominal hollowing. #Significant difference from TST level 1. †Significant difference from pelvic tilt. Critical $t = 2.97$ for 184 df.
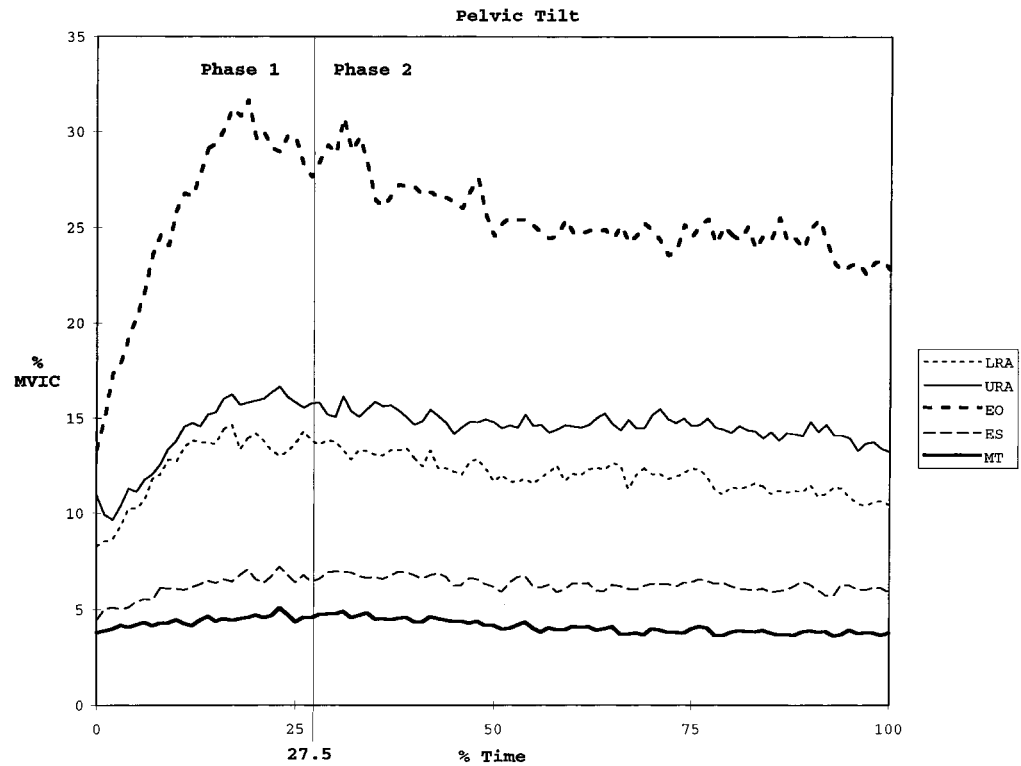
Pelvic Tilt

Fig 4. Ensemble-average curves (*n* = 24) for the pelvic tilt exercise. Coefficients of variation for LRA, URA, EO, ES, and MT are 54%, 50%, 60%, 60%, and 80%, respectively.

respectively. The pelvic tilt NRMS amplitude for the EO was significantly higher ($p < .0016$) than the abdominal hollowing and TST level 1 exercises for both phases, whereas the TST level 1 EO activation was only higher than the abdominal hollowing for phase 2. The RA amplitudes for the abdominal hollowing exercise were significantly lower ($p < .0016$) than the amplitudes recorded for the pelvic tilt and TST level 1 exercise.

The ensemble-average profiles for the 5 muscles are shown in figures 4 through 6 for the pelvic tilt, abdominal hollowing, and TST level 1 exercises, respectively. These figures show the typical pattern of activity for the majority of subjects for the 3
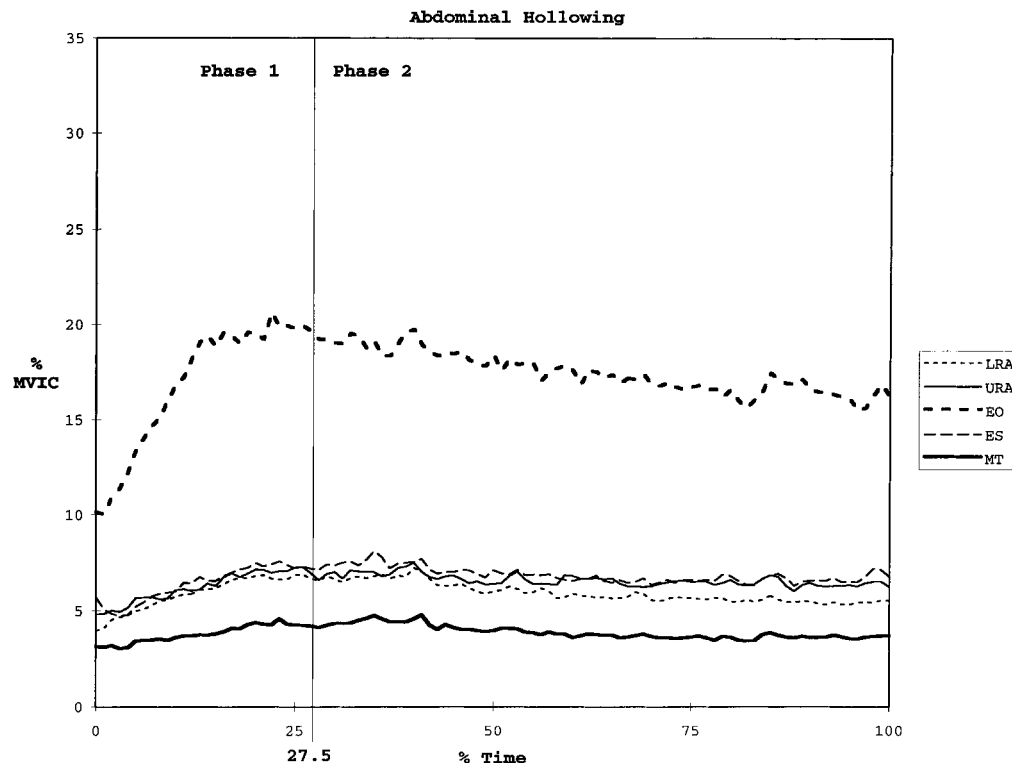
Abdominal Hollowing

Fig 5. Ensemble-average curves (*n* = 24) for the abdominal hollowing exercise. Coefficients of variation for LRA, URA, EO, ES, and MT are 56%, 48%, 59%, 56%, and 52%, respectively.
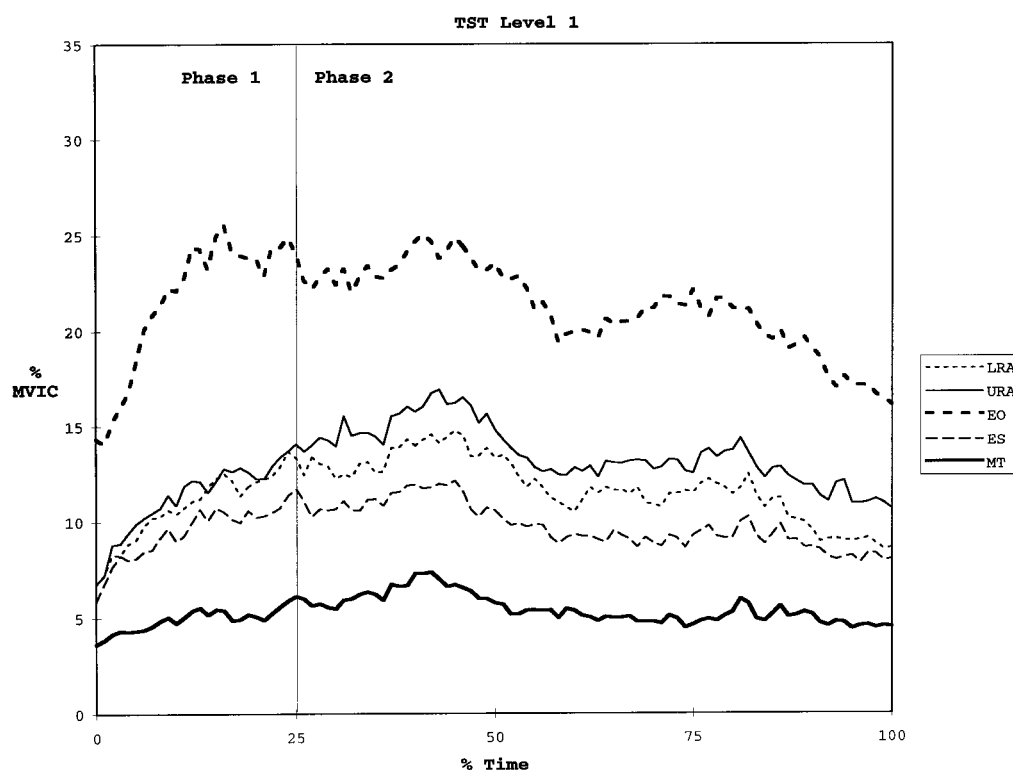
TST Level 1

Fig 6. Ensemble average (n = 24) curves for the TST level 1 exercise. Coefficients of variation for LRA, URA, EO, ES, and MT are 78%, 68%, 76%, 88%, and 107%, respectively.

exercises. No statistical testing was performed on the patterns, and with the exception of the initial increase in amplitude for the abdominal muscles, there were minimal changes in activation amplitude over time. Phase 2 of the TST level 1 exercise showed a slight biphasic trend; however, amplitude change was minimal. The 2 extensor sites maintained a constant level for the pelvic tilt and abdominal hollowing, as did the MT for the TST level 1 exercise over the total exercise time. The ES site for the TST level 1 exercise showed a gradual increase during phase 1 and a slight variation in amplitude during phase 2, similar to the 2 RA sites. The coefficients of variation on figures 4 through 6 for the ensemble-average profiles indicate large between-subject variability in the activation amplitudes used to perform the 3 exercises.

DISCUSSION

The purpose of this study was to measure and compare EMG amplitudes from selected abdominal and trunk extensor muscle sites during the performance of 3 therapeutic exercises used to manage LBP. The results show that the patterns of recruitment amplitudes for the 5 muscle sites examined were different among the exercises, and the multiple comparisons both support and refute some of the claims associated with the 3 exercises. EMG profiles show similarities and differences in trunk muscle activation among the muscles and exercises for this study sample of healthy men.

Although the sample was composed only of men, there was a range in subjects' age, mass, height, and physical activity. The minimal abdominal muscle test showed that this sample was similar to a previous report for unimpaired healthy subjects[28] because 25% of the subjects were unable to complete it. Because none of the covariates or subsets of covariates was significant, they do not readily explain the significant differences found in EMG data. Therefore, the variability in EMG amplitudes among subjects should be expected from a similar healthy population. Twenty of the 28 screened subjects had

difficulty performing the abdominal hollowing and TST level 1 exercises correctly during the initial session, indicating the exercises pose a motor learning challenge to some subjects.[14,15] The practice sessions were sufficient for 26 of the subjects to perform the 3 exercises correctly on the test day. Correct and consistent performance of the exercises was important because differences in EMG amplitudes between correct and incorrect performance of the pelvic tilt have been reported,[23] and consistency of performance was shown to improve with learning.[14] The 2 subjects who were unable to perform the exercises on test day were not tested because incorrect performance could confound the results. Because no significant trial or order effects were found, we assumed a consistent performance was achieved. In contrast to choosing data from 1 trial to represent the motor pattern,[7,24,41] the mean NRMS of the 5 trials was calculated to represent the EMG amplitudes required for each subject to perform each exercise, recognizing the potential for slight variability among trials because of normal instability in motor performance.

Exercise Comparisons

The patterns of activation amplitudes for the 3 exercises were different, substantiated by the statistically significant muscle-site-by-exercise interaction and shown by the interaction plots in figures 2 and 3. These results provide evidence that the 5 muscle sites were recruited in different relative proportions to perform the exercises. The comparisons among exercises and among muscle sites specifically show where these differences occur and shed light on the motor strategies used to perform the exercises. One tester gave all instructions and identified phases using specific criteria to minimize variability between tests. There were no large bursts of activity during any of the exercises; therefore, slight delays in identifying the end of phase 1 because of human error would have minimal effect on the RMS amplitudes for the 2 phases.

Similar to findings for the stabilization phase alone,[7] pelvic

tilt NRMS amplitudes were higher for all 3 abdominal sites for both phases compared with the abdominal hollowing exercises. Although RA sites were higher for the pelvic tilt, they were less than 15% of MVIC and therefore do not support claims that the abdominal hollowing exercise is a better stabilization manuever,[7] based on claims that the pelvic tilt recruits high activity from the RA.[7] The results also do not support claims that abdominal hollowing is better able to recruit selectively the EO[7,14] because both exercises recruited the EO to significantly higher NRMS amplitudes than the 2 RA sites, with the pelvic tilt EO activity significantly higher than the abdominal hollowing. Previous studies did not normalize to a maximal effort,[7,14] making between-muscle site comparisons difficult, especially given the reported interrelation among abdominal muscles.[28]

Phase 1 for the abdominal hollowing and TST level 1 exercises are essentially the same; therefore, the significantly higher RA activity for the TST level 1 was not expected. A plausible explanation for the differences was that all subjects were prepared for the postural adjustment required in the TST because they had practiced the exercises.[6,42] The higher abdominal muscle activity for all 3 abdominal sites for phase 2 of the TST level 1 was expected compared with abdominal hollowing because the leg-raising perturbation should require higher muscle activity to stabilize the spine. Of interest, the pelvic tilt generated the same activity in the RA and a higher amplitude for the EO as the TST level 1 for healthy subjects.

Linear and quasilinear relationships have been reported between percentage of maximal torque and percentage of maximal RMS amplitudes.[43] This relationship has been used to evaluate training effects of therapeutic exercises based on surface EMG recordings.[4,44] The percentages of MVIC found in this study (<30% MVIC) provide evidence that the intensity at which the abdominal muscles contract could produce an aerobic training effect if repeated,[4] but not a strength training effect[44] for healthy subjects. The overload principle provides the basis for eliciting a strengthening response, and muscle contraction intensities of 60% or higher of their maximal voluntary level are normally recommended to promote a strength training effect.[44] The percentage of MVIC for the LRA and URA for the pelvic tilt was consistent with previous qualitative descriptions of mild to moderate activity[41]; however, no studies reported abdominal EMG as a percentage of MVIC. The specific verbal commands used resulted in abdominal muscle recruitment and not just the hip extensors, as was the original intent of the exercise.[45] It is inconclusive whether abdominal muscles are involved in tilting the pelvis; however, the normalized results in this study provide a physiologic basis on which to examine the demand on these muscles and support the claim that the pelvic tilt can elicit abdominal activity with specific commands.[12] Because the NRMS amplitudes for the RA sites for TST level 1 were similar to the pelvic tilt, the potential training effects would be similar to the pelvic tilt. Consistent with the literature,[7,41] the low activation amplitudes for the abdominal hollowing exercise show the minimal strengthening potential associated with this maneuver. The submaximal normalization procedures used in other studies have made it difficult to establish the level at which abdominal muscles were recruited to perform this task,[7,41] but our RA findings are consistent with a recent study that attempted to normalize its data to maximal efforts for the RA.[14] These data provide expected recruitment amplitudes as a percentage of MVIC for a healthy sample; however, different results could be expected for individuals who have difficulty performing the exercises or for those with LBP.

The NRMS amplitudes for both trunk extensor sites were low

(7% MVIC) for the pelvic tilt and abdominal hollowing exercises, which corroborated previous studies.[7,36] Blackburn and Portney[36] concluded that the pelvic tilt reduced paraspinal activity in response to the stretch, and the low MT amplitude was similar to their relative amplitudes. Without specific commands to contract the trunk extensors, as suggested by Elia et al,[5] who explored the stabilizing potential of the pelvic tilt exercise, low trunk extensor activity should normally be expected compared with the abdominals. Low amplitudes of antagonist coactivation have been considered important to promote a good muscle stabilization pattern during the abdominal hollowing,[7] and 4 of the 5 muscles produced activity less than 10% of MVIC. The higher ES amplitude for TST level 1 compared with the other 2 exercises supports the role of the ES during the leg lift task, and although it was only 10% of MVIC, activity less than 25% of MVIC has been deemed important for maintaining stability.[4] The more lateral ES site was activated higher in the TST level 1 exercise than the more medial MT site, collaborating with previous findings that the more lateral back muscle sites were more active in counteracting forces produced during movements in the sagittal plane,[30,46] whereas the MT muscle has been considered important for stabilization during rotations.[3,26,35] Further investigation of the effects of different progression levels[16] may show more distinctive roles for these muscles. Although the potential for cross-talk on the MT from the ES exists, both raw and normalized amplitudes were very low for the MT, which indicates minimal activity recorded at this site for all 3 exercises.

A low percentage of MVIC from the trunk musculature stabilizes the spine during normal movements, and motor control, not just muscle strength, is important to dynamic stability training.[1,2,4,8] Our results showed that the recruitment amplitudes do not support a strength training effect; however, all 3 exercises recruited the 5 muscle sites and perhaps with increased repetition, could improve the endurance of these muscles, which are an important component associated with dynamic stability.

Comparing Activation Amplitudes

The EO amplitudes were 2 to 3 times higher than the 2 RA sites for the 3 exercises, thus supporting selective activation of this muscle to a greater percentage of MVIC. Most EMG studies of the pelvic tilt report raw amplitudes,[7,21,24,41,47] which partially explains the inconsistency in between-muscle comparisons.[18] The higher EO amplitudes support selective recruitment for the abdominal hollowing maneuver[3,7]; however, this study provides the first quantitative EMG evidence supporting the theory that TST level 1 selectively recruits the EO.[3,28]

Previous claims of selective recruitment of the LRA versus the URA for the pelvic tilt exercise[7,21] or abdominal hollowing[7] were not supported; however, our results corroborate reports of no difference between RA sites for the pelvic tilt exercise.[23] We found no studies that examined the EMG of URA and LRA during the TST level 1. The NRMS amplitudes and EMG profiles for both RA sites support homogeneous activation, not selective recruitment of the LRA and URA for healthy subjects performing the 3 study exercises.

Normalization

Normalization must be considered when drawing conclusions from EMG studies of therapeutic exercises, in particular when making between-muscle comparisons.[4,14,18,44,48] Differences of opinion exist about the best normalization procedures[31,33,49,50]; however, normalizing to a single exercise or a submaximal effort must be done cautiously.[14,44] This is particu-

larly important for the abdominal muscles because they are not activated in a linear manner[28] and different exercises have been shown to elicit maximum EMG from different muscle sites for different subjects.[33,34] Researchers reporting on procedures for using surface EMG to assess low back dysfunction have recently recommended a maximal effort for normalization purposes.[48] Although there have been difficulties eliciting maximal efforts,[14] the percentage of maximum that a muscle is activated has a physiologic meaning, providing a basis for interpreting the EMG amplitudes and comparing them among muscle sites.[4,31,44,48-50] It was assumed that subjects in this study produced a maximal effort during the normalization procedures; however, if they did not, then the reported relative amplitudes would be overestimated. This would provide even stronger evidence to support the conclusions related to strengthening potential or minimal trunk extensor coactivation for these exercises.

Qualitative Assessment of EMG Profiles

No previous reports of the EMG patterns for the 3 exercises were found, although raw tracings for individual subjects can be found for the pelvic tilt[41] and abdominal hollowing for selected muscles.[42] The coefficients of variation in figures 4 through 6 were high for the ensemble-average patterns; however, for most muscle sites, they were similar to those reported for walking, a well-learned cyclic activity.[39] The profiles support synergistic activation among the abdominal muscles for the pelvic tilt and TST level 1 exercises during phase 1 because all 3 sites increase during this phase. The gradual increase in activation for the ES and abdominal sites shown in figure 6 during phase 1 of the TST level 1 supports coactivation among the abdominals and ES, an important component of stability.[25] Further study is needed to compare the patterns and determine whether they differ for those unable to perform the exercises correctly.

Clinical Implications

Choosing exercise approaches in the management LBP is difficult because of the multifactorial nature of the problem,[3] difficulty determining exact causes, and number of treatment options available. Using surface EMG to manage low back dysfunction has provided valuable objective information.[1,2,4,48] Knowing the normal recruitment pattern for therapeutic exercises is essential to understand the potential impact of an exercise approach for specific causes of low back dysfunction. These data provide an objective foundation to help decide the value of the 3 exercises in the management of specific low back disorders. It is hypothesized that those who are unable to stabilize the spine or perform these exercises correctly and those with LBP would have different relative EMG amplitudes compared with the healthy unimpaired subjects in this study. Determining where these differences exist in those with low back dysfunction compared with healthy subjects should improve objectivity in decisions about exercise treatment approaches intended to recruit specific muscle sites.

CONCLUSION

A comprehensive analysis of surface EMG showed measurable differences in the relative EMG amplitudes among exercises and muscle sites, providing evidence that the exercises were different with respect to muscle activation patterns. For this healthy unimpaired sample, none of the exercises recruited the muscle sites to a level deemed effective for a strength training response. There was evidence to support selective recruitment of the EO compared with the 2 RA sites, but not between the LRA and URA for all 3 exercises. There was

evidence to support abdominal and ES coactivation during the TST level 1 exercise, but there was minimal trunk extensor activity for the pelvic tilt and abdominal hollowing exercises.

References

1. O'Sullivan PB, Twomey L, Allison G. Dysfunction of the neuromuscular system in the presence of low back pain—implications for physical therapy management. J Manual Manipulative Ther 1997;5:20-6.
2. Richardson C, Jull G, Hodges P, Hides J. Therapeutic exercises for spinal segmental stabilization in low back pain. Toronto: Churchill Livingstone; 1999.
3. Deyo RA, Philips WK. Low back pain: a primary care challenge. Spine 1996;21:2826-32.
4. Arokoski JPA, Kankaanpaa M, Valta T, Juvonen I, Partanen J, Taimela S, et al. Back and hip extensor muscle function during therapeutic exercises. Arch Phys Med Rehabil 1999;80:842-50.
5. Elia DS, Bohannon RW, Cameron D, Albro RC. Dynamic pelvic stabilization during hip flexion: a comparative study. J Orthop Sports Phys Ther 1996;24:30-6.
6. Lee HWM. Progressive muscle synergy and synchronization in movement patterns: an approach to the treatment of dynamic lumbar instability. J Manual Manipulative Ther 1994;2:133-42.
7. Richardson C, Jull G, Toppenberg R, Comerford M. Techniques for active lumbar stabilisation for spinal protection: a pilot study. Aust J Physiother 1992;38:105-12.
8. Cholewicki J, McGill SM. Mechanical stability of the in vivo lumbar spine: implications for injury and chronic low back pain. Clin Biomech 1996;11:1-15.
9. Robinson R. The new back school prescription: stabilization training part 1. Occup Med 1992;7:17-31.
10. Saal JA. The new back school prescription: stabilization training part II. Occup Med 1992;7:33-42.
11. White AH, Anderson R. Conservative care of low back pain. Baltimore: Williams & Wilkins; 1991.
12. Cailliet R. Low back pain syndrome. 5th ed. Philadelphia: FA Davis; 1995.
13. Dumas GA, Reid JG, Wolfe LA, Griffin MP, McGrath MJ. Exercise posture and back pain during pregnancy: part 1. Exercise and posture. Clin Biomech 1995;10:98-103.
14. Allison GT, Godfrey P, Robinson G. EMG signal amplitude assessment during abdominal bracing and hollowing. J Electromyogr Kinesiol 1998;8:51-7.
15. Jull G, Richardson C, Toppenberg R, Comerford M, Bui B. Towards a measurement of active muscle control for lumbar stabilisation. Aust J Physiother 1993;39:187-93.
16. Wohlfart D, Jull G, Richardson C. The relationship between the dynamic and static function of abdominal muscles. Aust J Physiother 1993;39:9-13.
17. Sahrmann SA. The Shirley Sahrmann exercise series 1 [videotape]. St. Louis (MO): Videoscope; 1991.
18. Vezina MJ, Hubley-Kozey CL, Egan DA. A review of the muscle activation patterns associated with the pelvic tilt exercise used in the treatment of low back pain. J Manual Manipulative Ther 1998;6:191-201.
19. Miller MI, Medeiros JM. Recruitment of internal oblique and tranversus abdominis muscles during the eccentric phase of the curl-up exercise. Phys Ther 1987;67:1213-7.
20. Snijders CJ, Bakker MP, Vleeming A, Stoeckart R, Stam HJ. Oblique abdominal muscle activity in standing and sitting on hard and soft seats. Clin Biomech 1995;10:73-8.
21. Flint MM, Gudwell J. Electromyographic study of abdominal muscular activity during exercise. Res Q 1965;36:29-37.
22. Guimaraes ACS, Aurelio Vaz M, De Campos MIA, Marantes R. The contribution of the rectus abdominis and rectus femoris in twelve selected abdominal exercises. J Sports Med Phys Fitness 1991;31:222-30.

23. Sarti MA, Monfont M, Fuster MA, Villaplana LA. Muscle activity in upper and lower rectus abdominus during abdominal exercises. Arch Phys Med Rehabil 1996;77:1293-7.
24. Walters CE, Partridge MJ. Electromyographic study of the differential action of the abdominal muscles during exercise. Am J Phys Med 1957;36:259-68.
25. Marras WS, Mirka GA. Muscle activities during asymmetric trunk angular accelerations. J Orthop Sports Physiother 1990;8:824-32.
26. Panjabi M, Abumi K, Duranceau J, Oxland T. Spinal stability and intersegmental muscle forces: a biomechanical model. Spine 1989;14:194-9.
27. Kendall FP, McCreary EK, Provance PG. Muscles testing and function. 4th ed. Baltimore: Williams & Wilkins; 1993.
28. Gilleard WL, Brown JMM. An electromyographic validation of an abdominal muscle test. Arch Phys Med Rehabil 1994;75:1002-7.
29. Ortengren R. Noise and artefact. In: Kumar S, Mital A, editors. Electromyography in ergonomics. Bristol: Taylor & Francis; 1996. p. 97-107.
30. Vink PE, van der Velde A, Verbout AJ. A functional subdivision of the lumbar extensor musculature: recruitment patterns and force-RA-EMG relationships under isometric conditions. Electromyogr Clin Neurophysiol 1988;28:517-25.
31. Winter DA. EMG interpretation. In: Kumar S, Mital A, editors. Electromyography in ergonomics. Bristol: Taylor & Francis; 1996. p. 109-25.
32. Redfern MS. Functional muscle: effects on electromyographic output. In: Soderberg GL, editor. Selected topics in surface EMG for use in the occupational setting: expert perspectives. Morgantown: (WV) National Institute for Occupational Health and Safety Publishers; 1992, p. 104-20.
33. McGill SM. Electromyographic activity of the abdominal and low back musculature during the generation of isometric and dynamic axial trunk torque: implications for lumbar mechanics. J Orthop Res 1991;9:91-103.
34. Vezina MJ. Electromyographic analysis of three trunk stability exercises in normal healthy subjects [master's thesis]. Halifax (NS): Dalhousie University; 1997.
35. Ng J, Richardson C. EMG study of erector spinae and multifidus in two isometric back extension exercises. Aust J Physiother 1994;40:115-21.
36. Blackburn SE, Portney LG. Electromyographic activity of back musculature during Williams' flexion exercises. Phys Ther 1981;61:878-85.
37. Press WH, Teukolsky SA, Vetterling WT, Flannery BP. Numerical recipes in Fortran. Cambridge (UK): Cambridge Univ Pr; 1992.
38. Vezina MJ, Hubley-Kozey CL. A comparison of the electromyographic normalization procedures for abdominal and trunk extensors. Proceedings of NACOB'98 North American Congress on Biomechanics: Aug 14-18, 1998; Waterloo, Ontario; 1998, p. 401-2.
39. Winter DA, Yack HJ. EMG profiles during normal human walking: stride to stride and intersubject variability. Electroencephalogr Clin Neurophysiol 1987;67:402-11.
40. Levene H. Contributions to probabilty and statistics. Palo Alto (CA): Stanford Univ Pr; 1960. p. 278-92.
41. Partridge MJ, Walters CE. Participation of the abdominal muscles in various movements of the trunk in man: an electromyographic study. Phys Ther Rev 1959;39:791-800.
42. Hodges PW, Richardson CA. Contraction of the abdominal muscles associated with movement of the lower limb. Phys Ther 1997;77:132-44.
43. Lawrence JH, DeLuca CJ. Myoelectric signal versus force relationship in different human muscles. J Appl Physiol 1983;54:1653-9.
44. Anderson EA, Ma Z, Thorstensson A. Relative EMG levels in training exercises for abdominal and hip flexor muscles. Scand J Rehabil Med 1998;30:175-83.
45. Williams PC. Lesions of the lumbosacral spine: part 11. Chronic traumatic (postural) destruction of the lumbosacral intervertebral disc. J Bone Joint Surg Am 1937;19:690-703.
46. Dofferhof ASM, Vink P. The stabilising function of the mm ilioscostales and the mm multifidi during walking. J Anat 1985;140:329-36.
47. Carman DJ, Blanton PL, Biggs NL. Electromyographic study of the anterolateral abdominal musculature utilizing indwelling electrodes. Am J Phys Med 1972;51:113-29.
48. Kasman GS, Cram JR, Wolf SL. Clinical application in surface electromyography: chronic musculoskeletal pain. Gaithersburg (MD): Aspen; 1998.
49. Kumar S. Electromyography in ergonomics. In: Kumar S, Mital A, editors. Electromyography in ergonomics. Bristol: Taylor & Francis; 1996. p. 31-45.
50. Burden A, Bartlett R. Normalisation of EMG amplitude: an evaluation and comparison of old and new methods. Med Eng Phy 1999;21:247-57.

Suppliers
a. dAMT-8 EMG; Bortec Electronics, Inc, 7172 Sierra Morena Blvd, Calgary, Alberta, T3H 3G6.
b. Tecmac Lab Master; Scientific Solutions, Inc, 9323 Hamilton Dr, Mentor, OH 44060.
c. Meditrace chloride pellets; Graphics Control Corp, Buffalo, NY.
d. Microsoft Excel version 7.0; Microsoft Corp, 1 Microsoft Way, Redmond, WA 98052.
e. Minitab statistical software package, version 11Xtra; Minitab Inc, 301 Enterprise Dr, State College, PA 16801.