

# Neuromuscular Response to Cyclic Lumbar Twisting

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**Objective:** To study the influence of 10 min of cyclic twisting motion on abdominal and back muscle activities. **Background:** Repetitive (cyclic) occupational activity was identified by many epidemiological reports to be a risk factor for the development of work-related musculoskeletal disorders. Biomechanical and physiological confirmation, however, is lacking. **Methods:** Trunk muscle electromyography (EMG) was recorded while participants performed a continuous 10-min maximum lumbar cyclic twisting to the left, and maximum isometric twist to the left and right sides was measured before and after the exercise. **Results:** Abdominal muscles contracted symmetrically, independent of twisting direction. The left posterior muscles' integrated EMG (IEMG) decreased during the exercise, whereas the IEMG of the right posterior muscle increased. Simultaneously with increased antagonist coactivity level of the right posterior muscles after the exercise, decrease in maximal isometric left twisting torque was observed. The abdominal muscles did not exhibit any significant changes during the exercise. After the exercise, the right abdominals demonstrated a significant increase in effort, which was independent of the direction of the maximal effort isometric test. **Conclusions:** The change in muscle activity is attributed to neuromuscular compensation for the development of laxity and microdamage in the soft tissue (ligaments, discs, facet capsules, etc.) of the lumbar spine. **Application:** The results of this study increase understanding of the risk factors associated with low back disorder induced by labor-intensive occupations that involve cyclic lateral twisting.

## INTRODUCTION

Work-related musculoskeletal disorders are a major health problem daunting the industrialized countries. Epidemiological studies point out that the primary source of such musculoskeletal disorders is the exposure of joints to repetitive (cyclic) and static activities (Hoogendorn, Bongers, & De-Vet, 2000; Punnett & Wegman, 2004; Silverstein & Clark, 2004). Our previous research with a feline model produced experimental physiological and biomechanical evidence that exposure of the lumbar spine to cyclic and static work resulted in a neuromuscular disorder (Claude, Solomonow, Zhou, Baratta, & Zhu, 2003; LaBry et al., 2004; Sbriccoli et al., 2004; Solomonow, Baratta, Banks, Freudenberger, & Zhou, 2003).

In essence, the viscoelastic tissues of the spine (ligaments, discs, facet capsules, dorsolumbar fascia, etc.) demonstrate the development of creep during cyclic or static work. As the creep is sustained under high loads, prolonged loading (work) period, too little rest, or too many loading repetitions, the microdamage developed in the collagen fibers of the viscoelastic tissues accumulates (Woo, Aprelena, & Hoher, 1999) and surpasses a threshold that triggers an inflammatory response (Leadbetter, 1990; Solomonow, Baratta, Zhou, et al., 2003). The inflammation was associated with a neuromuscular disorder consisting of spasms and delayed hyperexcitability in the multifidus muscles lasting over 24 hr.

Our recent research with human participants exposed to static and cyclic loading of the knee

and lumbar spine (in anterior flexion-extension) confirmed that an acute neuromuscular disorder indeed develops in response to static and cyclic activities of 10-min duration, allowing extension of the findings from the feline model to humans (Chu et al., 2003; Olson, Li, & Solomonow, 2004, 2006; Sbriccoli, Solomonow, Zhou, Lu, & Sel-lards, 2005; Solomonow, Baratta, Banks, Freuden-berger, et al., 2003).

These human model studies have a common characteristic: Movement was limited to the sagittal plane (i.e., anterior flexion-extension). The sagittal plane motion activates the left and right side of the trunk muscles equally. Many occupational tasks, however, are not left and right symmetrical. The asymmetrical loading may create additional muscular and neurological demand for the body. The epidemiology (Hoogendorn et al., 2000) assert that lumbar twisting, for example, may also be a high risk factor in the development of musculo-skeletal disorders. Spine models confirm that lumbar twisting activities develop large stresses in the viscoelastic tissues and may indeed result in high risk for low back disorder (Granata & Marras, 1995; Marras & Mirka, 1992). Because such experimental biomechanical/physiological data are lacking, we wished to investigate them in this study.

Several reports have described the activity of the muscles associated with axial twisting of the spine. Marras, Davis, and Granata (1998), as well as McGill (1991) and Ng, Parnianpour, Richardson, and Kippers (2001), identified the external and internal obliques as the most active anterior muscles and the latissimus dorsi as the major posterior muscle active during twisting in the standing position. Coactivation of various muscles was observed in these studies and, importantly, Carlsoo (1961) found that some of the coactivation was not contributing to the twisting torque. Although these data provide guidance as to the primary muscles and their interaction during twisting, the changes associated with repetitive twisting over time and the impact of the resulting creep or tension-relaxation in the viscoelastic tissues remain unexplored.

We hypothesized that 10 min of single-sided cyclic twisting of the lumbar spine in healthy humans may cause significant changes in the function and synchrony of the associated lumbar/abdominal muscles and may leave the individual exposed to further injury. The exercise we employed was 10 min of maximum cyclic twisting (lateral lumbar rotation) from the neutral position to the left

along the longitudinal axis. The hypothesis was evaluated via changes in muscular activity during the cyclic exercise and with pre- and postexercise maximum isometric twisting stretch to both the left and right directions in the neutral position.

## METHODS

### Participants

Healthy volunteers participated in this experiment. Data were collected from 23 participants (12 women and 11 men). The average measurements and standard deviations of age, height, and body mass were  $26.5 \pm 4.8$  years old,  $173.4 \pm 8.9$  cm, and  $74.0 \pm 13.5$  kg, respectively. None of the participants reported any previous pain or disorders of either the back or lower extremities. Institutional Review Board approval and consent from each individual were obtained before data collection.

### Instrumentation

Customized shoulder and pelvic harnesses for measuring twisting torque (Figure 1) were used for data collection. The system consisted of a supporting framework housing a shoulder harness that was linked to a tensile force transducer in order to measure twisting torque. Additionally, a pelvic harness provided stabilization of the pelvic structures during the experiment. Velcro straps were used to comfortably secure the participants in a standing position within the harnesses.

To test our hypothesis regarding the influence of asymmetric motion on the coordination of muscles of the trunk, we chose the external oblique (EXO) and latissimus dorsi (LD) on both sides to represent muscles of the front and back bilaterally. It was assumed that surface electromyography (EMG) from the EXO will include some EMG from the deeper internal oblique and transversus and thereby represent the abdominal muscles activity as a group of synergists. Furthermore, because twisting torque was transmitted to our measurement apparatus via the shoulder, the LD was expected to be most active and to represent the dorsal muscles' activity, as it has a lateral vector component. The abdominals and LD were found by various investigators to be the prime movers in lumbar twisting (Marras et al., 1998; McGill, 1991; Ng et al., 2001) and were therefore expected to represent any possible changes over time during cyclic twisting.

Skin overlying the muscles of interest was

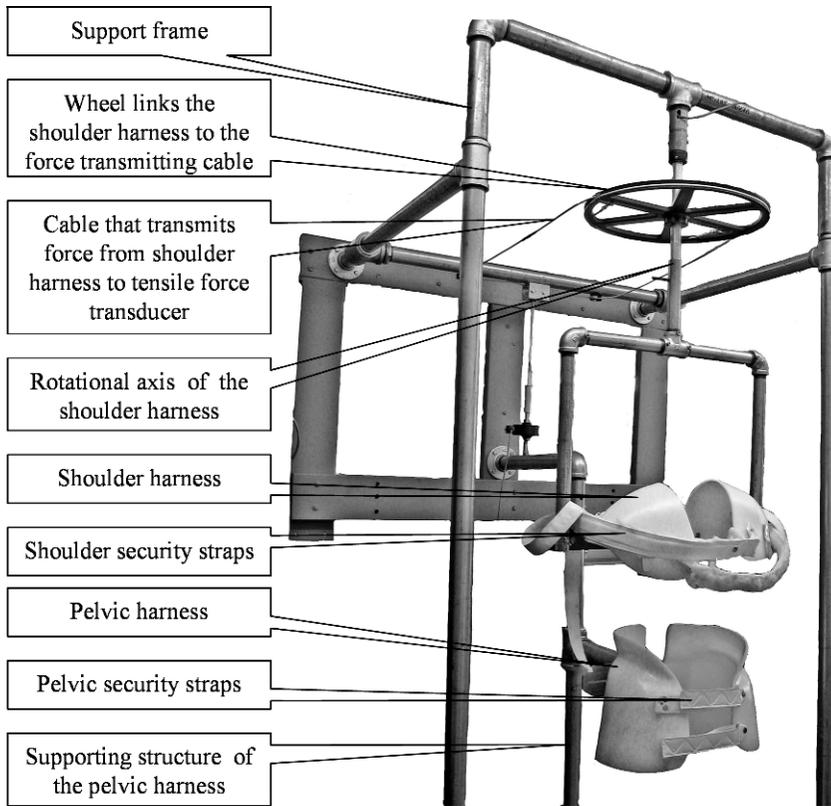


Figure 1. Customized shoulder and pelvic harnesses for measuring twisting torque. See text for details.

cleaned with rubbing alcohol prep pads and allowed to dry before four pairs of 1-cm diameter silver/silver chloride electrodes (30-mm inter-electrode distance) were applied. The electrodes were applied longitudinally over the bellies of the EXO and LD bilaterally. The electrodes on the left side were about 15 cm from the ones on the right side, symmetrically arranged about the middle line of the body. The electrodes in the front were along the lower edge of the rib cage, whereas the back ones were higher, at the same level as T10. Each electrode pair provided input to a differential amplifier of 110-dB common-mode rejection ratio, a gain capability of up to 200,000, and a band pass filter of 5 to 500 Hz. EMG activity was monitored continuously on a computer display.

The force and EMG signals were acquired by a 12-bit analog/digital board at 1000 Hz and stored digitally for further analysis.

### Procedures

After the protocol was discussed and all the questions that the participant may have had were

answered, the participant was fit adjusted in a standing position within the harness system. The height and width of the harnesses were adjusted individually. After the harnesses were secured, electrode sites were prepared and the differential EMG electrodes applied. A ground electrode was attached to the dorsal surface of the left wrist. The EMG signals were tested, and necessary adjustments were made to optimize data acquisition. Surgical prep-wrap was used to provide additional security of the electrodes to the abdomen and back. In all the twisting functions to be described, participants kept their arms crossed over their chest.

The participant was asked to produce a few test efforts of maximum trunk twisting to the left and right. Isometric twisting torque was ensured through the harness system design, which kept the relative position of the shoulders and pelvis fixed. The initial twisting attempts served as a warm-up but also provided an opportunity to verify the integrity of the data collection system. Ten minutes of rest were allowed before initiation of the protocol.

Three series of data were collected. Participants

were verbally encouraged to generate a maximum left-twisting isometric torque, followed by an attempt at a maximum right-twisting torque. Participants then produced a twisting effort resulting in a 100-N force in both directions. Three minutes of rest were allowed after each trial. Force production was monitored on an oscilloscope by the participant, allowing accurate maintenance of the force. The maximum and standard efforts were sustained for approximately 2 s to ensure that at least 1 s of steady isometric force and EMG data could be analyzed. The entire procedure was repeated three times, producing three data sets for each contraction.

After the pretests, the shoulder harness was removed and a 10-min cyclical left-twisting exercise followed. Twisting occurred from the neutral position to the leftmost possible position to generate a maximum stretch. Each twisting cycle was 10 s in duration, synchronized to the beat of a metronome, allowing 5 s to stretch and 5 s back to neutral. This amounted to 6 twists/min and 60 twists over the 10 min of exercise.

The participant was asked to maintain the maximum stretched position for 2 s in isometric contraction at the end of each minute, again to allow for at least 1 s of isometric force and EMG data to be analyzed. EMG activities of the four muscles were continuously collected during this 10-min exercise, although data sampling occurred only within the isometric periods. A 10-min exercise of a twist to the right was not performed.

Measurement of maximal isometric and at 100 N torque in the posttest procedure was identical to that in the pretest procedure with the exception of its temporal relationship to the exercise period.

**Analysis**

The DC component in the EMG data was removed. A 1-s section of isometric contraction data was extracted from the raw data in all of the following conditions: maximum and standard contractions from pre- and posttests, and maximum stretches during the exercise period. Integrated EMG (IEMG) and median frequency were computed.

To capture issues of symmetry, we calculated the relative magnitude of the isometric maximal effort EMG activity between the left and right side of the body by the ratio of IEMG of the agonist/antagonist as follows:

$$\text{IEMG ratio during twisting to the left} = \frac{\text{IEMG of the muscle on the left}}{\text{IEMG of the muscle on the right}} \quad (1)$$

$$\text{IEMG ratio during twisting to the right} = \frac{\text{IEMG of the muscle on the right}}{\text{IEMG of the muscle on the left}} \quad (2)$$

The same equations were applied to the abdominal and the back muscles. Similar equations substituting the median frequencies for the IEMG were also processed for each of the muscle groups.

The changes between the pre- and posttests were evaluated by calculating the percentage change for the following criterion measures: maximum torque, IEMG, and median frequency.

$$\text{Percentage change} = \frac{\left( \frac{\text{postexercise measure}}{\text{preexercise measure}} \right) - \left( \frac{\text{preexercise measure}}{\text{preexercise measure}} \right)}{\left( \frac{\text{preexercise measure}}{\text{preexercise measure}} \right)} 100\% \quad (3)$$

Data were statistically analyzed by using ANOVA with repeated measures and relevant post hoc trend analysis. Linear correlation was calculated when necessary. Alpha level was set at .05 for statistically significant difference.

**RESULTS**

The data from 6 participants (2 men and 4 women) could not be included in the report because of difficulty in maintaining adequate electrode contact throughout the exercise series. The analysis, therefore, represents the data from 17 participants. Further, there was no significant difference observed between men and women; therefore data from the two groups were pooled for further analysis.

EMG activities in the back muscles displayed twisting-direction-dependent characteristics, whereas those of the abdominal muscles were independent of the twisting direction (Figure 2). EMG data from pre- and postexercise tests were pooled because no differences were observed ( $p > .05$ ) before and after the 10-min maximum stretch exercise. No difference in median frequency was observed (ratio  $\approx 1.2$ ) when comparing maximal

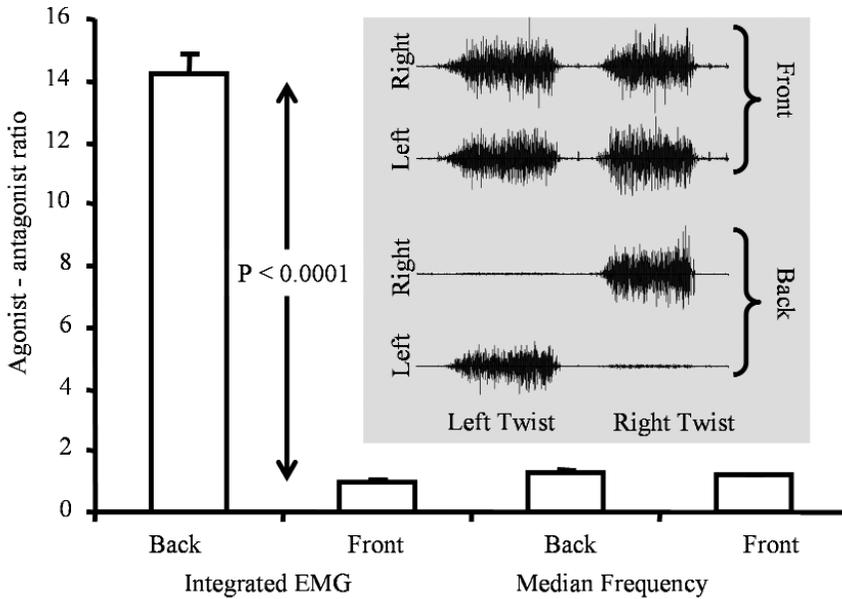


Figure 2. Agonist-antagonist ratios with exemplar data in the top-right corner. For a twisting motion to the right, muscle groups on the right side (front and back) are defined as agonists and those on the left are defined as antagonists. The agonist-antagonist distinctions are reversed when twisting to the left. See text for details.

effort twisting to the left versus the right; however, a dramatic difference ( $p < .0001$ ) in IEMG was observed. No correlation was observed between the ratios of IEMG and twisting direction for the abdominal muscles (ratio  $\approx 1$ ). The IEMG of the back muscles ipsilateral to the direction of rotation exhibited a magnitude approximately 14 times greater than that of the back muscles on the contralateral side, regardless of the direction of rotation.

One-second increments of isometric contraction EMG activity were recorded from the four involved muscle groups at the end of each minute during the 10-min maximum stretch exercise. The averaged IEMG and median frequency of those data are presented in Figure 3. No change in median frequency was observed during the 10-min exercise in any of the four muscle groups, although the left back and right front muscle groups appear to have a greater magnitude. The IEMG showed significant change over time ( $p < .05$ ). No change of the abdominal muscle IEMG was observed; however, the IEMG of the two back muscle groups changed in opposite directions. IEMG of the left back muscles decreased with a slope =  $-3.8$  ( $R^2 = .60$ ), whereas IEMG of the right back muscles increased along a slope that is approximately 1.4 ( $R^2 = .57$ ).

Percentage changes of the criterion measures after the 10-min exercise were constructed to re-

flect the changes induced by the exercise. The maximum isometric twisting torques to the left and right were reduced by a small (approximately 2%) but significant amount ( $p < .05$ ). The changes of the EMG data are presented in Figure 4. The muscles on the left (front and back) did not exhibit significant changes in IEMG or median frequency. A significant twisting-direction-dependent change was observed in the IEMG of the right back muscles. The IEMG increased approximately 9% while twisting to the left and decreased about 3.5% during opposite twisting effort. A uniform increase (approximately 4.5%,  $p < .05$ ) in the median frequency of the right abdominal muscles was observed in both twisting directions.

## DISCUSSION

The major observation of this study is that the left and right abdominal muscles contract symmetrically, regardless of whether the maximal effort test is twist to the left or to the right. IEMG of the left posterior muscles, however, was substantially greater than that of the right during the maximal isometric tests to the left and the exercise. Furthermore, the left posterior muscles' IEMG decreased with time during the exercise, and that of the right increased with time.

This observation is consistent with the isometric data observed after the exercise. A decrease in

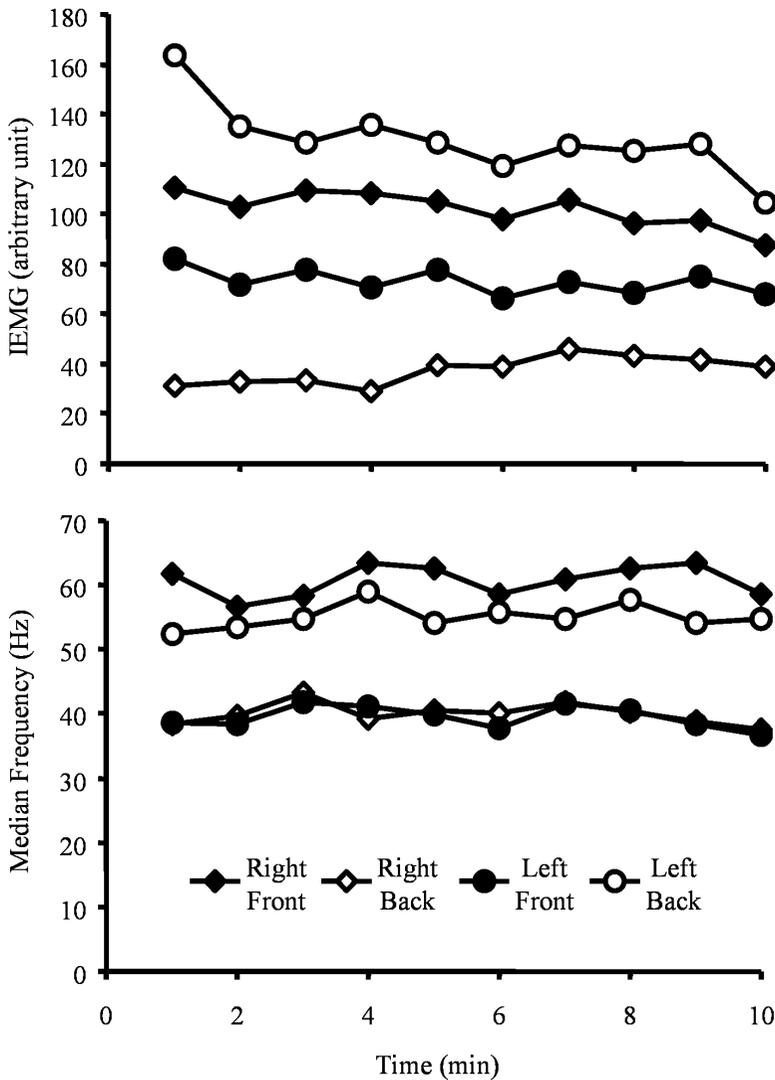


Figure 3. One-second increments of EMG activity during isometric contraction with maximum stretch. Top panel: Magnitude of the IEMG. Bottom panel: Median frequency. See text for details.

maximal isometric torque to the left was seen in the left posterior muscle. The right posterior muscle showed a postexercise-increased antagonist activity during maximal effort test to the left and decreased activity during maximal effort to the right. Although these changes in EMG activity were of the anterior and posterior muscles on the right, there were no significant postexercise changes in the IEMG of the anterior and posterior muscles on the left. After a 10-min left-twist exercise, the right abdominal demonstrated a significant increase in effort, independent of the direction of the maximal effort test.

Several issues should be pointed out before the results are discussed. The stimulus applied in

this study was mild. Participants performed only 10 min (60 cycles) of low-frequency cyclic maximum stretch to the left without load, whereas in most typical occupational or sports activities individuals are engaged for a substantially longer period of time, with load and at higher rates. The mild stimulus was chosen to protect the participants while complying with the ethical requirements. Despite the mild exercise, however, we expected that sufficient evidence of neuromuscular changes would be apparent, even if they were not expressed to their full effect.

Furthermore, despite the fact that maximal isometric twisting torque/EMG was evaluated in both directions in the pre- and postcyclic exercise, the

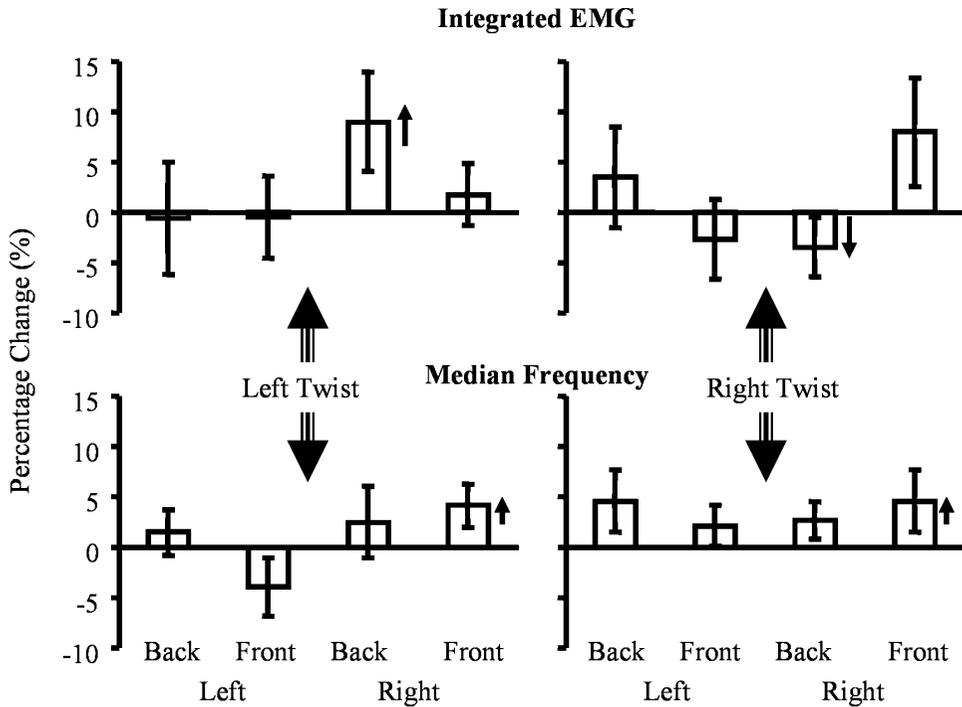


Figure 4. Percentage change after exercise; significant changes ( $p < .05$ ) are indicated by up or down arrows ( $\uparrow$ ,  $\downarrow$ ). Mean and standard error of the mean are represented by the bars and whiskers on the bars. See text for details.

EMG data collected during the exercise were not normalized with respect to the maximal. One should note that comparison of EMG data from isometric conditions with EMG from a free movement, for example, is inherently wrong and results in misleading conclusions. In free movement, issues related to changes in muscle length (length-tension), velocity/acceleration (force-velocity), and moment arm and velocity with phase shift produce profound changes in the force and associated EMG (Baratta, Solomonow, & Nguyen, 1996; Brereton & McGill, 1998; Hagood, Solomonow, Baratta, Zhou, & D'Ambrosia, 1990; Solomonow, Baratta, & D'Ambrosia, 1991; Vance, Solomonow, Baratta, Zembo, & D'Ambrosia, 1994).

In order to avoid erroneous and misleading conclusions, we assessed the EMG data collected during the cyclic exercise for changes over time in the same muscle and for changes in relationship between muscles using the activation ratios. Conversely, the pre- and postexercise EMG data were compared because they were collected in the same condition (i.e., isometric). It is therefore expected that the results can faithfully represent the effect of the cyclic twisting free of various distortions and artifacts.

Finally, EMG data collected during repetitive motion of the same function may represent the effect of changes in motor control attributable to skill acquisition. Such changes, however, were shown to require many daily repetitions over days or weeks (Bernardi, Solomonow, Nguyen, Smith, & Baratta, 1996). Therefore, it could be assumed that the changes reported here are attributable to the stated objective and not to skill acquisition.

The symmetrical activation of bilateral abdominal muscles in the preexercise isometric tests is not surprising, as it is well established that one of their important roles is to increase abdominal pressure, which in turn maintains the anterior stability of the lumbar spine (Cholewicki & McGill, 1996). In this case, stability is defined as the prevention of the vertebrae and discs from slipping anteriorly as well as prevention of anterior buckling of the lumbar spine.

Bilateral activation of the muscles is required to build up and maintain the pressure in the abdominal space. Biomechanically, however, the contraction of the ipsilateral abdominal muscles during lateral twisting to one side increases the resistance to the movement and requires increased force production from the posterior muscles to

overcome such resistance. Although such a contraction strategy may not be efficient from the force production perspective (Carlsoo, 1961), it may fulfill the requirements for anterior lumbar stability (Cholewicki & McGill, 1996) and injury prevention. The symmetrical activity of the abdominal muscles, therefore, suggests that anterior lumbar stability may be more important than movement efficiency.

There were no significant changes observed in the IEMG and the median frequency of the abdominal muscles during the 10-min exercise, indicating that the control strategy of motor units probably remained fairly constant and that fatigue was absent.

After the 10 min of cyclic twisting to the left, the median frequency of the right abdominal muscles showed a significant ( $p < .05$ ) increase of 4.5% with a nonsignificant increase in IEMG regardless of the direction of the maximal effort twisting. The median frequency of the EMG represents the average conduction velocity of action potentials in the muscle. Increase in the action potential conduction velocity suggests that larger motor units (of higher conduction velocity) became active (recruited) and increase the force generated by the muscle (Solomonow, et al., 1990). The function of the abdominal muscles, therefore, became nonsymmetrical because of the prolonged cyclic twisting.

The increase in the right abdominal muscle activity has to be explained, together with the increased right posterior muscle activity during and after the left-twist exercise. The simultaneous increase of activity in the two muscles suggests increased stiffness of the right trunk while performing maximal left twist. That probably also increased the abdominal pressure and the associated anterior stability, together with posterior stability, in an attempt to compensate for the laxity developed in the viscoelastic tissues during the cyclic stretching. The simultaneous increase in the activity of the abdominal and posterior muscles on the right side may have summed up to a very small contribution to the force level generated in maximal twisting to the left.

The increase in the right abdominal activity was 4.5% and statistically significant. It should be noted that the surface area covered by the abdominal muscles is large; small increases in its activity and its associated force and shortening may drastically reduce the abdominal cavity volume and elicit a significant increase in pressure. The

relatively small changes in the activity of the abdominals may, therefore, have a strong impact on abdominal pressure and lumbar stability.

In both the pre- and postexercise isometric tests, the activity of the posterior muscles was not symmetrical; the muscle ipsilateral to the direction of motion was very active, as expected. We observed the interaction between the left and right posterior muscles during the asymmetrical exercise (maximum stretch to the left). The IEMG of the left was greater and decreased with time, whereas the IEMG of the right was low but increased with time (significant interaction,  $p < .05$ ).

This interaction demonstrates that the different muscle groups react differently to the exercise. The left posterior muscles were the prime movers. The decreased IEMG of this group of muscles during the exercise was associated with a constant median frequency, indicating that fatigue was absent. The decreased IEMG was most likely attributable to decreasing firing rate of the same active motor units, which have little impact on median frequency (Solomonow et al., 1990). The reduction of the left posterior muscles' activity during the exercise may therefore be considered as a neural response to the development of tension-relaxation (e.g., laxity) in the viscoelastic structures. Less force was required to overcome the decreasing opposing tension in the viscoelastic tissues while performing the same function. Indeed, there was a significant 2% postexercise decrease in maximal left twist torque.

The purpose of the significant increase in activity of the right abdominal muscle during postexercise maximal twist to the right should be considered. That increase was accompanied by a simultaneous decrease in activity of the right posterior muscle. The right abdominal muscle increases the resistance to maximal twist to the right and decreases the efficiency of the movement. Most likely, the increase in abdominal pressure during the cyclic exercise (and, hence, the increased lumbar stability necessary to offset the laxity/creep that develops in the viscoelastic structures) is more important than force production.

It seems that the right abdominal muscle assumes the compensation because of the direction of the exercise. Left twist cyclic exercise was applied during which, as described previously, an increase in the right abdominal activity may improve movement efficiency. However, these neuromuscular changes lingered after the exercise

and negatively affected twisting to the right, which may represent a form of disorder. Prolonged cyclic left twisting activity, therefore, seems to degrade the ability of the muscles to perform a twist in the contralateral direction while compensating for viscoelastic laxity.

The changes in the activity levels of the left and right posterior muscles were evident during the twist exercise and also manifested in the maximal isometric forces after the exercise. The changes in the right abdominal were evident only after exercise in the isometric tests. The gradual changes in the activity of the posterior muscles were probably attributable to the decrease in the ligamentomuscular reflex level as the creep was developing in the viscoelastic tissue during the cyclic exercise (Claude et al., 2003; Solomonow, Zhou, Harris, Lu, & Baratta, 1998; Stubbs et al., 1998).

The postexercise increase in right abdominal activity, however, may be a manifestation of the initial hyperexcitability that we repeatedly observed in the feline model after a period of cyclic loading (Claude et al., 2003; Navar, Zhou, Lu, & Solomonow, 2006). The function of such initial hyperexcitability is most likely to protect the lumbar spine and the viscoelastic tissues while they attempt to recover the majority of the creep developed during loading.

Overall, the changes observed suggest that prolonged one-sided lateral twist elicits distinct neuromuscular changes that represent the ability of muscles to compensate for loss of tension in the viscoelastic structures, attributable to the developed creep/laxity, by increased abdominal pressure and by stiffening of the torso. This was associated with a degradation in muscular ability to perform maximal-effort twist in the contralateral direction. The central outcome suggests that the compensatory response was aimed at preservation of lumbar stability at the expense of degraded performance.

Although the development of creep/laxity in the viscoelastic structures was not measured directly, it was assumed from our long experience with animal models and humans (Chu et al., 2003; Claude et al., 2003; LaBry et al., 2004; Sbriccoli et al., 2005; Solomonow, Baratta, Banks, & Freudenberger, et al., 2003) that creep developed as the cyclic left twist was performed. The neurological changes based on degradation of neural signal from afferents within the viscoelastic tissues seem to modify the muscular function such that de-

creased lumbar stability could be compensated for at the expense of performance in a twist to the contralateral side. With stronger stimuli applied for a longer period, one could possibly anticipate more significant and obvious changes. From a practical standpoint, one-sided lumbar twisting may be considered an activity that should not be continued for prolonged periods, as it elicits neuromuscular changes that may impair function.

## ACKNOWLEDGMENTS

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