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Surface Electromyographic Activity of the Abdominal Muscles During Pelvic-Tilt and Abdominal-Hollowing Exercises

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Objective: To investigate surface electromyographic (EMG) activity of the rectus abdominus and external oblique abdominus muscles during pelvic-tilt and abdominal-hollowing exercises performed in different positions.

Design and Setting: 2 × 3 (exercise by position) within-subjects design with repeated measures on both factors. All testing was performed in a university laboratory.

Subjects: Twenty-six healthy, active young adult females.

Measurements: Surface EMG activity was recorded from the left and right rectus abdominus and external oblique muscles while the 2 exercises (pelvic tilt and abdominal hollowing) were performed in different positions (standard, legs supported, and legs unsupported). The standard position was supine in the crook-lying position, the supported position was with hips and knees flexed to 90° and legs supported on a platform, and the unsupported position was with hips and knees flexed to 90° without external support. Peak EMG activity was normalized to a maximum voluntary isometric contraction for each muscle.

Results: For the rectus abdominus, there was an interaction between position and activity. Abdominal hollowing produced significantly less activity than the pelvic tilt in all positions. The difference between the 2 exercises with the legs unsupported was of a greater magnitude than the other 2 positions. For the external obliques, there was significantly lower activity during the abdominal hollowing compared with the pelvic tilting. The greatest muscle activity occurred with the legs-unsupported position during both exercises.

Conclusions: Abdominal-hollowing exercises produced less rectus abdominus and external oblique activity than pelvic-tilting exercises. Abdominal hollowing may be performed with minimal activation of the large global abdominal muscles.

Key Words: core stability, neuromuscular control, abdominal exercises

Strengthening exercises for the abdominal muscles are frequently used in the rehabilitation of low back pain. The question of which abdominal muscles and exercises should be targeted in the treatment of low back pain is debated among clinicians. Bergmark[1] classified muscles acting on the lumbosacral spine as being either "local" or "global." It is hypothesized that the local muscles, such as the transverse abdominus and internal oblique abdominals, are essential for stabilization of the lumbosacral spine.[2] The global muscles, including the rectus abdominus and external oblique abdominals, are responsible for producing gross movements of the trunk and pelvis.[3]

The use of posterior pelvic-tilting exercises has been advocated for the conservative management of low back pain.[4,5] Although pelvic tilts are often components of low back pain rehabilitation programs, evidence supporting their effectiveness is scarce.[6] The rectus abdominus and external oblique muscles have been shown to be substantially active during pelvic tilts and other exercises, such as sit-ups, that move the spine.[7] Some speculate that the pelvic-tilting exercise should be contraindicated because this maneuver preloads the spinal structures that often cause low back pain.[6]

An alternative approach to abdominal muscle exercise in the treatment of low back pain is abdominal hollowing. This exercise is thought to retrain the transverse abdominus by having patients isometrically contract or "draw in" the abdominal wall without movement of the spine or pelvis.[8] This exercise is designed to emphasize deep local muscle activity while minimizing that of the more superficial global muscles. Contracting the transverse abdominus may increase fascial tension and intraabdominal pressure, thus creating a more rigid cylinder around the spine.[9]

There have been several reports of abdominal electromyographic (EMG) activity during abdominal muscle exercises[7,10–15] but only a few investigations that have examined the abdominal-hollowing exercise.[16–19] Furthermore, little is known about the muscular responses to changing body positions while performing the pelvic-tilt and abdominal-hollowing exercises. Therefore, our purposes were to investigate differences in EMG activity of the superficial abdominal muscles while performing the pelvic-tilt and abdominal-hollowing exercises and to determine whether changing the position of the legs causes a change in muscle activity while performing these 2 exercises. Our hypotheses were that there would be greater EMG activity of the rectus abdominus and external obliques with pelvic-tilt exercises as compared with abdominal-hollowing exercises and that performing these 2 exercises in different leg positions would cause increased EMG activity compared with the traditional position.

METHODS

Subjects

Twenty-six healthy female college students (age = 19.9 ± 1.9 years, height = 162.9 ± 7.3 cm, mass = 57.9 ± 7.0 kg) volunteered. All subjects participated in recreational or intercollegiate athletic activity. Each subject read and signed an informed consent form approved by the Pennsylvania State University's Institutional Review Board and completed an injury history questionnaire. Only female subjects were studied because the variation in the amount and distribution of subcutaneous tissue between the sexes could have confounded the results. There is no reason to believe that males and females would perform differently on these exercises. Potential subjects were excluded if they reported a history of low back pain, abdominal injuries, or hip injuries that required care from a physician or had an estimated body fat percentage greater than 24% as determined by skinfold measurements.[20] This value was chosen because of the risk of greater impedance during EMG data collection in subjects with body fat composition greater than 24%.[21]

Instrumentation

The Biofeedback Pressure Cuff Unit (Chattanooga Group, Hixson, TN) was used to monitor the position of the lumbar spine during the exercises (Figure 1). The feedback unit comprised a trisectional inflatable rectangular cushion (23 × 14 cm) connected to a pressure gauge (measuring 0–300 mm Hg) and an inflation device.

Surface EMG (Biopac Systems Inc, Santa Barbara, CA) was used to quantify rectus oblique and external oblique muscular activity. Preamplified, 10-mm contact area Ag-AgCl disposable electrodes with an interelectrode distance of 2 cm were used. The EMG signals were analyzed using AcqKnowledge software version 3.5 (Biopac Systems). The following settings were used: band width = 10 to 500 Hz, input impedance = 2 MΩ (differential), common mode rejection ratio = 110 dB, maximum input voltage = ± 10 V, sampling rate = 1200 Hz, gain = 1000.

Subject Preparation

Alcohol wipes were used for cleaning the surface of the skin before electrode placement. To record rectus abdominus activity, a pair of electrodes was placed on both the left and right aspects of the umbilicus and oriented parallel with the muscle fibers. For the left and right external obliques, a pair of electrodes was placed above the anterior superior iliac spine, halfway between the iliac crest and the ribs at a slightly oblique angle.[21] A ground electrode was placed on the tibial tuberosity.

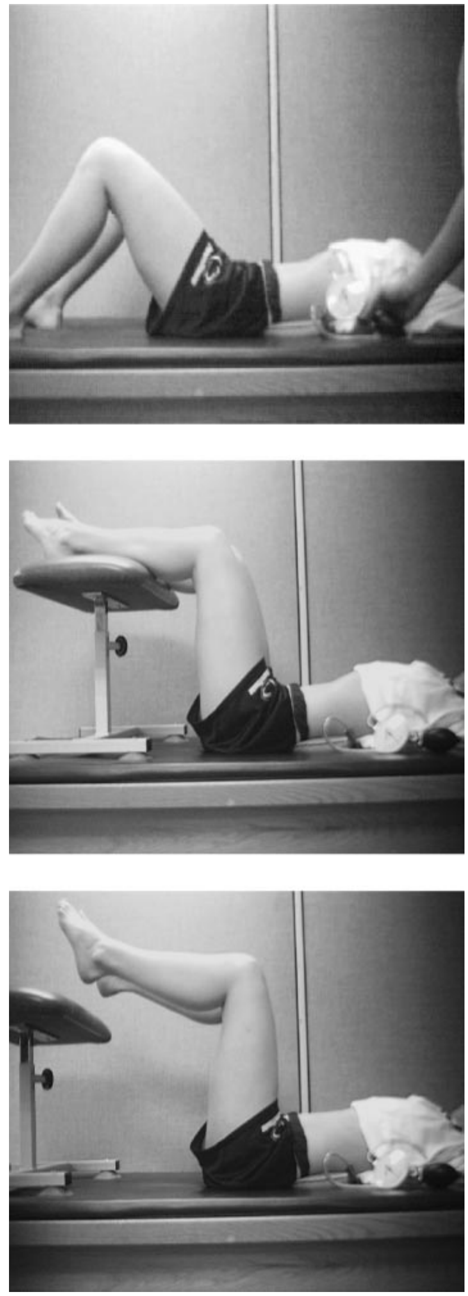

Figure 1. The exercises were performed with subjects lying with the biofeedback cuff under their lumbar spine in 3 positions: normal (crook lying), legs supported, and legs unsupported.

Electrode placement was verified by inspection of the signal during voluntary contraction.

Maximum voluntary isometric contractions (MVICs) of each muscle were collected to allow normalization of the EMG data. Maximum rectus abdominus activation was obtained with the subjects supine in a bent-knee sit-up posture with knees at 90° (crook lying) and the arms placed across the chest. The subject was instructed to attempt a sit-up while the researcher provided a matched resistance to prevent motion.[22] For the external oblique MVIC, the subject lay on her side with the knees bent and the thighs secured to the table with a strap. The trunk was rotated so the shoulders were facing upward and the arms were placed across the chest. The subject was instructed to attempt to rotate the shoulder to the opposite side while the researcher provided matched resistance to prevent motion.[16] This was repeated for both the right and left external oblique muscles. Three 5-second trials of all MVICs were recorded.

Testing Protocol

After completion of the MVICs, subjects were instructed on how to perform the pelvic-tilt and the abdominal-hollowing exercises by the primary investigator (C.L.D.). Each subject was allowed 10 to 15 practices for each exercise. All subjects were instructed to place their hands on their abdomen for tactile feedback during both exercises. For the pelvic tilt, subjects were instructed to contract the lower part of abdominal muscles to rotate the pelvis posteriorly so that the lumbar spine became flat against the table. If performed correctly, subjects were supposed to feel their superficial abdominal muscles contract. Subjects held the position for 5 seconds. For the abdominal hollowing, subjects were instructed to draw the lower part of the abdomen up and in toward the spine, without movement of the trunk or pelvis. If performed correctly, subjects felt their abdomen hollow. Subjects held the trunk and pelvis in that position for 5 seconds while continuing to breathe normally.

The Biofeedback Pressure Cuff Unit was used to ensure the subjects were performing the exercises correctly. The pressure cuff unit was placed under their lumbar spine and inflated to 40 mm Hg before the exercises were performed. When the subject performed the pelvic tilt correctly, the pressure increased above 60 mm Hg. If the subject performed the hollowing correctly, the pressure either stayed at 40 mm Hg or dropped.[8,23]

Once the subjects were able to perform the 2 exercises consistently and correctly, they performed the exercises in 3 different positions. The standard position was with feet flat on the table (crook lying), the supported position was with hips and knees flexed to 90° and legs supported on a platform, and the unsupported position was with hips and knees flexed to 90° and legs held without external support (see Figure 1). The order of exercises and positions was assigned in a counterbalanced manner to prevent the order of the tasks from influencing the results. Subjects held each contraction for 5 seconds and then returned to the resting position. Each subject had 1 minute of rest between each trial and 5 minutes of rest between the pelvic-tilting and the abdominal-hollowing exercises. Three trials were recorded for each task.

Data Processing

Custom MATLAB (Mathworks Inc, Natick, MA) routines were written to process the raw EMG data. Because of the location of the electrodes on the trunk, an electrocardiograph (ECG) artifact was present in the signal of all muscles from which data were collected. This was particularly problematic during the abdominal-hollowing exercise because of the small magnitude of superficial muscle activity with this exercise. Although a portion of the EMG signal was lost, we felt it necessary to filter the data to remove the heart-rate artifact. Following correction for baseline drift, the data were run through a high-pass, fourth-order, zero-lag Butterworth filter with a cutoff frequency of 75 Hz. The root mean square was calculated over a 0.5-second moving window. The peak amplitude for each trial was determined and the average of the 3 trials calculated. The mean exercise values were normalized to the MVIC values for both muscles; thus, the dependent variable for each muscle was the percentage of MVIC during the respective activity. Because of a hardware error, 11 subjects did not have usable recordings from their right rectus abdominus, and 1 subject did not have usable recordings from the right and left external oblique. For these subjects, only their usable EMG signals were processed and analyzed.

Statistical Analysis

Paired *t* tests were calculated to assess differences between left and right muscles (rectus abdominus and external obliques) during both exercises in each of the 3 positions. The level of significance was adjusted with a Bonferroni correction (0.05 divided by 12 comparisons) to $P < .004$ to account for multiple comparisons. No significant differences between left and right external obliques or left and right rectus abdominus muscles were identified. For the remainder of the analysis, the right and left data were pooled together. For each muscle, a 2 × 3 within-factor repeated-measures analysis of variance was performed. The first factor was exercise with 2 levels (pelvic tilt, abdominal hollowing), and the second factor was position with 3 levels (standard, legs supported, legs unsupported). Paired *t* tests were performed as post hoc analyses. All analyses were performed with SPSS 10.0 statistical software (SPSS Inc, Chicago, IL).

RESULTS

For the rectus abdominus muscle, a significant interaction between position and exercise ($F_{2,80} = 7.59$; $P = .001$) was identified. In all 3 positions, the pelvic tilt produced more rectus abdominus EMG activity than the abdominal hollowing. The difference with the legs unsupported was of a greater magnitude than the other 2 positions. No substantial difference in muscle activity was noted between the standard and supported positions for the abdominal hollowing ($P = .25$), but the supported position produced less activity than the standard position for the pelvic tilt ($P = .002$; Figure 2).

Although the interaction between position and activity was not significant for the external obliques ($F_{2,98} = 2.6$; $P = .08$, $1 - \beta = .50$), main effects were significant for exercise and position. The pelvic tilt produced significantly more external oblique EMG activity than the abdominal hollowing regardless of position ($F_{1,49} = 116.6$; $P = .0005$). Regardless of exercise, there was significantly more external oblique EMG activity when the exercises were performed in the unsupported position than in the supported and standard positions ($F_{2,98} = 72.81$; $P = .0005$; Figure 3).

DISCUSSION

Our first hypothesis was supported, as the abdominal-hollowing exercise produced significantly less rectus abdominus and external oblique EMG activity than the pelvic-tilt exercise. Previous research supports our finding. Vezina and Hubley-Kozey[18] reported greater rectus abdominus and external oblique activity with pelvic-tilting exercises than with abdominal-hollowing exercises when performed in the standard position. Similarly, Allison et al[16] compared the abdominal-hollowing exercise with abdominal bracing (cocontraction of all abdominal muscles) and found greater rectus abdominus activity with bracing. The abdominal-hollowing exercise was de-

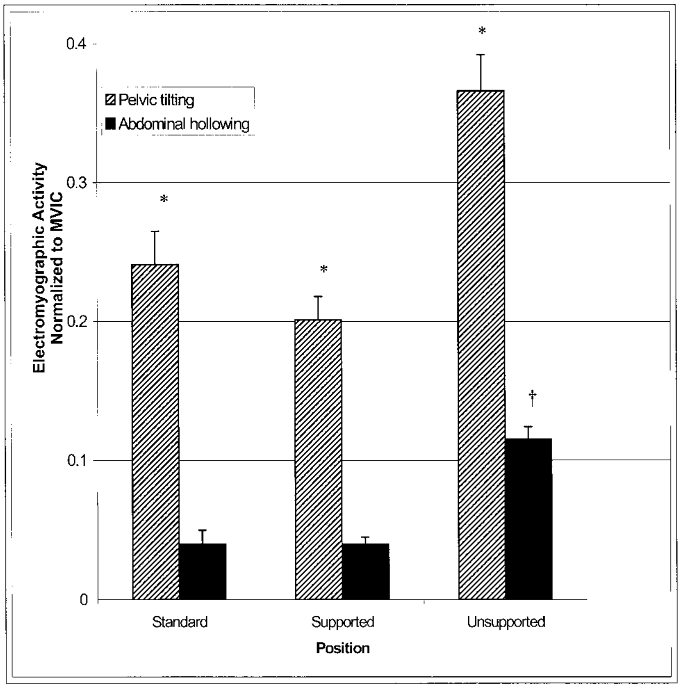

Figure 2. The exercise-by-position interaction for rectus abdominus surface electromyographic activity was significant ($F_{2,80}$ = 7.59; P = .001). *Rectus abdominus activity was greater during the pelvic tilt versus the abdominal hollowing in all 3 positions ($P < .05$). Although the activity during the hollowing was unchanged in the standard and supported positions, the activity during the pelvic tilt decreased in the unsupported position. #Rectus abdominus activity was greater in the unsupported position than in the other positions during the abdominal hollowing ($P < .05$). MUIC indicates maximum voluntary isometric contraction.

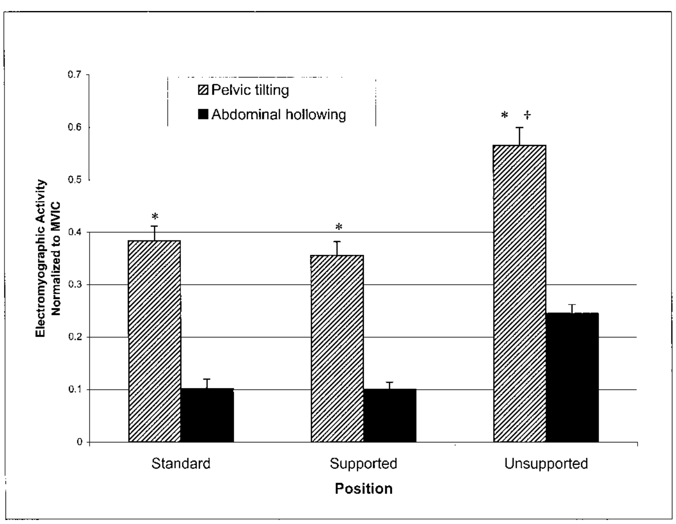

Figure 3. For the external oblique muscle, main effects were significant for exercise ($F_{1,49}$ = 116.6; P = .0005) and position ($F_{2,98}$ = 72.81; P = .0005). *Surface electromyographic activity was significantly greater for the pelvic tilt than for the abdominal hollowing ($P < .05$). #Electromyographic activity was also significantly greater when performing the exercises with the feet unsupported, compared with the other 2 positions ($P < .05$).

veloped for neuromuscular retraining and kinesthetic awareness of the transverse abdominus.[8,9,24] Although we did not measure transverse abdominus muscle activity, our results show that abdominal hollowing resulted in less global muscle activity. This may be advantageous in the early stages of treatment of low back pain.

The second purpose of our study was to determine whether muscle activity changed when the exercises were made more challenging by altering the position of the legs. In the feet-unsupported position, both the rectus abdominus and external oblique were significantly more active than in the other positions. This was true for both exercises and confirmed our second hypothesis. In the unsupported position, subjects had to actively hold their legs in an elevated position. For the abdominal-hollowing exercise, there was no difference in rectus abdominus and external oblique activity between the standard and legs-supported positions. This indicates that the hollowing exercise can be performed in the legs-supported position without substantially increased activation of the large, global muscles such as the rectus abdominus and external oblique. The crook-lying and legs-supported positions may be more advantageous positions for limiting global muscle activity than the legs-unsupported position.

Other authors have also examined methods to make the abdominal-hollowing exercise more challenging. Allison et al[16] found that rectus abdominus surface EMG activity increased incrementally as abdominal-hollowing was performed at increasing loads determined with the biofeedback pressure cuff. Conversely, oblique abdominal surface EMG activity did not change substantially with increasing loads. The authors concluded that with increasing loads, abdominal hollowing was no longer being performed correctly because the rectus abdominus was being substituted for the transverse abdominus. These results demonstrate the importance of teaching patients to not increase the cuff pressure during performance of the hollowing exercise. Beith et al[19] investigated surface EMG activity of the rectus abdominus, internal oblique, and external oblique muscles during abdominal hollowing performed in prone and 4-point kneeling positions. They reported that the internal obliques were activated in all subjects during abdominal hollowing in both positions. The external obliques were activated less often (45% of subjects during 4-point kneeling trials and 75% during prone), whereas the rectus abdominus was activated in only 10% of subjects during both positions. The authors concluded that isolated activity of the deep abdominal muscles may not always be achievable when performing abdominal hollowing in these positions.[19] These results illustrate the challenges of transferring the abdominal-hollowing exercises to more functional positions while retaining proper muscle-recruitment strategies.

The pelvic tilt is frequently prescribed in the early stages of a rehabilitation program for low back pain; however, some question the efficacy of this exercise in the early stages of treatment.[6] Our study, as well as the previous work of others,[16–18] demonstrates that pelvic tilting causes substantial recruitment of global muscles such as the rectus abdominus and external obliques. Recruitment of these global muscles may be contraindicated in people with symptomatic low back pain because concentric contraction of the abdominal muscles causes the spine to flex.[25] It may be unwise to recommend this exercise during the early phases of rehabilitation for some patients with severe low back injuries because of preloading of the spinal structures, such as the annulus fibrosis and posterior ligaments.[6,26]

Our study was not without limitations. Because of an ECG artifact in our EMG signals of the superficial abdominal muscles, we high-pass filtered our data at 75 Hz, thus filtering out some of the EMG signal. Because of the low amplitude of EMG signal produced during the abdominal-hollowing exercises, we felt it necessary to remove the ECG artifact so as not to confound our EMG amplitude values. We felt that filtering the lower aspect of the EMG spectrum was more advantageous than having the ECG artifact confound our small EMG amplitudes. Our results are only of the EMG spectrum above 75 Hz, and readers should thus interpret our results accordingly. We cannot speculate on how our results would be different if we were able to analyze the full spectrum of EMG activity. We were also limited in the ability to assess the activation of the deeper abdominal muscles during the abdominal-hollowing exercise. Therefore, we attempted to assess correct performance of the abdominal-hollowing exercise by using the pressure cuff and demonstrating that substitution of the rectus abdominus and external oblique was not occurring. Other authors have used invasive techniques such as fine-wire intramuscular electrodes to study the deeper muscles. Lastly, our study was performed on healthy young adults, and the generalizability of our results to patients with low back pain is not known.

In conclusion, the abdominal-hollowing exercise does not produce as much rectus abdominus and external oblique muscle activity as the pelvic tilt. Furthermore, the abdominal-hollowing exercise can be performed, without increased activation of the rectus abdominus and external oblique muscles, in the standard and legs-supported positions. These findings should be considered when selecting rehabilitation exercises for neuromuscular retraining of the abdominal muscles.

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