Recruitment of Internal Oblique and Transversus Abdominis Muscles During the Eccentric Phase of the Curl-up Exercise

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The purpose of this study was to analyze the results of a training method to increase voluntary recruitment of internal oblique and transversus abdominis muscles. Forty volunteers were assigned to either a Control or an Experimental Group. Training consisted of multisensory (auditory, tactile, visual, and kinesthetic) cuing focused on the lower abdominal muscles during the slow curl-back (eccentric) phase of curl-up exercises with the subjects' feet unsupported. We recorded integrated electromyographic (IEMG) values using surface electrodes from internal oblique and transversus abdominis muscles during pretest and posttest exercises. Using an analysis of covariance, posttest IEMG values of the Experimental Group were significantly higher ($p < .001$) than the Control Group. Our results reveal that multisensory cuing with the feet unsupported during the curl-back is an effective method of increasing combined recruitment of internal oblique and transversus abdominis muscles. Motor skills developed by this technique are discussed in relation to optimal trunk function and rehabilitation.

Key Words: *Abdominal wall, Exercise therapy, Physical therapy.*

Common adult disorders of the trunk, such as low back pain and inguinal hernias, are associated with weakened lower abdominal muscles and their improper or inadequate use in daily activities.[1–7] In sedentary individuals, trunk muscle imbalance develops that favors strength in postural muscles, such as the iliopsoas, compared with weakness of the more phasically acting abdominal muscles.[7] In addition, the iliopsoas muscle, with its extensive lumbar attachment, contributes potentially hazardous compressive and lordotic forces on the lumbar spine[8] and intervertebral disks,[9] if not balanced by the stabilization forces of the abdominal muscles.[3,7,8]

Awareness and recruitment of abdominal muscles in exercise and daily activity appear to be required to maintain balance of the trunk musculature. Thus, training should be directed toward voluntary recruitment of abdominal muscles during common trunk training exercises such as the curl-up.

Using electromyography, Janda and Schmid showed that stabilizing the feet dorsally during curl-ups facilitates iliopsoas muscle predominance.[7] Controlling the curl-up without the feet anchored requires pelvic stabilization and trunk coordination skills, which are essential for functional trunk training.[3,10]

In a pilot study, we used intramuscular EMGs recorded from fine-wire electrodes to examine the relationship of the iliopsoas, abdominal, and gluteus maximus muscles during curl-ups, with and without dorsal foot stabilization. Our raw EMG data recorded from three subjects support the results of Janda and Schmid[7] and suggest that an inverse relationship exists between internal oblique and iliopsoas muscle activity during the curl-back (eccentric) phase of curl-ups. No other abdominal muscles appeared to be so closely related to iliopsoas muscle activity during curl-ups. After training, the individuals' iliopsoas muscle activity decreased, whereas the activity of the abdominal muscles, particularly the internal oblique muscle, increased markedly.

This apparent substitution would be anticipated from the anatomical and kinesiological similarities of the two muscles (Fig. 1). Both the internal oblique and the iliopsoas muscles are attached dorsally and ventrally and apply forces onto the pelvis and the spine (the iliopsoas muscle directly and the internal oblique muscle through its attachment to the lumbodorsal fascia). The internal oblique and transversus abdominis muscles are the only two abdominal muscles that are attached from the anterior trunk to the lumbar spine by the lumbodorsal fascia, the strongest low back supportive structure.[3,11] They also are the only abdominal muscles passing superior to the inguinal canal that supply active support in response to intra-abdominal pressure.[6]

Authors of previous studies of abdominal muscle exercise have examined different muscle groups with different methods. They have focused on the activity of the prime movers, specifically the rectus abdominis and external oblique muscles, rather than the stabilizing muscles that encircle the trunk—the internal oblique and the transversus abdominis muscles.[12–18] Previous studies have not incorporated motor learning techniques for facilitating trunk and hip flexor muscle coordination.[12–19]

The objective of this study was to examine a method that has been used clinically to teach individuals to end their

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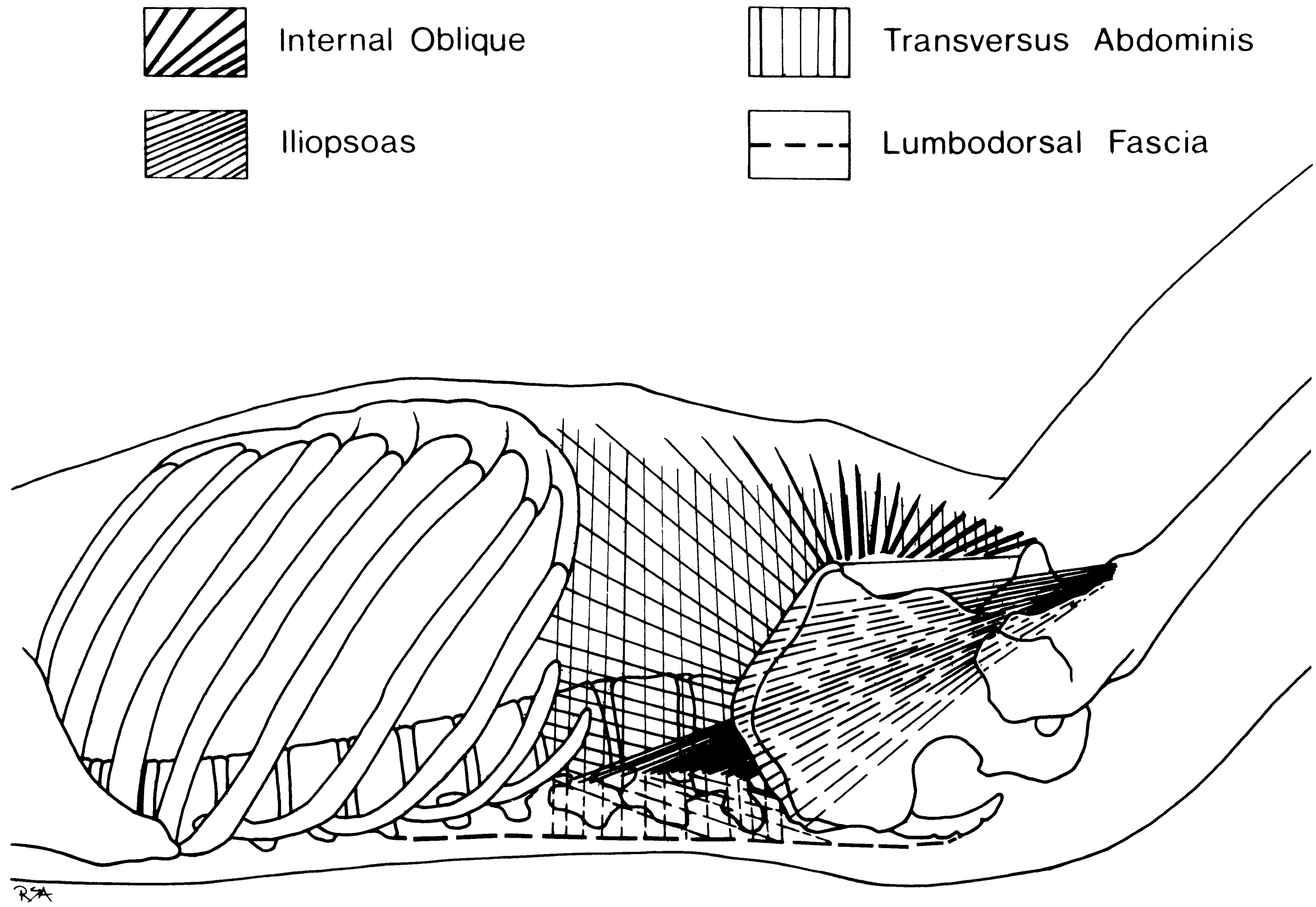

Fig. 1. Anatomical attachments of the internal oblique, transversus abdominis, and iliopsoas muscles.

dependence on feet stabilization during curl-ups and to develop pelvic stabilization skills useful in daily activities of back care.[20] We analyzed the results of training designed to increase voluntary recruitment of the anterior fibers of the internal oblique and transversus abdominis muscles during the curl-back phase of curl-up exercises. Surface EMGs were processed by the technique of integrated electromyography (IEMG). Our training method consisted of multisensory cuing during the curl-back phase. We made comparisons between an Experimental Group and a Control Group. We hypothesized that no significant difference would occur in combined IEMG values from the anterior inferior portion of the internal oblique and transversus abdominis muscles when comparing the Control Group with the Experimental Group after training.

METHOD

Subjects

The subjects were healthy male volunteers, between the ages of 25 and 40 years, who were able to perform the test exercise without complications. The mean age of the total group was 31.1 years, the mean height was 181.1 cm, and the mean weight was 75.6 kg (Tab. 1). Before recruitment of the participants, we numbered files individually from 1 to 40. We then used a table of random numbers to classify each file as experimental subject (T) or control (C). We assigned a file to each subject corresponding to the chronological order in which he entered the study. Twenty subjects were in each group.

Instrumentation

Our instrumentation has been reported in detail elsewhere.[21,22] The EMG equipment used was designed to provide a frequency response of 10 to 200 Hz. The EMG unit consisted of a differential voltage amplifier driving a voltage control oscillator whose pulse frequency output was counted on an electronic counter. By counting the pulses, a direct integral of EMG voltage over time was obtained. When the integral was divided by the time base, the mean level of electrical activity in the muscle group over a period of time was recorded as microvolts root mean square (μVRMS). At all test sessions, the EMG signals were monitored continuously by the primary investigator (M.I.M.) using an oscilloscope for identifying possible movement artifacts.

Procedure

On arrival, each subject read and signed a consent form explaining the procedure and purpose of the study. He then removed his shirt, belt, and shoes. His stockings remained on to decrease foot friction on the vinyl-surfaced plinth. A towel was used on the plinth where skin contact would be made.

Each subject assumed a supine position on the plinth. The recording equipment was not visible to the subject. The primary investigator placed a ground electrode on the volar aspect of the subject's wrist and two active electrodes 15 mm apart and parallel to the inguinal ligament over the retroaponeurotic triangle.[1,23] This site for IEMG recording of the internal oblique muscle is, as described by Floyd and Silver,

TABLE 1
Means and Standard Deviations for Experimental and Control Groups

Source	Total Group (N = 40)	Experimental Group (n = 20)	Control Group (n = 20)
Age (yr)			
$\bar{X}$	31.10	31.00	31.30
s	3.22	3.23	3.19
Height (cm)			
$\bar{X}$	181.13	182.25	180.21
s	3.56	3.53	3.58
Weight (kg)			
$\bar{X}$	75.57	78.02	73.03
s	2.72	2.64	2.81

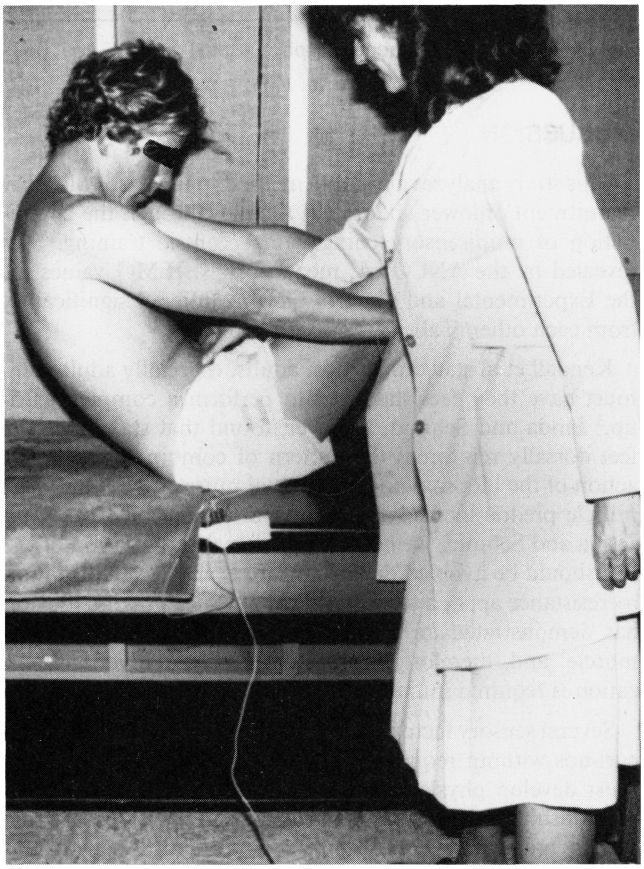

Fig. 2. Experimental Group subject being given multisensory cue training.

a triangular segment of the inferior anterior portion of the muscle that is separated from the skin surface only by the aponeurosis of the external oblique muscle.[1] The only muscle directly below the internal oblique muscle in this triangle is the transversus abdominis muscle, which functions with the internal oblique muscle as a trunk stabilizer.[3] Their activities cannot be separated totally in function nor with EMG. Our IEMG recordings, therefore, represent the combined activity of the two muscles.

According to reports in the literature describing surface IEMG recording in relationship to electrode placement, the narrower the electrode placement, the shallower the pickup.[24] The field recorded is the segment of skin surface that is between the electrodes. Our narrow electrode placement of 15 mm most likely recorded chiefly the activity of the internal oblique muscle, but also may have included the transversus abdominis muscle. Recording of electrical signals from other muscles was unlikely because of the close placement of the electrodes.

The primary investigator gave verbal instructions and a physical demonstration of the testing procedure to each subject. The subject was allowed two practice trials before the testing began. The primary investigator recorded only the curl-back phase of the curl-up exercise, which was performed in time to a metronome set at three-second intervals. The subject flexed his knees creating a hip angle of 130 degrees. He held his arms horizontally, not touching anything during the curl-back phase of the exercise until at rest. He was allowed to push with his arms to assist with the curl-up phase, if necessary.

During the five pretest trials, each subject first was commanded: "Come up." When the subject's upper torso was in the vertical plane, he then was commanded: "Ready, and go, 2, 3" (in time with the metronome rhythm). The subject was to be back in the supine position at the count of three. Simultaneously with the command of "Go," the investigator pushed the switch initiating the three-second period of IEMG data collection. The subjects had rest periods of about three seconds between trials.

The posttest trials for all subjects, which followed either the Experimental Group or the Control Group procedures, were performed exactly as the pretest trials. Each subject performed one practice trial to reaccustom him to the three-second timing before the posttest trials began. The same investigator conducted all of the instruction, testing, and recording.

The primary investigator gave each of the participants in the Experimental Group multisensory cue training that included auditory, tactile, visual, and kinesthetic cues. She told the subject: "This is a 'contemplate-your-navel' exercise. As you curl back, look at your navel; pull it up and against your spine with your abdominal muscles, feeling them very tight, doing all of the work to lower yourself smoothly, so that your feet remain resting on the surface." The investigator also tapped the subject's lower abdomen to provide tactile muscle stimulation as he performed the curl-back phase of the exercise. This procedure was repeated for five curl-backs (Fig. 2). The examiner then told the subject that he should apply what he had just learned to the posttest procedure.

The examiner instructed each Control Group subject to perform five abdominal muscle strengthening exercises in his usual manner. If requested, she stabilized his feet. Each Control Group subject was instructed as follows: "I would like you to perform five repetitions of the exercise you perform most frequently for your abdominal muscles. I will hold your feet down or you can use support as you do at home." The speed of the exercise varied according to the individual.

Data Analysis

We used a pretest-posttest control group true experimental design. We compared the results of the Control and Experimental Groups by an analysis of covariance (ANCOVA) using the analysis-of-variance program of the Statistical Package for the Social Sciences. Our raw data consisted of the IEMG values of the five pretest trials and the five posttest trials. The mean value of the five pretest trials was the covariate variable, and the mean value of the five posttest trials was the dependent variable. The mean values of the five posttests were

TABLE 2
Intraclass Correlation Coefficients

Variable	Total Group (N = 40)	Experimental Group (n = 20)	Control Group (n = 20)
Pretest	.98	.98	.98
Posttest	.98	.96	.99

TABLE 3
Means and Standard Deviations of Integrated Electromyographic Pretest and Posttest Values and Adjusted Posttest Values (in μVRMS)

Variable	Total Group (N = 40)	Experimental Group (n = 20)	Control Group (n = 20)
Pretest			
X̄	74.13	72.37	75.88
s	36.02	32.79	39.78
Posttest			
X̄	105.99	144.60	67.38
s	70.78	77.62	33.46
Adjusted post-test			
X̄	...	145.79	66.19
s	...	...	...

TABLE 4
Analysis of Covariance Comparing Control and Experimental Groups

Source	*df*	SS	MS	*F*	*p*
Covariates					
Pretest mean values	1	19783.16	19783.16	6.51	.01
Main effects					
Experimental Group	1	63220.54	63220.54	20.82	.001
Error	37	112380.30	3037.30		
TOTAL	39	195384.00	5009.85		

adjusted based on the analysis of the pretest data to account for regression of pretest values. We used .05 as the level of significance. To determine reliability of the IEMG data, we analyzed the five individual test values for each pretest and posttest session using the alpha model intraclass correlation coefficient (ICC[1,k]).

RESULTS

The mean and standard deviation values for age, height, and weight of the subjects are shown in Table 1. The results of the ICC indicated that the pretest and posttest IEMG values were highly reliable (Tab. 2). Integrated electromyographic values are displayed in Table 3 and illustrated in Figure 3. As shown in Table 3, the mean adjusted pretest IEMG values were 72.37 μVRMS for the Experimental Group and 75.88 μVRMS for the Control Group. The mean adjusted posttest IEMG values were 144.60 μVRMS for the Experimental Group and 67.38 μVRMS for the Control Group. The ANCOVA revealed a statistically significant difference ($p < .001$) between the Experimental and Control Groups (Tab. 4).

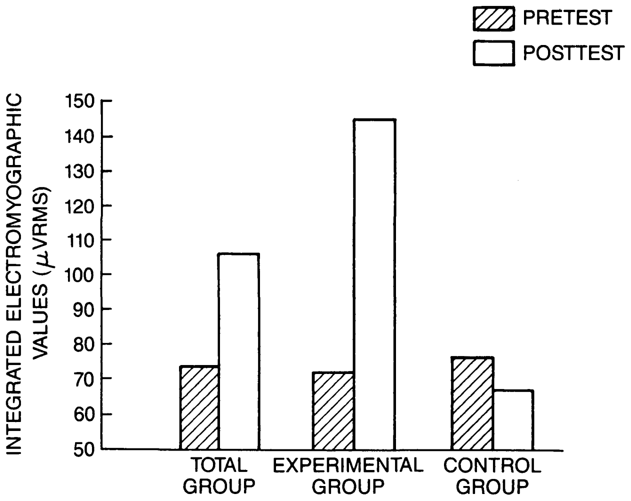

Fig. 3. Integrated electromyographic (IEMG) pretest and posttest values.

DISCUSSION

This study analyzes a training method to increase voluntary recruitment of lower abdominal muscles through the combination of multisensory cuing with eccentric training.[25] As revealed by the ANCOVA, mean posttest IEMG values for the Experimental and Control Groups differed significantly from each other (Tab. 4).

Kendall et al stated that most adults, especially adult men, must have their feet stabilized to perform a complete curl-up.[3] Janda and Schmid, however, found that stabilizing the feet dorsally reinforces the pattern of combined concentric action of the iliopsoas and abdominal muscles, with iliopsoas muscle predominance.[7] Based on our findings and those of Janda and Schmid, we believe that dorsal stabilization of the feet should be avoided during curl-up exercises. Stabilization by resistance applied to plantar flexion instead of dorsiflexion has demonstrated an inhibitory influence on the iliopsoas muscle[7] and, therefore, is a reasonable alternative if stabilization is required initially.

Several sensory factors may influence the ability to perform curl-ups without requiring feet stabilization. The individual must develop physical awareness of the subtle substitution relationship of the abdominal muscles and the iliopsoas muscles to break patterns of dependency on the strength and dominance of the iliopsoas muscles. To experience this awareness, the individual first must challenge the substitution relationship between the lower abdominal muscles and the iliopsoas muscles by using a movement that involves the activity of both muscle groups. The individual then must learn to gain control with the lower abdominal muscles dominating the force of the movement.

The means of such kinesiological awareness is through multisensory input. Various sensory neuromuscular techniques can be used for such training.[26,27] The cuing technique used in this study can be applied to large groups, without sophisticated training or equipment. The visualization cues to "contemplate your navel" and to "pull it up and against your spine with your abdominal muscles" use a familiar visual locus in the lower abdominal area from which the individual can focus the direction of motor response. The phrase "contemplate your navel" not only provides a visual cue, but has a humorous quality. If laughter occurs, the internal oblique and transversus abdominis muscles are further recruited because they are major participants in the activity of laughter.[1,6]

The compressive and lordotic forces of the iliopsoas muscles on the spine and intervertebral disks are hazardous if allowed to predominate movement habits.[9] Because predominance of the iliopsoas muscles over the abdominal muscles during curl-ups is fostered when the feet are stabilized dorsally, the curl-up should be performed without such stabilization.[7] Unfortunately, curl-up exercises with the feet stabilized dorsally is the standard testing method used in school, military, and adult fitness programs in the United States.[28]

The method discussed in this article teaches abdominal muscle awareness and voluntary control to break the patterns of dependence on the iliopsoas muscles in exercise and functional trunk movement. The specific trunk stabilization skills involved in this method are useful in other trunk movement methods including isolated posterior pelvic tilt and Kennedy's dynamic abdominal bracing,[10] techniques that require pelvic coordination independent of leg position, stabilization, or motion.

The positions selected for this training method can be modified clinically for the individual, but the concept of increased awareness and control with the eccentric contraction and multisensory input can be applied to any exercise variation selected. This method can be used in health education to encourage habits of trunk coordination and muscular balance that may be applied functionally and throughout the individual's life.

Further examination of this training method should focus on the relationship of iliopsoas muscle activity to that of the internal oblique muscle. Any study of the iliopsoas muscle requires intramuscular EMG, necessitating deep placement of needle electrodes. This training technique, which recruits muscular stabilization of the spine through attachments to the lumbodorsal fascia, should be applied to disk-compression studies of curl-up exercises.

CONCLUSIONS

We analyzed a training method designed to increase voluntary recruitment of the internal oblique and transversus abdominis muscles during curl-up exercises. When comparing the Control Group with the Experimental Group, we found a statistically significant difference favoring the Experimental Group. The training method involved a slow eccentric, or curl-back, phase without foot stabilization and multisensory kinesthetic cuing for recruitment of the lower abdominal muscles. Factors suggested as having a possible influence on the positive results of the training method included the teaching of sensory awareness with multisensory cuing. This method demonstrates clinical potential for breaking the patterns of dependency on the iliopsoas muscle while developing the strength and functional coordination skills of the spinal and pelvic stabilizing muscles.

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