Ref

Altered Abdominal Muscle Recruitment in Patients With Chronic Back Pain Following a Specific Exercise Intervention

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The efficacy of specific exercise interventions that advocate training the co-contraction of the deep abdominal muscles with lumbar multifidus for treating chronic back pain conditions has not been tested. A randomized controlled trial involving 42 subjects with a specific chronic back pain condition investigated whether this form of intervention results in changes to the ratio of activation of the internal oblique relative to the rectus abdominis. Data were collected before and after the intervention, using surface electromyography, while subjects performed different abdominal maneuvers. Subjects were randomly allocated to either a specific exercise group or control group. Following intervention, the specific exercise group showed a significant ($p < 0.05$) increase in the ratio of activation of the internal oblique relative to the rectus abdominis. The control group showed no significant change. The study findings provide evidence that the conscious and automatic patterns of abdominal muscle activation can be altered by specific exercise interventions.

Key Words: *abdominal muscles, exercise, low back pain*

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The ligamentous spine is known to be unstable at loads far less than that of body weight (21). The neuromuscular system must therefore fulfill the supplementary and adaptive roles of maintaining postural stability while controlling and initiating movement (11). The oblique and transverse abdominals, with coactivation of the lumbar multifidus, are muscles considered to provide an important stiffening effect on the lumbar spine, enhancing its dynamic stability (2). The internal oblique and transversus abdominis muscles in particular are known to be primarily active in providing rotational and lateral control to the spine while maintaining levels of intra-abdominal pressure and imparting tension to the thoracolumbar fascia (7–9,33). A number of studies has documented a degree of functional independence between the deep abdominal muscles (internal oblique and transversus abdominis) and muscles better designed for torque production, such as the rectus abdominis and external oblique, during various tasks (7–9,32).

Recent studies indicate that the deep abdominal muscles undergo changes in their functional performance in populations with chronic low back pain (18,19,23). Furthermore, clinicians and researchers have described the presence of subtle changes or shifts in the pattern of abdominal muscle activation in subjects with chronic low back pain. These patterns have been described as substitution or overriding activation of the rectus abdominis during attempts to preferentially activate the deep abdominal muscles (23,27,30).

Exercise programs designed to improve the function of the abdominal muscles have been widely advocated by clinicians for the treatment of low back pain for many years (17, 20). Some clinicians have advocated trunk curl-up exercises and exercises that incorporate high levels of rectus abdominis activity (13,16,22). More recently, other clinicians have advocated exercises designed to activate more specifically the deep abdominal muscles, based on the finding of specific dysfunction of these muscles in subjects with chronic low back pain (27).

Research investigating different abdominal exercises has confirmed that some exercises are more specific for activating the deep abdominal muscles than others (32). The abdominal drawing in maneuver (the action of drawing the abdominal muscles in toward the spine) is one exercise known to result in preferential activation of the internal oblique and transversus abdominis muscles with little contribution by the rectus abdominis in the pain-free population (23,32). This pattern of muscle

activation has been advocated as an appropriate exercise for facilitating the dynamic stabilizing role of these muscles. Indeed, it has been suggested that the correct functioning of the deep abdominal muscles is particularly critical in subjects with chronic low back pain where the anatomical stability of the spine has been compromised in order to provide dynamic stability and control to the lumbar spine during functional tasks (27).

Researchers have reported that an inability to perform the abdominal drawing in maneuver differentiated chronic low back pain from pain-free subjects (19,23,28). Furthermore, Edgerton et al suggest that when a muscle or a group of muscles are weakened, subtle shifts in the pattern of motor activity occur, enabling synergistic muscles to generate the necessary forces required for functional tasks (12). This is known as "muscle substitution" and is often difficult to observe by unskilled gross muscle testing but may be detected using electromyography (3,12). This view is supported by the findings of a recent study which reported that subjects with chronic low back pain were unable to preferentially activate the internal oblique from that of the rectus abdominis during the abdominal drawing in maneuver. On the other hand, subjects without chronic low back pain were able to preferentially activate the internal oblique from that of the rectus abdominis during the maneuver (23). These findings support the view of clinicians that muscle substitution of large torque-producing synergists, such as the rectus abdominis, occurs in patients with chronic low back pain when deep abdominal contractions are attempted (27).

In light of the findings of deep abdominal dysfunction and muscle substitution reported in populations with chronic low back pain, clinicians have advocated and claimed to be able to train specifically the contraction of the deep abdominal muscles without dominant substitution of the rectus abdominis (27). Until this time, however, no study has investigated whether subjects with chronic low back pain are in fact capable of learning this motor pattern. Nor is there evidence to suggest that this form of exercise is able to alter either the conscious and automatic patterns of abdominal muscle recruitment in subjects with a chronic low back pain condition. Furthermore, the question remains unanswered whether this form of training results in enhanced dynamic stability to the trunk during functional tasks.

The muscle synergy may reflect a neurological change, thereby altering the motor program by which muscles are recruited.

The aim of this study was to investigate whether a specific exercise intervention directed at the deep abdominal muscles results in an increased ability to isolate the activation of these muscles from the rectus abdominis during the abdominal drawing in maneuver in a specific patient population with chronic low back pain. Subjects were selected on the basis that they had a chronic back pain condition considered to be attributable to a radiological diagnosis of spondylolysis or spondylolisthesis. This condition was chosen as it is considered to be one of the most obvious manifestations of lumbar instability (26).

METHODS

Subjects

A randomized controlled test-retest study design with a blind investigator was employed. Forty-four subjects of both genders entered the trial over a 4-month period. Inclusion criteria were restricted to subjects of either gender whose low back pain symptoms were chronic and had persisted longer than 3 months with no sign of abating. Subjects entered the study if their symptoms and clinical presentation were considered to be attributable to the radiological diagnosis of spondylolysis or spondylolisthesis by their medical specialist. Subjects were excluded if they: had symptoms that were considered not to be attributable to the presence of the spondylolysis or spondylolisthesis by the treating medical specialist; scored less than 2/10 on the visual analogue pain scale for their average pain intensity levels over the previous 2 weeks; had undergone a specific stabilizing exercise intervention; had a diagnosed psychological illness; had undergone spinal surgery; or had a diagnosed inflammatory joint disease or displayed overt neurological signs (sensory paraesthesia or motor paresis). Subjects were withdrawn from the study if they withdrew their consent, demonstrated a lack of compliance to carry out the exercise intervention (less than 50% compliance on the subject compliance form), or showed any persistent exacerbation of their symptoms. Subjects were recruited from physiotherapy practices, general and specialist medical practices, and pain management clinics in the Perth metropolitan area. Ethical approval for the study was granted by the Human Ethics Review Committee of Curtin University, Perth, Western Australia.

Subjects signed an informed consent form and then underwent the testing procedure carried out by an investigator blind to group allocation. On completion of the initial testing, the subjects were randomly assigned to either a specific exercise group or a control group. Randomization was performed by an independent source, such that 22 subjects were randomly allocated to each group as

they were recruited to the study over the 4-month period. The intervention period was set at 10 weeks. At the completion of the intervention period, all subjects were retested by the same investigator blind to the group allocation.

Test Procedure

Activity of the internal oblique and upper rectus abdominis muscles was measured unilaterally using surface electromyography while subjects performed the double leg raise exercise and the abdominal drawing in maneuver (23,29). The activity level of the transversus abdominis could not be measured directly as intramuscular electromyography was not employed.

Double leg raise exercise The subject was positioned in supine crook lying with hips flexed to 45°. The instruction was to raise both feet 1 cm off the plinth and hold the position for 5 seconds. This submaximal isometric contraction was used to normalize the surface electromyography data, as maximal contractions are known to be unreliable in subject populations with low back pain (5), and submaximal contractions have been shown to be more reliable than maximal contractions (1). The double leg raise was the submaximal contraction selected, as it is known to activate all the abdominal musculature to stabilize the pelvis during the maneuver (4). Previous pilot investigations had shown this movement pattern to result in high levels of activation of both muscles relative to background noise. Statistical analysis revealed that the double leg raise activated both muscles to similar levels and was repeatable within and between testing sessions [intraclass correlation coefficient $(ICC)_{(1,1)}$ = 0.84–0.96]. The total root mean square of the double leg raise data was used to normalize the data collected during the abdominal drawing in maneuver.

Abdominal drawing in maneuver The abdominal drawing in maneuver was performed in the manner described by Richardson et al (29). Each subject was positioned in supine crook lying with hips flexed to 45°, and a pressure biofeedback monitor (Chattanooga Australia Pty. Ltd., Brisbane, Queensland) was placed under the lumbar lordosis between S1 and L1, with another beneath the subject's feet. The pressure was set to 40 mmHg. Each subject was instructed to contract their deep abdominal muscles by drawing the navel up in a cephalad direction and in toward their spine, so as to draw in the lower abdomen. The head and upper trunk were to remain stable and subjects were not permitted to flex forward, push through their feet (as noted by the pressure biofeedback monitor under the subjects' feet), or tilt their pelvis (29). The exercise was repeated until the subject understood the procedure and was able to carry it out while breathing. The subject was then instructed to carry out the same procedure and try to gently flatten the back to gain a steady rise of 10 mmHg on the pressure gauge under the subject's lumbar spine. If the instructor noted that the procedure was being performed incorrectly, the subject was instructed how to correct it.

The abdominal drawing in maneuver was chosen to assess deep abdominal muscle function, as it has been shown in pain-free populations to preferentially activate the deep abdominal muscles with minimal activation of the rectus abdominis (23, 32). However, in patients with chronic low back pain, a reduced ability to isolate this pattern of activation has been reported (23). The abdominal drawing in maneuver has been shown to be repeatable between trials (29) and, in recent times, this method of activating deep abdominal muscle function has been widely adopted by physiotherapists working in clinical practice as a means of evaluating and training the function of the deep abdominal muscles. During this form of muscle testing, clinical observations of muscle substitution have been reported to occur in patients with chronic low back pain (30).

The electromyography equipment used consisted of a Medelec PA63 preamplifier (Medelec MS6, Surrey, England) which was connected to an AAG Mk III amplifier/filter (Medelec). The Medelec specifications are as follows: it has an input impedance series mode of 100 MΩ in parallel with 15 pF (pico Farad) and common mode > 100 MΩ in parallel with 30 pF. It has a common mode rejection ratio > 50,000:1 at 50 Hz. The band width of the amplifier is 0.016 Hz–32 KHz, with selectable low frequency and high frequency time constants. The gain setting was 50 mv/div and the band pass filtering was 8–800 Hz. The output from the amplifiers was sampled at 1,600 Hz via MacAdios II and recorded onto disc.

The electrode sites were prepared to maintain skin impedenace less than 5 KΩ as described by Gilmore and Meyers (14). Two 3M® red dot Ag/AgCl 2-cm diameter electrodes were placed 20 mm apart over the right upper rectus abdominis muscle (5 cm inferior to the xiphoid process and 3 cm laterally from the midline) and over the right internal oblique muscle (3 cm cephalad and medial to the anterior superior iliac spine) (15,25). A ground electrode was placed over the acromion process. Care was taken to ensure exact electrode placement to guarantee retest accuracy when reapplying the electrodes following the intervention period.

Contractions were performed for each muscle to ensure the correct placement of the electrodes and that cross-talk between the recording sites was negligible (29). For the upper rectus abdominis, the subject was instructed to flex the head and upper trunk and, for the internal oblique,

the subject was instructed to gently draw in the lower abdominal wall muscles (32).

Testing Protocol

Amplitude normalization of surface electromyography data Each subject initially performed a double leg raise and was instructed to hold the position for 5 seconds. When the subject had gained a steady isometric contraction, the surface electromyography of the abdominal muscle activity was recorded for 3 seconds. Two recordings were made.

Abdominal drawing in maneuver Each subject performed three trials. For each trial, subjects were required to gain a pressure rise of 10 mmHg on the pressure biofeedback monitor and maintain this level for 10 seconds. The last 3 seconds of each trial was recorded to disk.

The electrocardiographic activity was selectively removed from the raw signal by visual inspection to avoid contamination of the results. The total root mean square of the surface electromyography data of the upper rectus abdominis and internal oblique was then calculated. The average of the two double leg lift and the three abdominal drawing in maneuver recordings was then calculated. The abdominal drawing in maneuver data were then amplitude normalized using the double leg raise data for these muscles. The ratio of activation of the internal oblique relative to the rectus abdominis was then calculated (internal oblique/rectus abdominis).

Intervention

The specific exercise group underwent a 10-week treatment program directed on a weekly basis by one of four manipulative physiotherapists who practice in different parts of the Perth metropolitan area. All therapists had significant experience and expertise in this specific exercise approach to treatment of the low back region. The treatment approach given was standardized, such that all therapists adhered to the guidelines as follows.

The intervention involved subjects being taught exercises designed to: *1)* train the specific contraction of the deep abdominal muscles without excessive activity of the rectus abdominis. This pattern of activation described by Richardson and Jull (27) has been shown in the normal population to generate activity in the deep abdominals with minimal activity in the rectus abdominis (23,32); and *2)* train the specific contraction of the deep abdominal muscles with co-contraction of lumbar multifidus proximal to the pars defect. This pattern of activation has been shown to promote a co-contraction pattern of the deep abdominals and lumbar multifidus (27).

The holding time for these exercises was gradually increased in conjunction with a pressure biofeedback monitor to the point where subjects were able to perform 10 contractions with 10-second holds. These exercises are precise contractions involving low levels of voluntary contraction to ensure that subtle patterns of muscular substitution were prevented (27).

Once an accurate and sustained contraction of these muscles was achieved, the exercises were progressed by applying low load on the muscles by initiating controlled movement of the limbs. For example, if the co-contraction pattern was initiated in supine crook lying, then the progression of a controlled single leg slide or lateral leg dropout was instructed. In four-point kneeling, the progression would be flexion of one of the upper limbs while maintaining an appropriate pattern of co-contraction. In prone, the co-contraction was progressed with controlled knee flexion or hip extension. Subjects were required to perform the exercises at home on a daily basis. The exercise program was designed to take approximately 15 minutes. Subjects also completed a daily exercise sheet to monitor their compliance.

Once accurate activation of the co-contraction patterns (1 and 2) was achieved without substitution of the rectus abdominis and with controlled breathing, they were immediately incorporated into functional holding postures and activities known to previously aggravate the subjects' symptoms. Subjects were encouraged to activate these muscles regularly during daily activities.

The control group underwent treatment over a 10-week period, as directed by their treating practitioner. This consisted of all but one of the subjects performing regular weekly general exercise, such as swimming (10), walking (seven), and gym work (two). Ten of the subjects also reported performing trunk curl-up exercises on a regular basis. No subjects reported performing specific lumbar spine stabilizing exercises or the double leg raise as an exercise.

Two subjects were withdrawn from the study prior to follow-up testing. One specific exercise group subject was withdrawn because of lack of compliance, and one control group subject failed to return for the follow-up assessment. Subject characteristics are detailed in Table 1.

Data Analysis

Data analysis was performed to assess for differences in abdominal muscle activation within each group and between the groups following the intervention period.

1) Double leg raise data *a)* Repeated measures analyses of variance (ANOVA) were performed on the double leg raise data to assess the reliability of the task between test trials. Intraclass correlation coefficients ($ICC_{1,1}$) were calculated from the ANOVA; *b)* A repeated measures ANOVA was performed to assess differences in the levels of activation of the rectus abdominis and internal oblique within each group following

Characteristics	Control Group			Specific Exercise Group		
	n	$\bar{X}$	SD	*n*	$\bar{X}$	SD
Gender						
Males	15			12		
Females	6			9		
Age (years)		33.38	10.41		28.76	9.13
Height (cm)		171.43	8.68		174.76	12.64
Weight (kg)		76.71	14.29		78.38	12.38
Duration of symptoms (months)		28.28	20.03		29.05	28.48
VAS pain scores (previous 2 weeks)		53.14	25.82		58.57	24.41
Oswestry functional disability scores		25.71	16.00		28.66	15.24

VAS = Visual analogue scale.

TABLE 1. *Subject characteristics on entry to the study.*

the intervention; and *c)* One-way ANOVAs were performed to assess differences in the levels of activation of the rectus abdominis and internal oblique between the groups based on the change in the level of muscle activation following the intervention (preintervention score − postintervention score = change score).

2) Abdominal drawing in maneuver data *a)* Repeated measures ANOVA were performed on the abdominal drawing in maneuver data to assess the reliability of the task between test trials. Intraclass correlation coefficients ($ICC_{1,1}$) were calculated from the ANOVA; and *b)* Statistical analyses were performed (as described in 1b and 1c) on the raw and amplitude normalized abdominal drawing in maneuver data to assess for differences in the levels of activation of the rectus abdominis and internal oblique, within and between the groups following intervention.

3) Ratio data The same analyses described in 2a and 2b were performed on the raw and amplitude normalized abdominal drawing in maneuver data when placed in the form of a ratio (internal oblique/rectus abdominis).

The level for statistical significance was set at the 95% confidence limit.

RESULTS

One-way ANOVA performed on the data of the two groups revealed that on entry to the trial there were no statistically significant differences between the groups on the basis of their age, height, weight, duration of symptoms, pain intensity and functional disability scores, or abdominal drawing in maneuver muscle activity ratios.

Double leg raise surface electromyography data Analysis of variance performed on the double leg raise data revealed a high degree of reliability between trials on the same day, with $ICCs_{(1,1)}$ ranging between 0.89 and 0.97 for both rectus abdominis and internal oblique muscles before and after intervention (Table 2).

Statistical analysis of the surface electromyography data for the control group during the double leg raise revealed a statistically significant increase ($F_{(1,20)} = 7.18$, $p = 0.014$) in the level of upper rectus abdominis activation but no significant change in the level of internal oblique activation following the intervention period. Conversely, the specific exercise group showed no change in the level of rectus abdominis activation following the intervention but a statistically significant increase ($F_{(1,20)} = 4.96$, $p = 0.037$) in the level of internal oblique muscle activation (Table 3, Figure 1). Analysis of group differences revealed a statistically significant difference ($F_{(1,20)} = 4.5$, $p = 0.046$) between the groups for the degree of change in the level of upper rectus abdominis activity following the intervention period (Table 3).

Post hoc analysis was performed on the control group double leg raise data to determine whether the change observed in the level of rectus abdominis activity following the intervention was influenced by the different types of exercise that were reported to be carried out within the control group. The control group was therefore divided into two groups: those who reported to carry out general exercise programs and trunk curl-up exercises on a regular basis and those who only reported carrying out general exercise programs. Analysis of variance testing revealed that subjects who reported to regularly carry out trunk curl-up exercises displayed a significant increase in the level of rectus abdominis muscle activity following the intervention period ($F_{(1,9)} = 6.8$, $p = 0.028$) but no significant difference in the level of internal oblique muscle activity ($F_{(1,9)} = 0.45$, $p = 0.519$). On the other hand, subjects who reported carrying out general exercise

Trials	Control Group		Specific Exercise Group	
	Rectus Abdominis	Internal Oblique	Rectus Abdominis	Internal Oblique
Double leg raise (two trials)				
Preintervention	0.898	0.971	0.903	0.972
Postintervention	0.967	0.949	0.982	0.944
Abdominal drawing in maneuver (three trials)				
Preintervention	0.827	0.858	0.927	0.923
Postintervention	0.866	0.951	0.885	0.907

TABLE 2. *Intraclass correlation coefficients for the reliability of the double leg raise and abdominal drawing in maneuver between trials.*

Muscle	Outcome Measures									
	Control Group					Specific Exercise Group				
	Before		After		p Value for Difference	Before		After		p Value for Difference	p Value for Group Difference
	$\bar{X}$	SD	$\bar{X}$	SD		$\bar{X}$	SD	$\bar{X}$	SD		
RA	509	317	635	439	0.014*	406	307	421	345	0.659	0.046*
IO	649	499	608	404	0.624	459	291	636	598	0.037*	0.293

* *Indicates statistical significance.*
RA = Rectus abdominis.
IO = Internal oblique.

TABLE 3. *Within and between group differences based on the levels of internal oblique and rectus abdominis muscle activation during double leg raising [root mean squared, nonnormalized surface electromyography (mV)].*

programs only showed no significant difference in the levels of either rectus abdominis ($F_{(1,10)} = 1.68$, $p = 0.224$) or internal oblique ($F_{(1,10)} = 0.72$, $p = 0.415$) muscle activity following the intervention period (Figure 2).

Abdominal drawing in maneuver (nonnormalized and amplitude normalized surface electromyography) Analysis of variance performed on the abdominal drawing in maneuver data revealed a high degree of reliability between the three trials on the same day, with $ICCs_{(1,1)}$ ranging between 0.82 and 0.95 for both rectus abdominis and internal oblique muscles before and after intervention (Table 2).

Analysis of the nonnormalized surface electromyography data for the abdominal drawing in maneuver revealed a significant increase in the level of internal oblique activity in the specific exercise group following intervention ($F_{(1,20)} = -7.35$, $p = 0.013$). No other statistically significant changes were observed in the other comparisons. However, a significant difference between the groups ($F_{(1,20)} = 4.17$, $p = 0.047$) on the basis of change in the level of rectus abdominis activity following intervention was observed (Table 4).

Analysis of the amplitude normalized abdominal drawing in maneuver data revealed no statistically significant differences within or between the groups on the basis of the levels for rectus abdominis and internal oblique activity following the intervention.

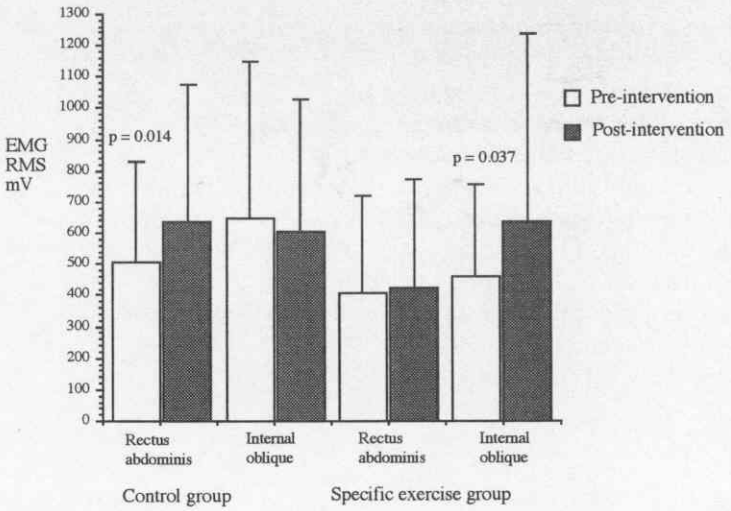

FIGURE 1. *Pre- and post-intervention double leg raise data for the rectus abdominis and internal oblique in th control and specific exercise group [nonnormalized root mean square (RMS) electromyography (EMG) data mean, and standard deviation].*

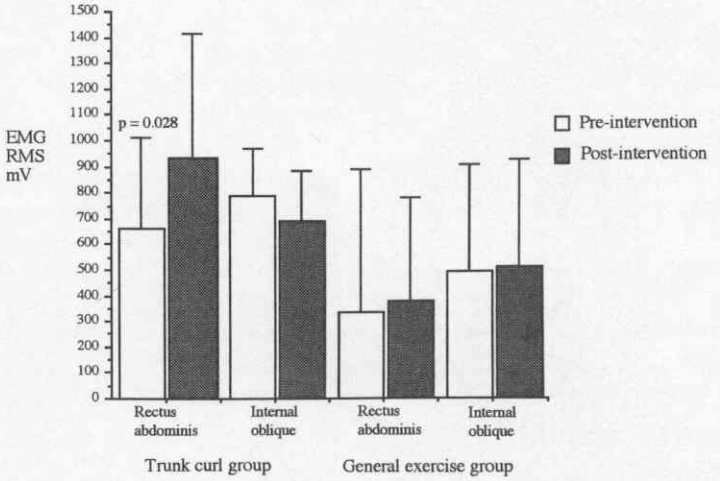

FIGURE 2. *Pre- and post-intervention double leg raise data for the rectus abdominis and internal oblique in th control group subjects who performed trunk curl-up exercises and those who only performe general exercise programs [nonnormalized root mean square (RMS) electromyography (EMG) data, mean, an standard deviation].*

	Outcome Measures									
	Control Group					Specific Exercise Group				
	Before		After		p Value for Difference	Before		After		p Value for Difference	p Value for Group Difference
	$\bar{X}$	SD	$\bar{X}$	SD		$\bar{X}$	SD	$\bar{X}$	SD		
Nonnormalized surface electromyography (mV)											
RA	112	89	138	110	0.286	143	158	84	42	0.099	0.047*
IO	385	397	430	649	0.564	295	212	405	242	0.013*	0.451
Amplitude normalized surface electromyography											
RA	0.29	0.24	0.26	0.16	0.420	0.35	0.22	0.30	0.22	0.433	0.861
IO	0.85	0.73	0.83	0.93	0.858	0.77	0.43	0.96	0.64	0.087	0.194

* *Indicates statistical significance.*
RA = Rectus abdominis.
IO = Internal oblique.

TABLE 4. *Within and between group differences based on the levels of internal oblique and rectus abdominis muscle activation during the abdominal drawing in maneuver (root mean squared, nonnormalized and amplitude normalized surface electromyography).*

Abdominal drawing in maneuver—Ratios Calculation of the ratio of activation (internal oblique/rectus abdominis) for the nonnormalized abdominal drawing in maneuver data revealed a significant difference in the specific exercise group ($F_{(1,20)} = 19.7$, $p = 0.0002$), with an increase in the ratio following the intervention. A significant difference ($F_{(1,20)} = 41.7$, $p < 0.0001$) was detected between the groups on the basis of the change in the ratio of activation following the intervention (Table 5, Figure 3).

Calculation of the ratio for the amplitude normalized abdominal drawing in maneuver data revealed a significant increase in the ratio of activation following the intervention ($F_{(1,20)} = 5.53$, $p = 0.029$), but no change was detected in the control group. However, this difference was not statistically significant between the groups based on the calculation of change scores (Table 5, Figure 3).

DISCUSSION

Double Leg Raise

The normalization procedure must be independent from the treatment effect in order for it not to influence or contaminate the data to be amplitude normalized. The double leg raise was chosen as the amplitude normalization procedure in this study as it is a submaximal contraction activating all the abdominal muscles, capable of being performed by subjects with back pain, and shown previously to be reliable both within and between testing sessions. When the reliability of the double leg raise exercise was again assessed in this trial, the results indicated that this motor pattern was highly repeatable within testing sessions for both groups before and after the intervention. This supports the findings of our earlier pilot research. However, when differences in the double leg raise data following the intervention were assessed, the results clearly indicate that significant changes had occurred in the levels of abdominal muscle activation in both groups.

Possible factors that could have influenced the repeatability of the double leg raise following the intervention period are altered levels of skin impedance, poor reproducibility of electrode placement, changes in percentage body fat, or a direct influence of the exercise intervention on the patterns of abdominal muscle activation. During testing, the level of skin impedance was monitored and controlled using an impedance meter and extreme care was taken to ensure exact electrode placement at retest. Our pilot data also indicated high intersession reliability of the double leg raise between test days, indicating that it is unlikely that factors such as skin impedance and electrode placement would have influenced the double leg raise data in

Ratios	Outcome Measures									
	Control Group					Specific Exercise Group				
	Before		After		p Value for Difference	Before		After		p Value for Difference	p Value for Group Difference
	$\bar{X}$	SD	$\bar{X}$	SD		$\bar{X}$	SD	$\bar{X}$	SD		
Nonnormalized	4.05	2.8	2.86	1.97	0.083	2.87	1.8	5.34	3.6	0.0002*	0.0001*
Amplitude normalized	3.69	3.1	3.41	3.3	0.689	2.79	2.1	3.80	3.4	0.029*	0.135

* *Indicates statistical significance.*

TABLE 5. *Within and between group differences based on the ratio of muscle activation (internal oblique relative to rectus abdominis) during the abdominal drawing in maneuver (root mean squared, nonnormalized and amplitude normalized surface electromyography).*

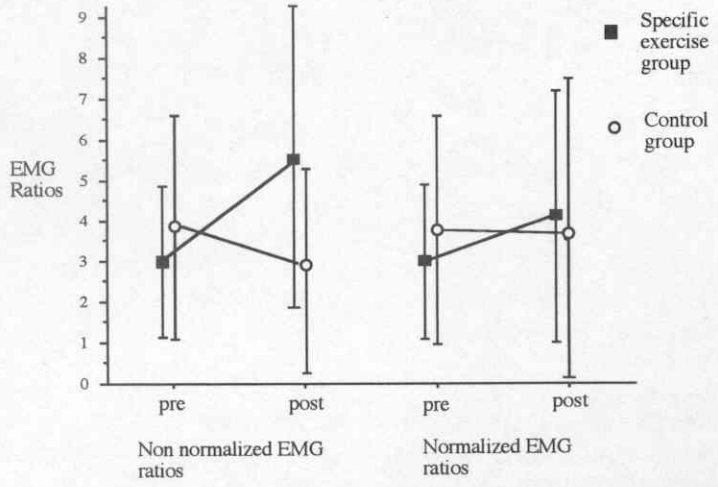

FIGURE 3. *Nonnormalized and amplitude normalized electromyography (EMG) ratios of activation (internal oblique/rectus abdominis), pre- and post-intervention for the control group and specific exercise group (mean, standard deviation).*

the manner observed. As changes in body weight and skin-fold thickness were not taken following the intervention period, a change in the percentage body fat cannot be ruled out as a possible factor influencing the reliability of the double leg raise electromyography data over the 10-week period. However, it is unlikely that a change in percentage body fat would only affect the electromyography profiles of the rectus abdominis muscle in control group subjects who reported to perform trunk curl-up exercises and in the internal oblique muscle in the specific exercise group. Rather, a change in percentage body fat would be likely to affect the electromyography profiles of both muscles in a similar manner. Indeed, it appears that the double leg raise was affected directly by the exercise intervention.

The findings suggest altered levels of muscular activation following intervention, with a higher level of rectus abdominis muscle activity during the double leg raise in the control group and a greater level of activity of the internal oblique in the specific exercise group. These findings gain particular significance in light of the exercise intervention prescribed for each group over the 10-week period. The control group participated in general exercise programs as directed by their treating practitioner, with 10 of the subjects reporting that they also performed trunk curl-up exercises on a regular basis (an exercise known to activate primarily the rectus abdominis). When post hoc analysis was performed on the control group data, it revealed that the increase in the level of rectus abdominis activity observed in the control group following the intervention occurred only in the group of subjects who reported to perform trunk curl-up exercises. There was no significant difference in the level of rectus abdominis or internal oblique activation following the intervention in the control group subjects who only performed general exercise programs. The specific exercise group, on the other hand, performed specific training of the deep abdominal muscles with special emphasis on noncoactivation of the rectus abdominis. This group showed no change in the level of rectus abdominis activation but a significant increase in the level of internal oblique muscle activation following the intervention period.

During pre- and post-intervention assessment, the investigator, blind to subject group allocation, made no reference to the abdominal muscles when subjects performed the double leg raise. Subjects were instructed to simply lift both feet off the bed by 1 cm. For this reason, the double leg raise provided an insight into each subject's automatic pattern of abdominal activation utilized to stabilize the trunk under load. These findings indicate that a change may have occurred in the automatic levels of activation within the abdominal musculature brought about by the intervention process. This may reflect a change in the motor program utilized during abdominal muscle activation or result from a physiological change within the muscle synergy secondary to the specifically directed nature of the exercise intervention.

Abdominal Drawing in Maneuver and Ratios

The results of abdominal drawing in maneuver data provide evidence to support the view that specific training of the deep abdominal muscles without significant coactivation of the rectus abdominis is possible in subjects with chronic low back pain. This was seen clearly in the nonnormalized abdominal drawing in maneuver data, with an increase in the level of internal oblique activity in the specific exercise group following the intervention. No significant differences were detected in the control group. When group differences were assessed on the basis of change scores following the intervention, a significant difference in the level of the rectus abdominis was found. This reflected a relative increase in the level of the rectus abdominis in the control group and a relative decrease in the specific exercise group following the intervention. However, because of the apparent influence of the intervention on the double leg raise data, these differences were reduced when the data were amplitude normalized.

The use of ratios has been employed to assess the relative synergis-

tic contributions of the vastus medialis and vastus lateralis to knee joint extension (6,31). More recently, ratios have been used in populations with chronic back pain to assess synergistic motor patterns within the abdominal musculature (23) and within the back musculature (12). Although functional differences within the abdominal musculature have been widely reported (7–9,32), muscles within the abdominal complex function in patterns of synergy and do not work in complete isolation from each other (4). Altered patterns of synergy or substitution in a muscle complex such as the abdominals may not always be detected by simply comparing the levels of muscle activation in one group of subjects to another (23). Consequently, calculating ratios between synergists has been shown to be a more sensitive means of highlighting these differences in synergistic activity between pain and nonpain groups (12, 23). Similarly in this study, calculating ratios was a more sensitive means of detecting differences between and within the two groups based on the patterns of activation between the internal oblique and rectus abdominis following the intervention period. Analysis of the nonnormalized abdominal drawing in maneuver data revealed a significant increase in the ratio of activation (internal oblique/rectus abdominis) in the specific exercise group following intervention. In the form of a ratio, the opposing shifts in patterns of activation of the rectus abdominis and internal oblique muscles following intervention were highlighted. Thus, a higher level of internal oblique activation and a lower level of rectus abdominis activity during the abdominal drawing in maneuver was reflected in an increase in the ratio. This difference was further highlighted when differences between groups based on change scores were assessed, with a significantly higher ratio of activation in the specific exercise group and a trend toward a lower ratio of activation in the control group following intervention. However, when the data were amplitude normalized, although a significant difference in the specific exercise group was still observed, the differences between the groups were lost.

The findings of this study raise important questions for researchers who endeavour to use electromyography to detect treatment effect following exercise interventions. The problem of selecting a normalization procedure that is repeatable, yet unaffected by the exercise intervention itself, appears to be a difficult task. This is especially the case when the aim of the treatment intervention being monitored is to alter the automatic pattern of motor activation within a muscle synergy such as the abdominals. Changes in synergistic muscle activation resulting from a treatment intervention effect may be cancelled out or significantly reduced secondary to a change in the normalization contraction itself. This certainly appears to be the case in this study. In such situations, the intersession testing error introduced by variable factors, such as skin impedance, subcutaneous tissue depth, and electrode positioning when analyzing raw surface electromyography data, if well controlled, may be significantly less than the contaminating effect of amplitude normalizing using data directly influenced by the intervention. In fact, Edgerton et al avoided amplitude normalization using surface electromyography, opting to correct electromyographical amplitudes for signal attenuation attributable to differences in adipose tissue depth. They suggest that sources of measurement error can be minimized sufficiently to reflect altered neural strategies within synergies (12).

The knowledge that different forms of abdominal exercises can preferentially activate and train different muscles within the abdominal muscle complex highlights the importance of specificity with exercise prescription. The results of this study support the view that the type of exercise prescribed to muscle synergists, such as the abdominal muscles, has the potential to influence both the conscious and subconscious or automatic patterns of abdominal muscle recruitment. Thus, exercises directed to train specifically the deep abdominal muscles appear to have the capacity to result in higher automatic levels of internal oblique recruitment during given tasks. In the same manner, exercises directed primarily at the rectus abdominis, such as trunk curls (commonly prescribed for patients with chronic low back pain), will likely result in a training effect of this muscle with little influence on the deep abdominal muscles. This finding may reflect a physiological change within the muscle secondary to a specific training effect, thus altering the manner by which it functions in a muscle synergy. On the other hand, this shift in the muscle synergy may reflect a neurological change, thereby altering the motor program by which muscles are recruited.

The findings of this study are also supported by that of Cresswell et al (10). They investigated the effect of 10 weeks of specific abdominal strength training involving resisted trunk rotations directed to activate primarily the anterolateral abdominal muscles in pain-free subjects. Following training, they found that the trunk rotation and extensor muscle strength of the subjects increased by 29.7% and 11%, respectively, whereas the flexor strength remained unchanged. Furthermore, the rate of intraabdominal pressure development during drop jumps and trunk perturbations increased after training. The findings of Cresswell et al (10) indicate that specific abdominal muscle training directed at the anterolateral abdominal muscles resulted in changes to their strength and, more significantly, the speed at which they were able to generate intraabdominal pressure during sudden trunk loading. These changes oc-

curred without any changes to the strength of the rectus abdominis, the primary trunk flexor. Cresswell et al's (10) study implies that directing exercises to train specifically the anterolateral abdominal muscles may influence their automatic pattern of synergistic recruitment during functional tasks, providing further evidence to suggest that the specificity of exercise when directed at muscle synergies, such as the abdominals, has the potential to influence different muscles within a synergy.

The findings of the present study and those of Cresswell et al (10) gain particular significance when the stabilizing role of the various abdominal muscles is considered. As reported earlier, the anterolateral abdominal muscles, in particular, the transversus abdominis and internal oblique, are considered important in the provision of dynamic stability to the lumbar spine. Furthermore, these muscles have been shown to be preferentially affected in subject populations with chronic low back pain (18,19). In situations where the anatomical stability of the spine has been compromised, such as with symptomatic spondylolysis or spondylolisthesis, it is logical that exercises be prescribed which are known to enhance preferentially the capacity of the neuromuscular system to provide dynamic stability to the spine. In such cases, the specific training of the deep abdominal muscles in patterns of co-contraction with lumbar multifidus would seem most appropriate. Indeed, this hypothesis is supported by our findings that the specific exercise group showed a sustained reduction in symptoms and an increase in functional mobility following the intervention period, where the control group showed no significant change (24). Further research is under way to investigate the long-term benefits of this form of intervention in other specific chronic low back pain populations where the anatomical stability of the spine has been compromised. Research is also currently being undertaken to further evaluate the potential of this form of specific exercise intervention to alter subconscious or automatic patterns of neuromuscular activation within muscle synergies such as the abdominals.

CONCLUSION

The results of this study support the view that the pattern of muscle activation within a synergistic muscle group such as the abdominals can be altered with a specific exercise intervention. This study provides evidence that the deep abdominal muscles can be specifically trained in subjects with a specific chronic low back pain without the overriding substitution of synergists such as the rectus abdominis. Furthermore, the findings of the study provide evidence that the type of exercise administered to muscle groups, such as the abdominal complex, influences the manner by which the muscle is automatically recruited during trunk-loading tasks. More specifically, subjects performing trunk curl-up exercises displayed a higher level of activation of the rectus abdominis during double leg raise, with little influence on the internal oblique muscle. Exercises designed to train specifically the deep abdominal muscles resulted in an increased level of activation of these muscles during abdominal drawing in maneuver and double leg raise. This study highlights the importance of exercise specificity when prescribing exercises in the rehabilitation of patients with specific chronic low back pain conditions, particularly in situations where the treatment objective is to enhance the dynamic control and stability of the spine. JOSPT

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