Back and Abdominal Muscle Function During Stabilization Exercises

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ABSTRACT. Arokoski JP, Valta T, Airaksinen O, Kankaanpää M. Back and abdominal muscle function during stabilization exercises. Arch Phys Med Rehabil 2001;82;1089-98.

Objectives: To assess the paraspinal and abdominal muscle activities during different therapeutic exercises and to study how load increment produced by varying limb movements and trunk positions could affect these muscle activities.

Design: A cross-sectional study comparing muscle activities between men and women.

Setting: Rehabilitation clinic in university hospital.

Participants: Twenty-four healthy volunteers (14 women, 10 men) aged 21 to 39 years.

Interventions: Subjects performed 16 different therapeutic exercises commonly used to treat low back pain.

Main Outcome Measures: Surface electromyography was recorded from the paraspinal (T9, L5) and abdominal (rectus abdominis, obliquus externus) muscles during these exercises. Average electromyographic amplitudes obtained during the excercises were normalized to the amplitude in maximal voluntary contraction (% MVC) to produce interindividually comparable muscle activity assessments.

Results: Mean average normalized electromyographic amplitudes (% MVC) of the exercises were below 50% MVC. At L5 level, the multifidus muscle activities were significantly higher ($p < .05$) in women than in men, whereas no significant difference was found at T9 level. Similarly, rectus abdominis and obliquus externus activities were significantly higher ($p < .001$, $p < .05$) in women than in men. Load increment in hands or unbalanced trunk and limb movements produced higher paraspinal and abdominal muscle activities ($p < .05$).

Conclusions: Simple therapeutic exercises are effective in activating both abdominal and paraspinal muscles. By changing limb and trunk positions or unbalancing trunk movements, it is possible to increase trunk muscle activities. Women were better able to activate their stabilizing trunk muscles than men; but it is also possible that men, having a much higher degree of strength on maximal contraction, only need to activate a smaller amount of that maximum to perform a similar activity.

Key Words: Abdominal muscles; Back; Electromyography; Low back pain; Muscles; Rehabilitation.

ACTIVE REHABILITATION has been increasingly advocated as a treatment for chronic low back pain (LBP).[1-5] Exercise-based active rehabilitation programs can reduce LBP intensity, alleviate functional disability, and improve back extension strength, mobility, and endurance.[6-10] Treatment guidelines for LBP in Great Britain and United States, for example, encourage active physical rehabilitation programs.[2,3]

Chronic LBP is associated with histomorphologic and structural changes in paraspinal muscles, that is, back muscles are smaller, contain more fat, and show a degree of selective muscle fiber atrophy.[11-15] Consequently, the lumbar paraspinal muscles are weaker[16-18] and exhibit excessive fatigability.[19-22] In addition, poor coordination of paraspinal muscles has been related to chronic LBP[23-25] and to excess lumbar muscle fatigability.[24-26] These changes are widely thought to result from disuse and deconditioning secondary to pain and illness, a process called the deconditioning syndrome.[16,27] More recent studies suggest that muscle spasms and reflex inhibition of the trunk muscles can also contribute to the deconditioning syndrome.[28-32] In active exercise treatment programs, these functional limitations can be improved, and this represents the basis and rationale for such programs.[8,10,33,34] Despite this knowledge, it is not known what type, frequency, or duration of exercises should be prescribed.[35]

It is difficult to estimate individual trunk muscle activities simply by observing human muscle movements. Surface electromyography is used to quantify the muscle activity and fatigability in objective manner.[36] In our recent electromyogram (EMG) study, we[37] showed that simple therapeutic exercises are effective in activating lumbar paraspinal muscles, and that surface and intramuscular electromyographic measurements are highly comparable in the assessment of lumbar multifidus muscle function. In that study, we focused on describing lumbar paraspinal muscle loading in isometric, dynamic, and quasi-dynamic therapeutic exercises. However, activity levels of the upper back and abdominal muscle in these exercises are not known. It is also not known whether it is possible to activate the local stabilizing muscles (eg, lumbar multifidus) simultaneously with the global muscles that mainly produce the trunk movements (eg, longissimus thoracis, rectus abdominis), because the role of the abdominal and back muscles in stabilizing the spine may be different.[38]

This study sought to assess the activities of the thoracic and lumbar paraspinal and abdominal muscles in different therapeutic exercises and to compare the results between men and women. A secondary aim was to study how load increment produced by varied limb movements and trunk positions increased the paraspinal and abdominal muscle activities.

METHODS

Subjects

Twenty-four healthy subjects (14 women, 10 men) aged 21 to 39 years participated in the study after signing written

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voluntary consent. The subjects were physiotherapists, doctors, and students. The mean ± standard deviation (SD) weight and height were 76.2 ± 8kg (range, 61–90kg) and 178 ± 8cm (range, 164–193cm) in men, and 61.7 ± 8.5kg (range, 50–74kg) and 167 ± 5cm (range, 159–176cm) in women, respectively. Their body mass index (BMI) was determined.

All subjects filled out the questionnaires concerning the history of LBP. The questionnaire variables were LBP intensity (visual analog scale), regularity, pain location (pain drawings), and functional disability (Oswestry Disability Index) (data not shown). Based on these questionnaires and clinical examination, subjects were considered to be healthy individuals without a LBP problem, ie, they did not report any past or current LBP, or did not have any current neurologic deficits; marked trunk, gluteal, or lower leg muscle tightness; or imbalance. Using a double-inclinometer[a] measurement technique, total lumbar range of motion (ROM), expressed in angular degrees, was determined.[39] The study was approved by the University of Kuopio Ethics Committee.

Surface Electromyography

After rubbing the skin with alcohol, pairs of disposable Ag/AgCl surface electrodes[b] were attached bilaterally over the following muscles (fig 1A, 1B): rectus abdominis (RA); 3cm lateral from the umbilicus[40,41]; obliquus externus (OE), halfway between the anterior-superior iliac spine and the inferior border of the rib cage at a slightly oblique angle running parallel with the underlying muscle fibers[40,41]; thoracic erector spinae, 2cm laterally from the midline running through the T9 spinal process parallel to the spine over muscle mass longissimus thoracis (LT)[40,41]; and multifidus muscles at L5, 2cm laterally from the midline running through the L5 spinal process.[37] At the L5 level, the electrodes were placed parallel with the underlying multifidus muscle fibers, as has been previously proposed by Biedermann et al.[42]

The interelectrode spacing between the recording electrodes was 2cm, and each electrode had an approximately 1cm^2 pick-up area. The reference electrodes were attached laterally from the recording electrodes (fig 1A, 1B). The subjects were allowed to move freely with the electrodes in place for about 15 to 20 minutes before the electromyographic recordings were made.

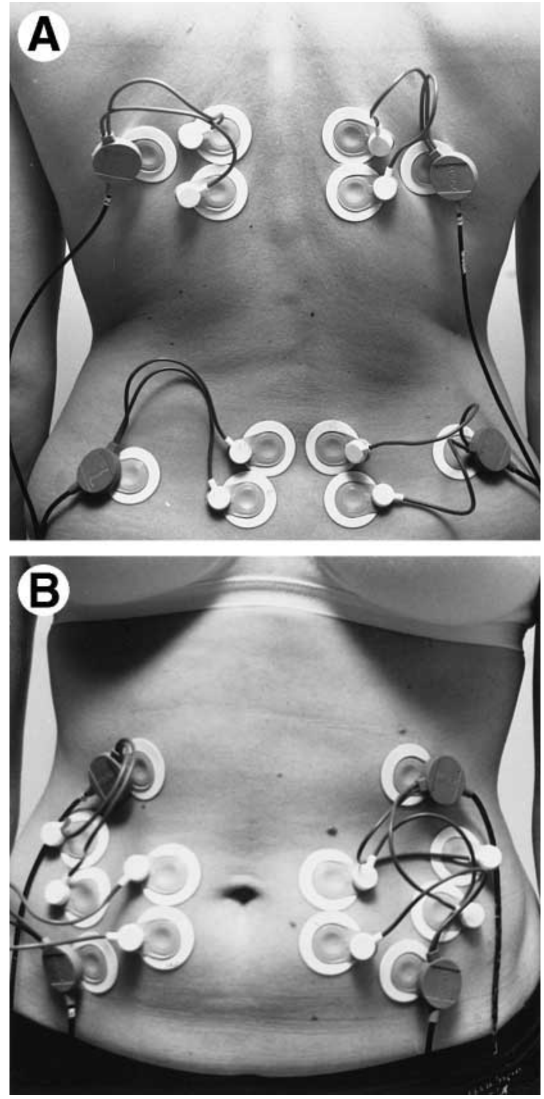

Fig 1. Bipolar surface electromyographic electrode arrangement over (A) the erector spinae muscles at T9 (longissimus thoracis muscle) and L5 (multifidus muscle) level and (B) over the rectus abdominis and obliquus externus abdominis muscles. The reference electrode and preamplifier in each recording electromyographic channel was placed lateral to the bipolar electrode arrangement.

Electromyographic Recording and Data Analysis

The ME 4000 EMG system[c] was used to record continuously bipolar surface EMGs with 8 channels. The cables with preamplifiers were used to ensure good signal quality. A pair of 10-cm long cables connected the recording electromyographic electrodes to the preamplifier in each EMG channel. The preamplifier was secured on place by attaching it to the corresponding reference electrode. A single 2.5-meter cable connected the preamplifier to the amplifier box. Raw electromyographic signals were recorded at the sampling rate of 1000Hz and analogically frequency band-pass filtered (high-pass corner frequency 7Hz and the anti-aliasing filter [Butterworth] with a corner frequency 500Hz), amplified (differential amplifier, common mode rejection ratio $>$ 130dB, gain 1000, noise $<$ 1μV), analog-to-digital converted (12 bit), and stored in a personal computer for later analysis.

For the electromyographic amplitude analysis, manually selected artefact-free raw electromyographic sections were used. The rectified electromyography was determined by calculating the absolute value of each data point and the mean value was defined for 100ms data segments. This data was plotted against time to assess the electromyographic average amplitude. The mean average electromyographic amplitude was defined as a mean value of all data points within the selected areas. In therapeutic exercises, 3 consecutive repetitions (dynamic) or 5- to 10-second data segments (isometric) were selected for the assessment of average electromyographic amplitudes, respectively.

The normalized muscle activity level (% maximum amplitude) in each therapeutic exercise task was determined by relating the obtained electromyographic amplitude to that electromyographic amplitude measured during the isometric maximal voluntary contraction (MVC; measured in standing position). The MVC of the back and abdominal muscles were tested using a LIDO Active Isokinetic Rehabilitation System.[d] During testing the subjects were standing on a nonslip material while their pelvis and thighs were fixed at 20° flexion by a stable metal frame that stabilized the pelvis and upper thighs posteriorly. Two 5-cm wide canvas straps were placed anteriorly over the anterior-superior iliac spine and over the thighs. A 15-cm wide supporting harness was tightened around the shoulders just below the medial end of the clavicles. The MVC of back (multifidus at L5, longissimus thoracis at T9) and abdominal muscles (rectus abdominis, obliquus externus abdominus) were tested in maximal isometric extension and flexion, respectively. For the maximal trunk flexion and extension torque measurements, 3 measurements were made in the standing position, each lasting for approximately 5 seconds. The highest maximal trunk flexion and extension torques (Nm) and electromyographic amplitudes (μV) were assessed for men and women. Average electromyographic amplitudes obtained during the investigated therapeutic exercises were normalized to the electromyographic amplitude at MVC (% maximal amplitude). It was assumed that all investigated muscles reached their maximal effort either during maximal flexion or extension.

Specific Exercises

Subjects were carefully taught to perform 16 therapeutic exercises under the guidance of the physiotherapist. Correct performance of the exercises was checked before the actual measurement and afterward from video recordings. None of the subjects were excluded because of incorrect performance of the exercises. The exercises were always performed in the same order. The subjects were allowed to rest 2 to 5 minutes between the exercises. Cycle frequencies in dynamic exercises were controlled by a metronome (repetitions min) and movement ranges were checked with an inclinometer during the practice trials. The exercises were made in prone, bridged, sitting, and standing positions. The exercises were as follows (figs 2–5).

Exercises in prone position. Exercise 1 (bilateral leg extension while prone): subjects laid prone with both knees straight and lifted their legs a few centimeters from the floor for 5 seconds. Exercise 2 (resisted bilateral leg extension while

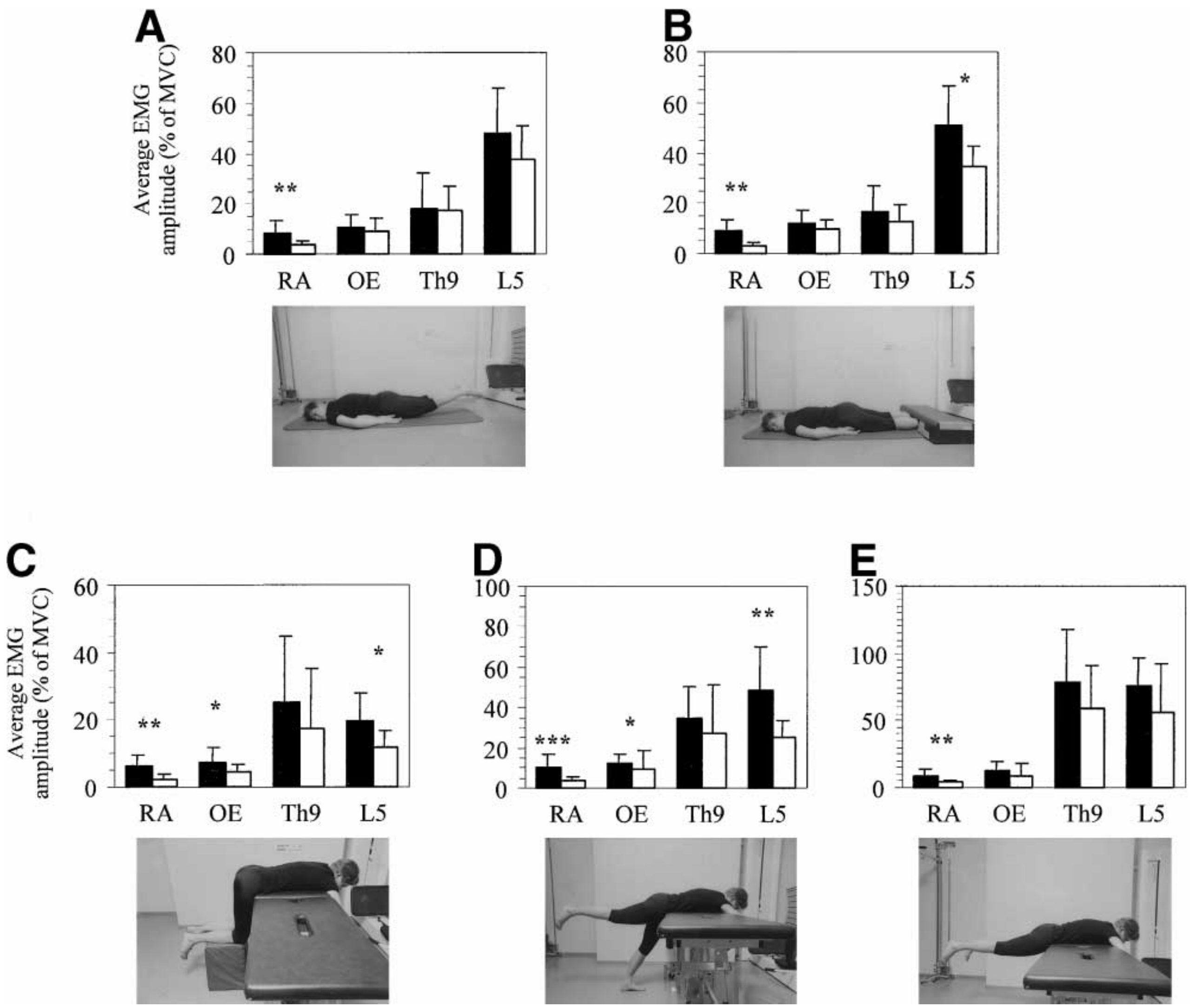

Fig 2. Mean ± SD average normalized surface electromyographic amplitudes (% MVC) in men (*n* = 10, □) and women (*n* = 14, ■) at rectus abdominis (RA), obliquus externus abdominis (OE), and erector spinae (T9 and L5 levels) muscles in prone position: (A) exercise 1: bilateral leg extension while prone; (B) exercise 2: resisted bilateral leg extension while prone; (C) exercise 3: lifting buttocks; (D) exercise 4: unilateral leg extension while upper body prone on the board; and (E) exercise 5: bilateral leg extension while upper body prone on the board. * $p < .05$, ** $p < .01$, *** $p < .001$.

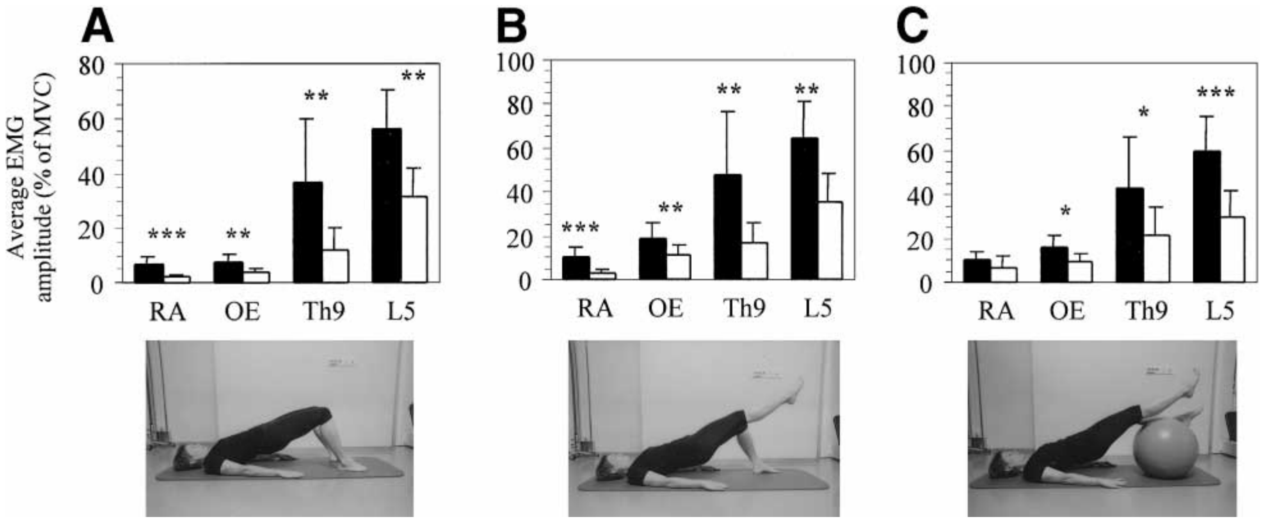

Fig 3. Mean ± SD average normalized surface electromyographic amplitudes (% MVC) in men ($n = 10$, □) and women ($n = 14$, ■) at RA, OE, and erector spinae (T9 and L5 levels) muscles in bridged position: (A) exercise 6: lifting hips up to the bridged position; (B) exercise 7: unilateral knee extension while keeping hips in bridged position; and (C) exercise 8: hips in the bridged position while lifting lower extremities on the exercise ball. * $p < .05$, ** $p < .01$, *** $p < .001$.

prone): subjects lay prone, with both knees straight, and lifted both legs simultaneously a few centimeters from the floor for 5 seconds against resistance. Exercise 3 (lifting buttocks): subjects laid their upper body prone on the board and lifted the buttocks upward. Exercise 4 (unilateral leg extension while upper body prone on the board): subjects laid their upper body prone on the board and lifted their right legs to the horizontal level for 5 seconds. Exercise 5 (bilateral leg extension while upper body prone on the board): same position as in exercise 4, but both legs were lifted simultaneously to the horizontal level for 5 seconds.

Exercises in bridged position. Exercise 6 (lifting hips up to the bridged position): subjects lifted their hips up to the bridged position for 5 seconds. Exercise 7 (unilateral knee extension while keeping hips in bridged position): subjects kept their hips in the bridged position and extended their knees. Exercise 8 (hips in the bridged position while lifting lower extremities on the exercise ball): subjects lifted their hips in the bridged position while lifting right lower extremity on the exercise ball.

Exercises in sitting position. Exercise 9 (weights in hands and altering shoulder flexion while sitting straight): subjects sat with their feet on the floor and held weights in the hands (women, 1kg; men, 2kg) with slightly flexed elbows, moving the weights up and down in the frontal plane while keeping back straight in sitting position (40 times/min) (modified from Arokoski et al[37]). Exercise 10 (weights in hands and altering shoulder flexion while sitting with the trunk in 30° flexion): the same position and movements as in exercise 9, but the trunk was held in 30° flexion (modified from Arokoski[37]).

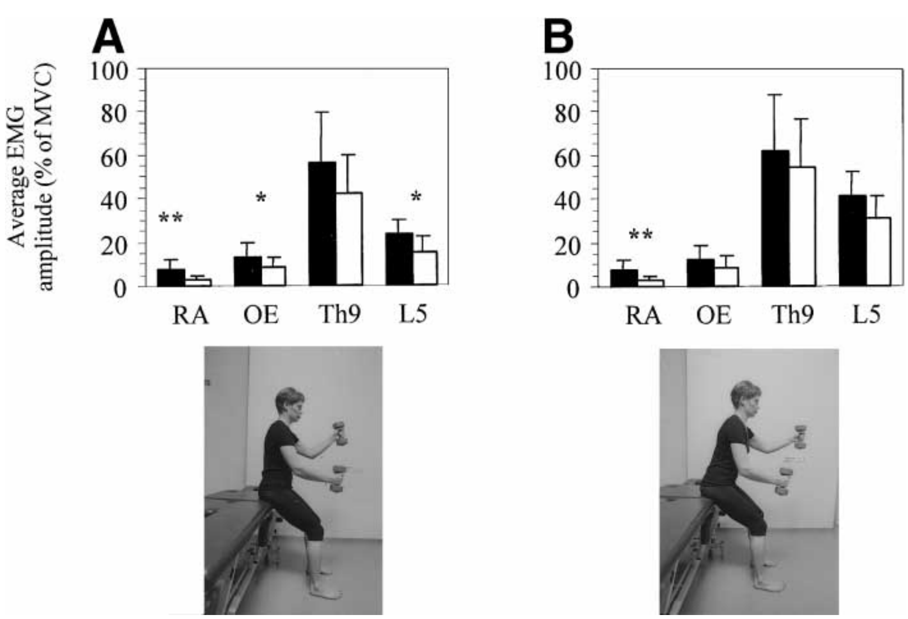

Fig 4. Mean ± SD average normalized surface electromyographic amplitudes (% MVC) in men ($n = 10$, □) and women ($n = 14$, ■) at RA, OE, and erector spinae (T9 and L5 levels) muscles while sitting: (A) exercise 9: weights in hands and altering shoulder flexion while sitting straight; (B) exercise 10: weights in hands and altering shoulder flexion while sitting with the trunk in 30° flexion. * $p < .05$, ** $p < .01$.

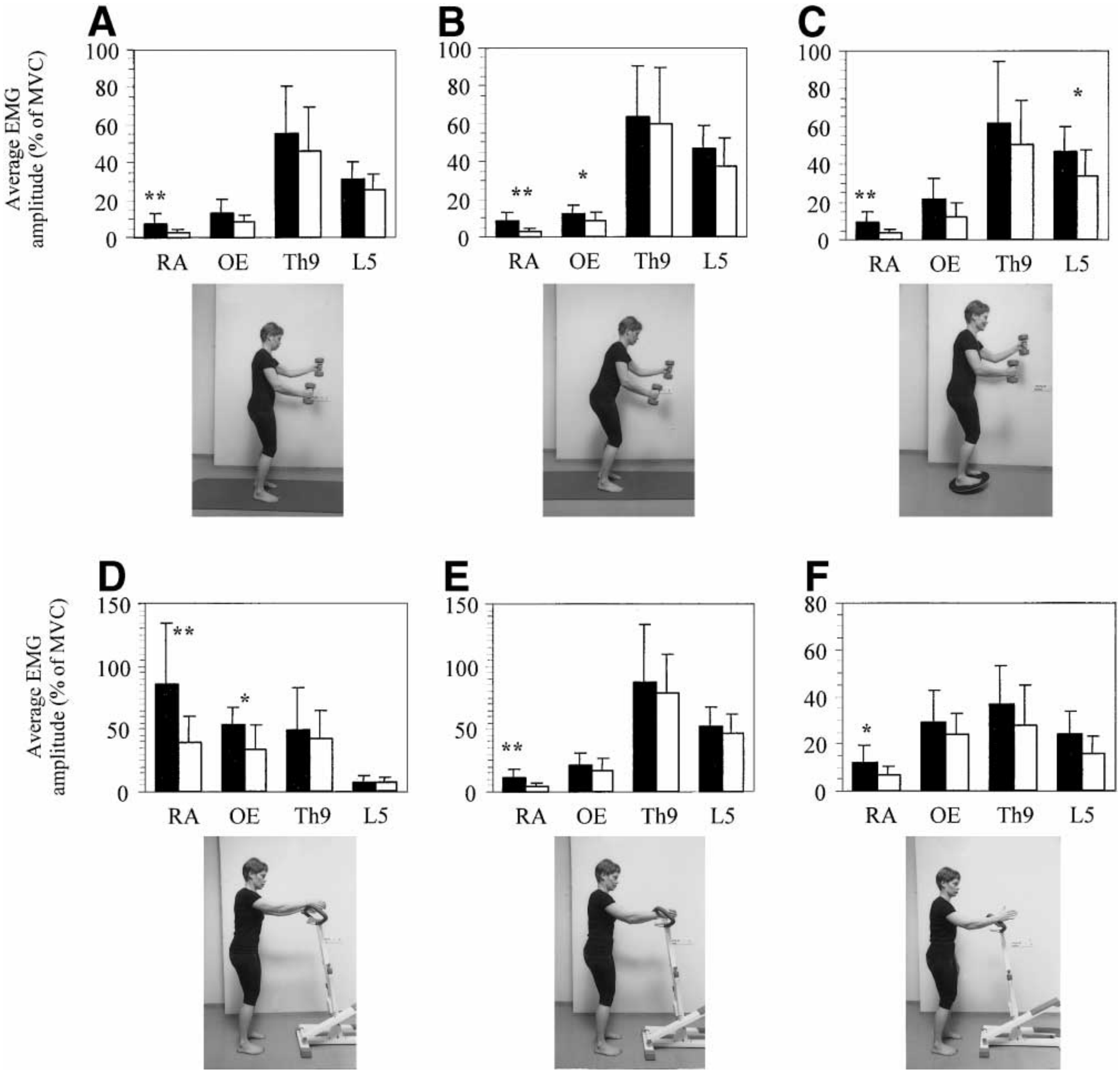

Fig 5. Mean ± SD average normalized surface electromyographic amplitudes (% MVC) in men (n = 10, □) and women (n = 14, ■) at the RA, OE, and erector spinae (T9 and L5 levels) muscles while standing: (A) exercise 11: weights in hands and altering shoulder flexion while standing straight; (B) exercise 12: weights in hands and altering shoulder flexion while standing with the trunk in 30° flexion; (C) exercise 13: weights in hands and altering shoulder flexion while standing straight on balance board; (D) exercise 14: resisted UE extension while standing; (E) exercise 15: resisted UE flexion while standing; (F) exercise 16: resisted UE adduction while standing. * $p < .05$, ** $p < .01$.

Exercises while standing. Exercise 11 (weights in hands and altering shoulder flexion while standing straight): subjects stood on the exercise carpet[e] while holding weights in the hands (women, 1kg; men, 2kg) with slightly flexed elbows, moving the weights up and down in the frontal plane (40 times/min) (modified from Arokoski[37]). Exercise 12 (weights in hands and altering shoulder flexion while standing trunk in 30° flexion): subjects stood on the exercise carpet trunk in 30° flexion and held-hand weights (women, 1kg; men, 2kg) with slightly flexed elbows, moving the weights up and down in the frontal plane (40 times/min) (modified from Arokoski[37]). Exercise 13 (weights in hands and altering shoulder flexion while standing straight on the balance board): subjects stood on a balance board and held weights in their hands (women, 1kg; men, 2kg) with slightly flexed elbows, moving the weights up and down in the frontal plane (40 times/min) (modified from Arokoski[37]). Exercise 14 (resisted upper extremity [UE] extension while standing): hips and knees were flexed about 10° to 20° in the standing position, legs slightly apart (at the same width as the pelvis), elbows slightly flexed and kept in the horizontal level while the lumbar spine was kept stationary. The physiotherapist resisted UE isometric extension for 5 seconds. Exercise 15 (resisted UE flexion while standing): the same

Table 1: Maximal Trunk Flexion and Extension Torques and Electromyographic Amplitudes

Parameters	Men	Women	*p*
Trunk flexion, max forces (Nm)	134.3 ± 51.9	78 ± 20.6	<.01
Trunk extension, max forces (Nm)	237.3 ± 41.2	150.9 ± 27	<.001
LT (T9), trunk extension max EMGamp* (μV)	234.5 ± 102.4	140 ± 58	<.05
Multifidus at L5, trunk extension max EMGamp* (μV)	257.6 ± 120.9	146.6 ± 63.2	<.05
RA, trunk flexion max EMGamp* (μV)	344 ± 220.2	123.9 ± 63.6	<.01
OE, trunk flexion max EMGamp* (μV)	237.1 ± 98.4	142.6 ± 67.7	<.05

NOTE. Data are means ± SDs.
Abbreviations: max, maximum; LT, longissimus thoracis; EMGamp, electromyographic amplitude; RA, rectus abdominis; OE, obliquus externus.
* Pooled data (right- and left-sided data averaged).

position as in exercise 14, but the physiotherapist resisted the isometric flexion of the UEs for 5 seconds. Exercise 16 (resisted UE adduction while standing): the same position as in exercise 14, but the physiotherapist resisted the isometric adduction of right UE for 5 seconds.

Statistical Analysis

All values are expressed as mean ± SD. Significance of difference between men and women, and between the electromyographic recording sites were evaluated by nonparametric Mann-Whitney *U* and Wilcoxon's matched-pairs signed-rank tests, respectively. Two-sided significance was defined as *p* less than .05.

RESULTS

The BMI of the men and women was 23.9 ± 1.8kg/m^2 (range, 21.3–27.4kg/m^2) and 22 ± 2.1kg/m^2 (range, 18.6–24.8kg/m^2), respectively (not significant). Total lumbar ROM in men and women was 74.6° ± 7.7° (range, 58°–83°) and 76.4° ± 9.5° (range 60°–97°), respectively (not significant).

The maximal trunk isometric forces and maximal electromyographic amplitude are listed in table 1. In men, the lowest level of longissimus thoracis muscle electromyographic activity (% MVC) occurred in exercises 2, 3, and 6, and the highest in exercises 5 and 15 (table 2; figs 2, 3, 5). Correspondingly, in men the lowest level of multifidus muscle electromyographic activity (% MVC) at L5 level was in exercises 3, 9, and 14, and highest in exercises 5 and 15 (table 2; figs 2, 4, 5). In women, the lowest level of longissimus thoracis muscle % MVC was in exercise 2, and the highest in exercises 5 and 15 (table 2; figs 2, 5). Correspondingly, the lowest levels of multifidus muscle electromyographic activity % (MVC) at the L5 level were detected in exercises 3 and 14, and highest in exercises 5, 7, and 15 in women (table 2; figs 2, 3, 5).

In men, the lowest level of rectus abdominis and obliquus externus abdominis muscle electromyographic activity (% MVC) was found in exercise 6, and the highest in exercise 14 (table 3; fig 3, 5). In women, the lowest levels of rectus abdominis and obliquus externus abdominis muscle electro-

Table 2: Normalized Average Electromyographic Amplitude* During Exercises in the Longissimus Thoracis (T9) and Multifidus (L5) Muscles From the Least to the Greatest Activity

Exercise Number and Position	Longissimus Thoracis (T9)				Multifidus (L5)			
	Men (*n* = 10)		Women (*n* = 14)		Men (*n* = 10)		Women (*n* = 14)	
	Left	Right	Left	Right	Left	Right	Left	Right
Prone								
3	15.4 ± 14.3	13.6 ± 19.1	24.1 ± 20.5	26.9 ± 21.1	11.9 ± 15.1	12.4 ± 5.7	19.3 ± 8.0	19.8 ± 10.1
2	14.4 ± 8.7	13.7 ± 7.4	15.4 ± 7.6	17.4 ± 14.7	36.8 ± 10.0	34.3 ± 7.2	50.0 ± 17.5	49.9 ± 15.3
1	18.0 ± 11.6	17.0 ± 7.9	16.1 ± 10.3	26.7 ± 18.5	39.2 ± 15.2	35.1 ± 11.8	47.4 ± 18.8	48.1 ± 19.5
4	34.1 ± 25.3	22.2 ± 34.0	43.5 ± 21.5	26.0 ± 13.0	24.5 ± 9.0	29.1 ± 10.1	47.6 ± 20.7	51.3 ± 23.7
5	63.3 ± 39.1	59.6 ± 37.1	74.4 ± 39.8	82.9 ± 44.8	62.1 ± 37.1	61.2 ± 43.2	76.7 ± 25.1	71.3 ± 20.1
Bridged								
6	13.9 ± 8.5	12.8 ± 9.9	33.8 ± 23.7	37.1 ± 25.8	35.5 ± 15.5	29.1 ± 11.4	57.5 ± 15.4	53.0 ± 14.6
8	12.2 ± 6.1	38.4 ± 20.4	22.9 ± 14.8	70.5 ± 34.7	28.3 ± 12.9	34.4 ± 15.0	53.7 ± 17.1	64.8 ± 19.8
7	13.0 ± 8.6	26.7 ± 12.3	25.5 ± 16.2	71.4 ± 52.2	36.4 ± 13.9	37.6 ± 14.7	62.2 ± 17.2	65.2 ± 17.8
Sitting								
9	46.1 ± 23.1	39.0 ± 26.1	53.3 ± 23.7	58.8 ± 27.7	17.8 ± 10.4	15.4 ± 5.3	23.2 ± 6.5	24.3 ± 7.3
10	58.1 ± 31.5	50.9 ± 28.4	58.9 ± 25.9	66.9 ± 30.6	13.3 ± 14.7	31.1 ± 9.1	41.0 ± 11.7	40.9 ± 12.0
Standing								
14	48.5 ± 31.6	41.7 ± 25.3	44.2 ± 34.9	53.5 ± 34.4	8.0 ± 4.6	6.9 ± 3.0	6.3 ± 4.0	7.5 ± 7.8
16	35.8 ± 27.1	24.6 ± 15.1	40.8 ± 16.4	31.3 ± 23.4	20.8 ± 13.4	12.2 ± 5.2	26.2 ± 10.9	21.1 ± 12.0
11	47.6 ± 28.5	44.4 ± 26.3	52.7 ± 25.7	58.4 ± 30.1	28.0 ± 12.9	12.9 ± 7.2	30.7 ± 11.6	29.5 ± 8.0
13	53.3 ± 31.7	47.8 ± 25.3	57.2 ± 29.5	67.5 ± 39.3	37.1 ± 18.9	34.1 ± 12.6	45.3 ± 12.8	47.1 ± 15.4
12	62.1 ± 38.2	61.2 ± 39.2	61.4 ± 31.6	66.6 ± 28.4	39.9 ± 18.5	37.6 ± 14.7	45.6 ± 13.9	46.6 ± 13.1
15	82.3 ± 37.2	70.6 ± 38.3	80.3 ± 45.3	96.1 ± 55.7	50.0 ± 21.1	45.5 ± 14.5	51.9 ± 16.0	48.6 ± 15.0

* Normalized average electromyographic amplitude (relative to amplitude in MVC) values are reported as mean ± SD.

Table 3: Normalized Average Electromyographic Amplitude* During Exercises in the Rectus Abdominis and Obliquus Externus Abdominis Muscles From the Least to the Greatest Activity

Exercise Number and Position	Rectus Abdominis				Obliquus Externus Abdominis			
	Men (n = 10)		Women (n = 14)		Men (n = 10)		Women (n = 14)	
	Left	Right	Left	Right	Left	Right	Left	Right
Prone								
3	2.7 ± 1.3	2.6 ± 1.7	7.1 ± 4.8	5.3 ± 2.6	4.4 ± 2.3	4.9 ± 2.8	7.6 ± 4.9	7.2 ± 4.3
1	3.4 ± 1.7	3.0 ± 1.8	8.8 ± 5.9	8.1 ± 5.1	8.1 ± 5.7	9.3 ± 6.4	10.6 ± 5.4	10.9 ± 6.1
2	ND	2.9 ± 1.6	ND	8.7 ± 4.9	9.3 ± 4.2	10.4 ± 5.4	11.8 ± 5.1	12.2 ± 5.8
5	4.1 ± 2.1	3.6 ± 2.5	9.9 ± 6.4	8.1 ± 3.8	9.7 ± 10.3	10.1 ± 9.9	11.4 ± 6.5	13.0 ± 7.6
4	4.3 ± 2.6	3.1 ± 2.5	11.9 ± 7.6	9.3 ± 5.4	8.1 ± 9.0	11.7 ± 13.1	11.9 ± 4.7	12.6 ± 5.4
Bridged								
6	2.4 ± 1.2	1.9 ± 1.2	7.3 ± 4.6	5.7 ± 2.8	3.7 ± 2.1	4.0 ± 2.3	7.9 ± 3.5	7.0 ± 3.5
8	5.9 ± 5.2	8.6 ± 8.1	8.9 ± 4.2	11.7 ± 5.3	8.5 ± 4.6	11.7 ± 14.2	11.2 ± 3.9	19.9 ± 8.5
7	3.2 ± 1.7	2.9 ± 1.6	9.8 ± 5.5	11.4 ± 4.3	10.8 ± 5.6	10.4 ± 4.6	18.3 ± 8.2	20.0 ± 8.2
Sitting								
9	3.2 ± 1.7	2.6 ± 1.6	8.2 ± 6.0	7.0 ± 4.1	8.4 ± 4.9	8.7 ± 4.6	12.8 ± 7.1	14.2 ± 6.9
10	3.5 ± 2.0	3.2 ± 1.9	8.3 ± 5.7	7.4 ± 4.1	9.0 ± 6.6	8.9 ± 6.1	11.9 ± 5.8	13.2 ± 6.4
Standing								
11	3.1 ± 1.6	2.9 ± 1.5	8.5 ± 6.6	6.9 ± 4.2	8.0 ± 5.0	8.7 ± 4.8	12.3 ± 6.9	13.8 ± 8.2
12	3.6 ± 2.0	3.3 ± 1.7	8.6 ± 6.1	7.4 ± 3.9	8.5 ± 6.5	8.6 ± 5.5	12.0 ± 14.5	12.5 ± 6.4
13	3.8 ± 2.2	3.5 ± 2.0	10.2 ± 6.7	8.9 ± 4.5	12.6 ± 19.5	12.9 ± 7.4	19.0 ± 9.5	23.2 ± 16.8
15	4.7 ± 2.2	4.5 ± 2.5	11.3 ± 8.6	10.2 ± 6.5	17.0 ± 12.1	17.2 ± 11.0	20.4 ± 9.5	22.4 ± 11.4
16	7.4 ± 4.2	5.9 ± 3.5	14.3 ± 9.3	10.0 ± 6.5	22.5 ± 15.7	23.3 ± 10.5	28.1 ± 14.8	29.8 ± 17.7
14	42.1 ± 25.4	34.8 ± 22.7	88.6 ± 56.7	83.8 ± 50.3	31.2 ± 22.9	37.2 ± 21.0	50.6 ± 14.7	56.6 ± 17.3

* Abbreviation: ND, not determined.
Normalized average electromyographic amplitude (relative to amplitude in MVC) values are reported as mean ± SD.

myographic activity (% MVC) were measured in exercises 3 and 6, and the highest in exercise 14 (table 3; figs 2, 3, 5).

In most exercises, women exhibited higher electromyographic activity (% MVC) than men. Normalized electromyographic amplitudes of the rectus abdominis (exercises 1–7, 9–16) and obliquus externus abdominis (exercises 3, 4, 6–9, 12, 14) were significantly higher in women than in men ($p < .05$) (figs 2–5). Normalized paraspinal electromyographic amplitudes at T9 (exercises 6–8) and L5 levels (exercises 2–4, 6–9, 13, 16) were significantly higher in women than in men ($p < .05$) (tables 1, 2; figs 2–5).

In the rectus abdominis, the average electromyographic activity (% MVC) of the pooled data (all data pooled across the exercises) were 13.8 ± 19.4 in women and 5.8 ± 8.9 in men ($p < .0001$) (fig 6). In the obliquus externus abdominis, the corresponding values were 17.0 ± 11.2 and 11.6 ± 7.6, respectively ($p < .05$) (fig 6). At the T9 level, the average electromyographic activity (% MVC) of the pooled data were 48.1 ± 20.2 in women and 36.6 ± 20.2 in men, respectively (not significant) (fig 6). At the L5 level, the corresponding values were 43.3 ± 18.1 and 29.5 ± 12.7, respectively ($p < .05$) (fig 6).

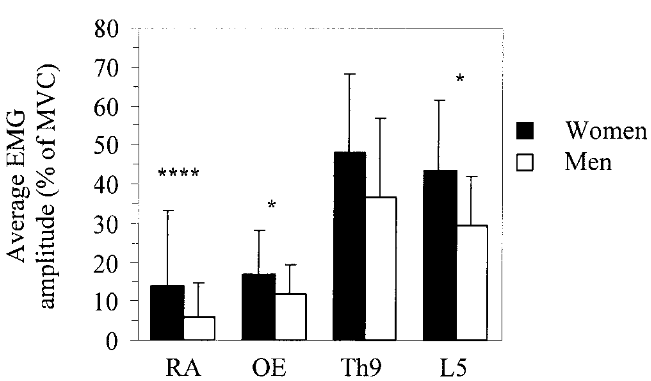

Fig 6. Mean ± SD average normalized surface electromyographic amplitudes (% MVC) of the pooled data (all data across the exercises pooled, n = 16) at RA, OE, and erector spinae (T9 and L5 levels) muscles. * $p < .05$, **** $p < .001$.

DISCUSSION

Trunk muscles has been divided into local and global muscles based on their role in stabilizing the trunk.[43] Multifidus, transversus abdominis, and obliquus internus abdominis muscles form the local stabilizing system; whereas longissimus thoracis, rectus abdominis, and obliquus externus abdominis muscles form the global stabilizing system. In the theoretical model, the stability of the spine is increased with either increased antagonistic flexor extensor muscle coactivation forces or increased intraabdominal pressure along with increased abdominal spring force.[44] Deep local stabilizing muscles, especially multifidus and transversus abdominis muscles, mainly contribute to spinal stability,[45,46] whereas global muscles are the prime movers of the trunk and do not support the spine segmentally.[47,48] It has been suggested that multifidus and transversus abdominis muscles must be contracted independently of the global muscles.[32] It is important to note that a high activity of global muscles is associated with increased spinal loading,[49,50] which might be harmful or at least pain-aggravating for LBP patients. Thus it is advisable to simultaneously study back and abdominal muscle loading in therapy exercises.

Most of the earlier studies have focused on investigating either abdominal[51-53] or back extensor muscles[37,54-57] during trunk flexion and extension exercises, respectively. Very few studies have simultaneously studied back and abdominal electromyographic activity during therapeutic exercises.[58-60] Because of differences in experimental setup between our previous study and this one, comparison of the results must be made with caution. In general, the best exercises for activating the lumbar paraspinal muscles have been suggested to be those involving hyperextension of the back from the prone position (eg, the prone arch exercise[54,56]) whereas during Williams's flexion exercises (eg, pelvic tilt, curl up, knees to chest) performed with posterior tilt minimize the electromyographic activity in the lumbar regions.[55] Our study showed that the back extensor muscles are also highly activated in standing (exercises 11–13, 15, 16), in sitting (exercises 9, 10), and in bridged position (exercises 6–8).

In the investigated exercises, the lumbar multifidus muscle function patterns appeared to be coupled with longissimus thoracis muscles at T9, thus local and global back muscle functions showed similar activation patterns and simultaneous function. In addition, in many exercises T9 longissimus thoracis electromyographic amplitude (% MVC) was higher as compared with the L5 multifidus. Only bilateral leg extension in the prone position (exercises 1, 2) seemed to produce clearly higher multifidus muscle activity when compared with other exercises and recording sites, indicating isolated lumbar muscle function. A similar finding had been reported earlier.[56,61] Ng and Richardson[56] also have shown that erector spinae and multifidus have greater activity during trunk holding (76%–79% of MVC) than in leg holding (66%–68% of MVC). However, it must be pointed out that lying prone on the floor and raising either leg (exercises 1, 2) or both legs simultaneously (exercise 5) from the floor may cause excessive compressive loads to the spine that may aggravate pain in LBP patients.

Standing trunk in 30° flexion with weights in the hands (exercise 12) or standing on the balance board while holding hand weights (exercise 13) produced higher back extensor muscle electromyographic activities (% MCV) than standing in a neutral position (exercise 11). Similary, sitting with the trunk in 30° flexion with weights in hand (exercise 10) or bilateral leg extension with the upper body prone on the board (exercise 5) produced higher back extensor muscle activities (% MCV) than sitting in neutral position with weights in hand (exercise 9) or unilateral leg extension with the upper body prone on the board (exercise 4). This indicates that additional weights in the hands or additional load produced by unbalanced limb movements increase trunk muscle activity, as has been shown earlier,[37,62] which may contribute to the maintenance of spinal stability. Unbalanced limb movements of the legs, ie, alternating shoulder flexion with weights while standing on a balance board (exercise 13), is also considered to be good proprioceptive exercise for lumbar spine. Subcortical control of stabilization can be achieved by proprioceptive exercise on a labile surface such as a balance board.[63] Faster subcortical control system is known to lead to a reduced muscle reaction time, which has been shown to improve the stability of the peripheral joints, pelvis, and lumbar spine.[63]

The direction of restricted upper limb movement appears to affect also the activation patterns of the trunk muscles. Simultaneous resisted UE extension while standing (exercise 14) caused high abdominal muscle activity, whereas resisted UE flexion while standing (exercise 15) caused high back muscle activity. Resisted UE adduction while standing (exercise 16) produced nearly as high muscle activities in both paraspinal and abdominal muscles. Thus by changing the upper limb positions in neutral standing position, varied trunk muscle activaties can be generated. This can be taken into account when planning an exercise programs.

The rectus abdominis was activated bilaterally in all exercises, whereas the obliquus externus abdominis muscle was active simultaneously with the same-side lower extremity (exercise 8). In rectus abdominis and obliquus externus abdominis muscles, the electromyographic amplitudes (% MVC) were below 20% during these exercises, indicating aerobic metabolism of the abdominal muscles.[64,65] In general, the activity in the abdominal muscles was lower than in the paraspinal muscles, which indicated that loading was mostly targeted to the paraspinal muscles in these exercises. This result was not unexpected, because obliquus externus abdominis and rectus abdominis muscles rotate the pelvis posteriorly and flex the trunk. These were not the main directions in these exercises.

It has already been shown that specific exercise treatment is more effective than types of conservative treatment modalities for LBP.[9,32] Patients with radiologic evidence of spondylolysis and spondylolisthesis benefited from a 10-week specific-exercise program as quantified by decreased pain and increased functional ability.[9] In another study, a 4-week exercise program normalized decreased cross-sectional area of the multifidus muscle as compared with the nonsymptomatic side.[32] Richardson et al[32] have shown that LBP patients have impaired motor control of the deep trunk muscles, transversus abdominis, and lumbar multifidus muscles that are important in providing segmental spine stability. Unfortunately, the function of transversus abdominis muscle was not studied. In our study, the activities of the multifidus muscles at L5 indicate that the current exercises are suitable for training the lumbar muscles that provide the segmental stability of the lumbar spine.

In clinical practice, we should find the safest method to exercise the local stabilizing muscles of the lumbar spine. The loading of the trunk muscles should be defined. Excessive spine loading should be avoided in back pain patients to prevent further structural damage.[32,59,60] McGill[60] has suggested that back pain patients should avoid, for example, exercises in which the upper body and legs are raised simultaneously when lying prone, exercises with a full range of spinal motion, and exercises performed in flexion. These exercises are accompanied with high levels of spinal loading.[59] It has already been suggested that back muscle contractions as low as 25% of MVC are able to provide maximal joint stiffness.[62] Furthermore, because lumbar stabilizing multifidus muscles are mainly composed of type I fibers,[66] only relatively low loads (approximately 30%–40% of MVC) are needed to improve their performance.[32] Accordingly, most of the exercises in our study (electromyographic amplitude $<$ 40%) are suitable for exercising the multifidus muscle function. Later in the active physical rehabilitation more intensive exercises with a higher other level of MVC can be used.

Women had lower maximal muscle strength than men, which also has been reported.[67] However, normalized electromyographic amplitudes of rectus abdominis, obliquus externus abdominis, and multifidus muscles were generally significantly higher in women than in men, reflecting higher abdominal and paraspinal muscle loading relative to MVC in women than in men. Thus, women seem better able to activate their stabilizing trunk muscles than men. A similar gender difference has already been reported for paraspinal muscles using similar experimental setup and therapeutic exercises.[37] This could be the aftermath of the anthropometric differences between men and women, allowing body parts to produce different relative loadings for men and women. However, there were no differences in low back mobility and BMI between the genders. Another option is that men, having a much higher degree of strength on maximal contraction, only need to activate a smaller amount of that maximum to perform a similar activity than women. The reason behind this gender difference remains unknown but still highlights the fact that relatively similar loading in men and women produces more paraspinal and abdominal muscle activity in women. This should be taken into account when planning the active physical rehabilitation programs for women with LBP to avoid excessive and possibly pain aggravating spinal loading.

Our study investigated trunk muscle activities in healthy individuals who had no current or past back pain problems. It is not known how these exercises would stimulate the trunk muscles in patients with chronic LBP. It is also possible that patients would have difficulties in performing some of these exercises, because of their current pain. Trunk muscle activities during the therapeutic exercises should also be investigated in chronic LBP patients and likewise, which therapeutic exercises are suitable for back pain patients.

CONCLUSION

Simple therapeutic exercises are effective in activating both abdominal and paraspinal muscles. Additional loads produced by altered body positions or unbalanced limb movements increased the trunk muscle activities. In general, in most of the exercises, women showed higher average normalized electromyographic amplitudes (% MVC) of the lumbar multifidus, rectus abdominis, and obliquus externus abdominis muscle activities than men.

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