

Effect of Abdominal Electrical Muscle Stimulation Training With and Without Superimposed Voluntary Muscular Contraction on Lumbopelvic Control

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Context: Electrical muscle stimulation (EMS) was designed for artificial muscle activation or superimposed training. **Objectives:** To compare the effects of 8 weeks of superimposed technique (ST; application of electrical stimulation during a voluntary muscle action) and EMS on the cross-sectional area of the rectus abdominis, lateral abdominal wall, and on lumbopelvic control. **Setting:** University research laboratory. **Design:** Randomized controlled trial. **Participants:** Fifty healthy subjects were recruited and randomly assigned to either the ST or EMS group. **Intervention:** The participants engaged with the electrical stimulation techniques (ST or EMS) for 8 weeks. **Main Outcome Measures:** In all participants, the cross-sectional area of the rectus abdominis and lateral abdominal wall was measured by magnetic resonance imaging and lumbopelvic control, quantified using the single-leg and double-leg lowering tests. **Results:** There were no significant differences in the cross-sectional area of the rectus abdominis (right: $P = .70$, left: $P = .99$) or lateral abdominal wall (right: $P = .07$, left: $P = .69$) between groups. There was a significant difference between groups in the double-leg lowering test ($P = .03$), but not in the single-leg lowering test ($P = .88$). There were significant differences between the preintervention and postintervention in the single-leg ($P < .001$) and double-leg lowering tests ($P < .001$). **Conclusions:** ST could improve lumbopelvic control in the context of athletic training and fitness.

Keywords: electrical stimulation, magnetic resonance imaging, cross-sectional area

Electrical muscle stimulation (EMS) uses a variety of electrical wave forms to artificially stimulate or superimpose training innervated muscles. EMS has been applied for muscle strengthening, facilitation of muscle contraction and motor control, and maintenance of muscle size and strength during prolonged immobilization in many rehabilitation settings.¹⁻⁴ In addition, EMS programs have been used to improve muscle strength in healthy individuals, and muscle performance in athletes.⁵⁻¹⁰

Neuromuscular adaptations resulting from EMS training in both healthy and diseased muscles can be as large as, but are rarely greater than, those resulting from voluntary contractions (VCs).^{11,12} Previous studies that compared the effects of different training methods showed that EMS induced either less than,^{13,14} or a similar amount of,¹⁵⁻¹⁷ neuromuscular adaptation compared with VC in healthy subjects. There is still controversy regarding whether EMS or VC is more effective, but they could also be considered as complementary stimuli that induce different physiological effects; for example, there is a

tendency for EMS to reverse the order of the motor unit recruitment observed with VC.^{18,19}

By superimposing VC and EMS (superimposed technique [ST]; application of EMS during voluntary muscle action), the physiological effects attributed to each stimulus may accumulate.²⁰ Because EMS mainly stimulates large motor units, whereas VC first recruits small motor units, it is possible that ST can recruit more motor units than EMS or VC alone.²⁰ Previous studies of the effects of ST have typically concentrated on isolated muscle groups, such as the quadriceps,²¹⁻²⁵ to increase muscle strength and muscle size and improve motor performance in sport. Regarding the abdominal muscles, previous studies investigated the effects of ST on their isometric strength and endurance.²⁶

Strength programs that focus on trunk stabilization strengthen the abdominal muscles, improve motor control, and decrease low back pain.²⁷⁻²⁹ The abdominal muscles involved in trunk stabilization include the transverse abdominal (TrA) and internal oblique (IO) muscles, whereas the external oblique and rectus abdominis (RA) muscles mainly contribute to lumbopelvic control (LC).²⁹⁻³² LC is generally considered to provide a foundation for lumbopelvic dynamic control; this allows for optimal control and transfer of load, which is transferred throughout the kinetic chain during functional movements.³³⁻³⁷ Instantaneous and efficient LC functioning requires successful integration of sensorimotor control.^{28,35,37-40}

It has been postulated that the abdominal musculature of most people is atrophied due to the effects of the sedentary modern lifestyle.⁴¹⁻⁴³ The RA and lateral abdominal wall (LAW) muscles (external oblique, IO, and TrA) play an important role, not only in appearance, muscle strength, and endurance, but also in LC. Although various electrical stimulation devices for the abdominal muscles are being marketed to the general public, there is still a lack of research on whether ST alone, EMS alone, or both in combination is most effective for improving abdominal functions. Thus, the purpose of this study

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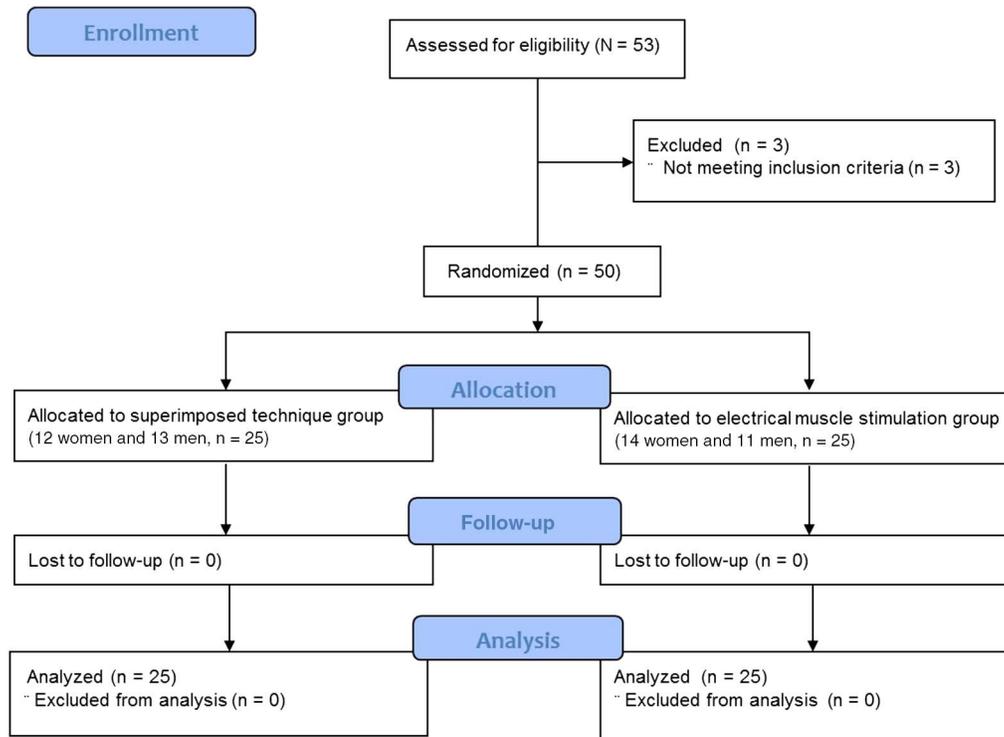


Figure 1 — Flow diagram of our randomized trial between groups.

was to compare the effects of 8 weeks of ST and EMS abdominal muscle training on muscle size and LC. We hypothesized that ST would be more effective than EMS for improving muscle size and LC.

stimulation were excluded from the study. Before the study, all subjects were briefed on the procedures thereof and signed an informed consent form approved by the institutional review board.

Methods

Subjects

The sample size was determined *a priori* using G*Power software (version 3.1.3; University of Trier, Trier, Germany)⁴⁴ based on the data of a pilot study that included 3 participants per group (ST and EMS). The sample size calculation was based on a power of 0.95, alpha value of .05, and effect size (f) of 1.23; more than 10 subjects were found to be required per group. Fifty healthy subjects without a history of hernia, cardiovascular disease, neurological disease, musculoskeletal dysfunction of the lumbar spine or pelvis, or claustrophobia were recruited and randomly assigned to the ST or EMS group (Figure 1 and Table 1). Participants with cardiac pacemakers or other electronic implants were excluded from the EMS group. Individuals who had an aversion to the sensation of electrical

Electrical Muscle Stimulation Training

The EMS was applied to the abdominal muscles using a SIXPAD Abs Belt (MTG, Nagoya, Japan). The EMS device consisted of a contoured, flexible, soft silicone belt with electrodes that were connected to the stimulator without externally visible leads or detachable gel pads. The EMS device delivered biphasic, symmetric pulses of 2 to 20 Hz, and pulse frequency and duration were controlled using a program that stimulated the RA and LAW muscles (mean intensity, 30.06 [7.47] mA [range: 18.28–41.83 mA]). Subjects were encouraged to increase the amplitude on the stimulator to elicit strong contractions of the abdominal muscles (within tolerable limits). Subjects were instructed not to perform volitional contractions during electrical stimulation and to consistently attach the center of the EMS device over the umbilicus.

Table 1 Subject Characteristics

Characteristics	ST group			EMS group			P
	Total (n = 25)	Men (n = 13)	Women (n = 12)	Total (n = 25)	Men (n = 11)	Women (n = 14)	
Age (SD), y	25.0 (3.3)	25.7 (3.6)	24.3 (2.7)	25.2 (2.0)	26.4 (1.8)	24.2 (1.7)	.39
Body height (SD), cm	169.0 (8.9)	176.7 (3.1)	160.8 (4.2)	166.3 (8.7)	173.5 (4.5)	160.7 (6.8)	.30
Body mass (SD), kg	66.3 (15.3)	77.1 (12.5)	54.6 (7.0)	64.3 (13.7)	77.4 (8.1)	53.9 (5.8)	.54
BMI (SD), kg/m ²	23.0 (3.6)	24.7 (3.5)	21.1 (2.7)	23.0 (3.5)	25.8 (3.2)	20.9 (1.7)	.89

Abbreviations: BMI, body mass index; EMS, electrical muscle stimulation; ST, superimposed technique.

Superimposed Technique Training

The ST subjects were electrically stimulated using the same EMS device and training protocol as in the EMS group. The mean contraction intensity was 33.30 (0.78) mA (range: 18.28–41.83 mA). In addition, they performed VCs via 2 abdominal crunch cycles over a 10-second period (1 cycle = 3 s of tetanic stimulation followed by a 2-s pause). For abdominal crunches, the subject was supine in the standard sit-up position, with the knees bent at 90° and the hands folded across the chest. The subject contracted the abdominal muscles by drawing the belly button inward (toward the spine), and then raised the head and shoulders upward until the shoulder blades cleared the table. Subjects held this position for 10 seconds and then returned to the starting position. The subjects were asked to perform 10 sets of abdominal crunches in accordance with the EMS training protocol for 4 weeks, followed by 15 sets for another 4 weeks.

Magnetic Resonance Imaging Assessment of Abdominal Muscle Size

Subjects were screened for contraindications to magnetic resonance imaging (MRI) by a medical practitioner before the study assessment. Subjects with metal implants or claustrophobia were excluded from the study. Subjects removed any metal objects on the body prior to the assessment and were then placed in a supine position. The MRI scans were obtained using a 1.5 T scanner (Magnetom Avanto; Siemens, Erlangen, Germany). Ten contiguous 5-mm-thick slices centered on the L3–L4 discs were acquired with the patient in a relaxed state, with the breath held at mid-expiration.^{45,46} Measurements of abdominal muscle size on MRI included the cross-sectional area (CSA) of the RA and LAW (intrareliability; intraclass coefficient [ICC] = .892). The MRI images were archived for later analysis using a measurement software package on a laptop computer.

Measurement of LC: Single-Leg and Double-Leg Lowering Tests

The single-leg and double-leg lowering tests were used to assess LC by measuring the subject's ability to control the spine during movements of the lower limbs.^{29,32,33,47,48} While in the supine position, the subject flexed the hip and knee to 90°. A Smart KEMA pressure sensor (KOREATECH Co, Ltd, Seoul, Korea) was set to 40 mm Hg and placed below the lordotic curvature of the spine between L1 and S1, with the hip and knee in 90° of flexion. Using its strap, the Smart KEMA motion sensor (KOREATECH Co, Ltd) was attached to the thigh between the greater trochanter and knee joint. During performance of the abdominal drawing-in maneuver, the pressure on the sensor was increased by 10 mm Hg. Subjects were asked to hold the lumbopelvic position by contracting the abdominal muscles while slowly lowering one or both legs to the supporting surface. One or both leg lowering (hip extension) angles were measured with a motion sensor, and LC was defined as the moment when the pressure sensor reading decreased below 50 mm Hg (Figure 2). Because the abdominal muscles are necessary for LC during leg motion, with greater leg lowering angle, the control of the lumbopelvis is improved. The leg lowering angle was normalized to subject height (in meters) × mass (in kilograms) for statistical analysis. The mean single-leg (ICC = .979) and double-leg lowering angles (ICC = .867) for 3 trials were used in the data analysis.



Figure 2 — Measurements of the (A) single-leg lowering test and (B) double-leg lowering test.

Procedures

This study was performed over a 6-month period from January to June 2018. During a preliminary session, all participants underwent MRI in the radiology center for baseline measurement of the CSA of the RA and LAW, and for a baseline assessment of LC. The order of the 3 tests (single-leg lowering test on either side and the double-leg lowering test) was randomized using an online program (<http://www.randomization.com>).

Electrical muscle stimulation and ST training were performed twice a day for 23 minutes for 8 weeks. Adherence to this schedule was confirmed by telephone every day, and the participants were encouraged to perform EMS training on at least 5 days per week.⁴⁹ The subjects were instructed not to perform additional fitness training or abdominal muscle exercises during the study. For all participants, the instrument settings remained the same as during the preliminary session.

Statistical Analysis

All statistical analyses were conducted using SPSS software (version 18.0; SPSS Inc, Chicago, IL). The Kolmogorov–Smirnov Z test was used to verify the normality of the data distribution. Descriptive statistics were used to analyze the abdominal muscle size and LC data, which were normally distributed. The ICC(3, 1) model was used to assess intrarater reliability regarding measurements of muscle size and LS. Analysis of covariance was used to compare the groups before and after the intervention, with the baseline values used as covariates. Data are presented as mean (SD). Effect sizes (r) and confidence intervals (CIs) for the primary outcomes were calculated to determine the clinical significance of the data. The r was constrained between 0 (no correlation) and 1 (perfect correlation); in this study, $0 \leq r < .1$ was classified as no effect, $.1 \leq r < .3$ as a small effect, $.3 \leq r < .5$ as a moderate effect, and $r \geq .5$ as a large effect.⁵⁰ For post hoc analyses, a paired t test was performed to determine premeasurement versus postmeasurement differences in each group. The significance level was set at $P < .05$ for all analyses.

Table 2 Comparison of Changes in Abdominal Muscle Size and LC, Preintervention Versus Postintervention, in the ST and EMS Groups

Category	Variables	Side	Session	ST group	EMS group	Mean change (95% CI)	Effect size
Abdominal muscle size, cm ²	CSA of RA (SD)	Right	Pre	5.32 (2.01)	5.18 (1.61)	-1.23 (-1.49 to -0.97)	0.66
			Post	6.51 (2.45)	6.45 (2.00)		
	CSA of LAW (SD)	Right	Pre	21.98 (7.94)	20.48 (6.87)	-1.34 (-1.80 to -0.88)	0.43
			Post	22.90 (7.79)	22.24 (7.46)		
	CSA of RA (SD)	Left	Pre	5.41 (2.04)	5.27 (1.72)	-1.13 (-1.41 to -0.85)	0.59
			Post	6.55 (2.33)	6.39 (2.27)		
CSA of LAW (SD)	Left	Pre	21.90 (7.26)	20.47 (6.98)	-1.78 (-2.35 to -1.20)	0.45	
		Post	23.59 (7.91)	22.34 (7.32)			
LC, deg/kg·m	Single-leg lowering test (SD)	-	Pre	0.46 (0.27)	0.42 (0.25)	-0.13 (-0.20 to -0.07)	0.25
			Post	0.58 (0.30)	0.56 (0.27)		
	Double-leg lowering test (SD)	-	Pre	0.23 (0.18)	0.24 (0.19)	-0.11 (-0.16 to -0.07)	0.35
			Post	0.39 (0.22)	0.30 (0.19)		

Abbreviations: CI, confidence interval; CSA, cross-sectional area; EMS, electrical muscle stimulation; LAW, lateral abdominal wall; LC, lumbopelvic control; RA, rectus abdominis; ST, superimposed technique.

Results

Table 2 presents the preintervention and postintervention results. There were no significant differences in the CSA of the RA (right-side mean change: -0.05; 95% CI, -0.31 to 0.21; effect size: 0.003; $P = .70$; left-side mean change: -0.001; 95% CI, -0.28 to 0.28; effect size, 0.000, $P = .99$) or the LAW (right-side mean change: -0.42; 95% CI, -0.88 to 0.04; effect size: 0.068; $P = .07$; left-side mean change: -0.11; 95% CI, -0.69 to 0.46; effect size: 0.003; $P = .69$) on either side between groups. A significant difference was observed between premeasurement and postmeasurement of the CSA of the RA (right: $P < .001$, left: $P < .001$) and the LAW (right: $P < .001$, left: $P < .001$) on both sides. Figure 3 illustrates the significant differences between the premeasurement and postmeasurement in each group, based on post hoc analysis.

A significant difference was observed between groups for the double-leg lowering test (mean change: 0.05; 95% CI, 0.01 to 0.10; effect size: 0.10; $P = .03$), but not between groups for the single-leg lowering test (mean change: -0.005; 95% CI, -0.07 to 0.06; effect size, 0.000; $P = .88$). There were significant differences between the premeasurement and postmeasurement for the single-leg ($P < .001$) and double-leg lowering tests ($P < .001$).

Figure 3 shows the significant differences between the premeasurement and postmeasurement for each group (ST: $P = .03$, EMS: $P = .01$), according to post hoc analysis of the single-leg lowering test data. Regarding the double-leg lowering test, a significant difference was observed between the premeasurement and postmeasurement in the ST group ($P < .001$), but not in the EMS group ($P = .14$).

Discussion

Abdominal and core muscle training has been highly emphasized for improving LC, preventing low back pain, and increasing physical performance in the clinical, sports, and fitness fields.^{27,34} Of the 2 types of contractions, ST induces more pronounced neuromuscular adaptation than EMS training alone.²⁰ However, EMS and VC together could lead to greater physiological adaptation than either contraction type alone. Our results indicate that 8 weeks of ST training of the abdominal muscles induced a greater

increase in LC in the double-leg lowering test compared with EMS training alone. Thus, ST training is a good option for improving LC, abdominal muscle performance, and lumbopelvic stability.

Regarding muscle size, no significant difference in the CSA of the RA and LAW was noted between groups in this study post-intervention. In previous studies, the integration of ST into training programs did not yield significant benefits over programs using EMS alone, with respect to the CSA of the quadriceps femoris.^{51,52} In addition, EMS and EMS combined with plyometric training have been shown to be more efficient than VC alone, but there was no significant difference between EMS and EMS combined with plyometric training on the CSA of the quadriceps femoris.⁵³ Consistent with the principle of specificity, targeted manipulation of training variables is essential for maximizing exercise-induced muscle hypertrophy.⁵⁴ Load has been shown to have an especially significant impact on muscle hypertrophy and is arguably the most important exercise-related variable for stimulating muscle growth.⁵⁴ In the present study, the ST was in the form of a crunch exercise combined with EMS, which may produce a load insufficient to yield group differences. The analysis did not reveal a significant difference in the CSA of the RA or LAW between the groups, so we could not confirm that ST was superior to EMS for increasing the CSA of the RA and LAW; moreover, muscle activation was not measured (eg, via the twitch interpolation technique). Further investigations, including the assessment of muscle activation, would help to clarify whether there was an activation deficit prior to training, and whether EMS training could eliminate any such deficit in muscle fiber recruitment.

The anterior and posterior trunk muscles provide the control necessary for stabilizing the lumbar spine during limb movement.^{27,55,56} To accurately assess the effect of interventions on core muscle performance, and to develop more effective exercise programs, clinicians need an objective measure that can assess abdominal muscle performance and/or motor function. Current muscle tests for assessing trunk stability include the double-leg lowering test⁵⁷ and the single-leg lowering test.^{32,33,58} In the present study, the single-leg lowering exercise was categorized as grade 3.0 (highest possible grade = 5.0 for double-leg lowering exercise), according to the lower abdominal muscle progression test.^{32,33} Thus, the double-leg lowering test requires higher performance compared with the single-leg lowering test.

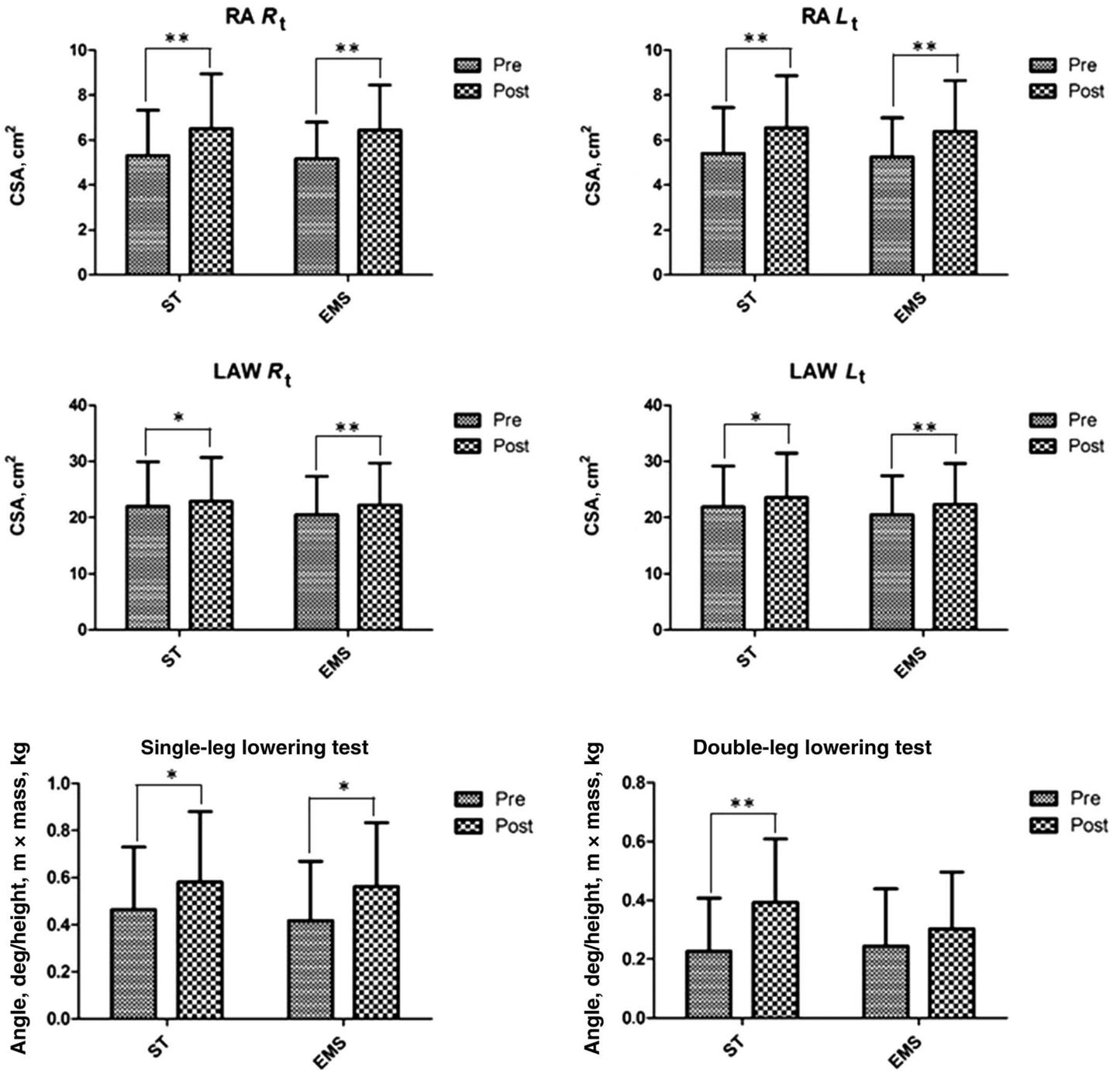


Figure 3 — Comparison of CSA of RA and LAW, and single-leg and double-leg loading tests among pre-EMS and post-EMS training sessions (**P* < .05; ***P* < .01). CSA indicates cross-sectional area; EMS, electrical muscle stimulation; LAW, lateral abdominal wall; RA, rectus abdominis; ST, superimposed technique.

Regarding LC, the single-leg lowering test angle was significantly increased after 8 weeks of training in both groups, but a significant difference was not seen between groups. However, there was significant difference between groups in the double-leg lowering test; moreover, a significant increase from baseline was seen in the ST group, but not in the EMS group. No previous studies investigated the effect of ST or EMS training on muscle function or performance in healthy subjects. IO and TrA contraction are helpful

for controlling intersegmental motion and responding to changes in posture and extrinsic loads. The IO and TrA contract together to increase intraabdominal pressure and provide support to the lumbar spine via the thoracolumbar fascia.⁵⁹ The external oblique keeps anterior pelvic tilt in check. In the single-leg and double-leg lowering tests, the subject is asked to coactivate the deep stabilizing muscles; then, without moving the spine or pelvis during leg lowering, the load of the leg produces a rotary force on the pelvis

and spine, such that the global muscles must contract to overcome this force and maintain the lumbopelvic position.²⁹ By analyzing the data produced by these tests, we were able to ascertain whether ST and EMS affect parameters of lumbopelvic stability, such as neuromuscular and motor control, or cause cocontraction of global and local abdominal muscles. The significant difference between the groups in the double-leg lowering test, which requires a higher level of neuromuscular coordination compared with the single-leg lowering test, suggests that ST improves neural adaptation, coordination, and cocontraction by stimulating the muscles via VC, where these muscles are not stimulated by EMS training alone.

The current study had several limitations. First, a control group is needed, with randomization between control, ST, and EMS groups, to allow comparison of the results. Second, it is difficult to generalize our results to various ages, because the current study focused on young men and women. Third, the subjects were normal individuals that were not patients with pain or diseases. Thus, further studies need to be performed on patients of various ages with musculoskeletal disease.

Conclusions

There were significant improvements in the CSA of the RA and LAW, as well as the LC, after the 8-week training program in both groups. There were no significant differences in the CSA of the RA or LAW, or the single-leg lowering test results, between groups. Therefore, EMS can be applied for improving the CSA of the RA and LAW in individuals who have difficulty with abdominal VCs due to surgery and immobility. The present study demonstrated that improvements in LC, as indexed by the double-leg lowering test, were greater in the ST training group than in the EMS training group. Thus, ST can be applied to improve LC in the context of athletic training and fitness.

Acknowledgments

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