Normal Trunk Muscle Strength and Endurance in Women and the Effect of Exercises and Electrical Stimulation

Part 2: Comparative Analysis of Electrical Stimulation and Exercises to Increase Trunk Muscle Strength and Endurance

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Several studies have shown positive correlations between muscle strength, flexibility, and the frequency of low-back pain. Weak trunk musculature and decreased endurance have thereby come to be identified as significant risk factors in the development of occupational back problems. Because it is widely accepted that exercise plays an important role in the conservative treatment and prevention of low-back pain, the goals of most rehabilitative programs involves improving the strength and endurance of the low-back pain patient. Whereas electrical stimulation has been shown to increase the muscle strength of the lower extremities, this effect has not been demonstrated for the trunk muscles. Part 2 is a prospective controlled study designed to document and to compare objectively the effects of electrical stimulation and exercise on trunk muscle strength. A total of 117 healthy women were divided randomly into four groups. Two groups received electrical stimulation with different electrical parameters, one group received exercises, and one group acted as a control group. The results showed that low-frequency electrical stimulation and exercises significantly ($P < .05$) increased isokinetic back-muscle strength compared to the control and medium-high-frequency electrical stimulation groups. Both types of electrical stimulation, however, significantly increased ($P < .05$) the endurance in the back muscles compared with the control and the exercise groups. This study showed that electrical stimulation may be a valuable treatment in the early care of low-back pain patients in maintaining and increasing strength and endurance of back muscles when a more active exercise program is too painful to perform. [Key words: electrical stimulation, exercise, trunk muscles, women]

RECENTLY, MUSCLE STRENGTH AS A possible factor in the etiology of low-back pain has received a great deal of attention. Cady et al[3] showed that among fire fighters muscle strength was an accurate prognostic indicator for the development of low-back pain. Chaffin,[5] in a study on manual-materials workers, also showed a positive correlation between strength capacity and the frequency of low-back pain. Biering-Sorensen[2] found that subjects with recurrent back pain had weaker trunk muscles and diminished flexibility when compared with asymptomatic subjects. Conversely, good isometric endurance in men appeared to prevent low-back problems. Thus, weak trunk muscle and decreased endurance have been identified as significant risk factors in the development and incidence of occupational back problems.

In a study comparing The Back School, physcial therapy, and a control group, no single treatment program effectively reduced the high recurrence rate of low-back pain.[1] It is, however, widely accepted that exercises play an important role in the treatment and prevention of low-back pain. The goal of most rehabilitative programs is aimed at improving the trunk strength and the endurance of the low-back pain patient. Electrical stimulation has been shown to be effective in increasing the strength of the muscles of the lower extremities,[6,7,11-13,18,21,25] but to our knowledge, its effect on trunk muscle strength has not been documented.

Many studies have compared electrical stimulation and exercise as methods of increasing muscle strength of the quadriceps (Table 1).[6,7,9,13-18,21,24,25] Making comparisons among these studies as difficult because of the varied protocols and electrical parameters used in each study. Electrical stimulation has been shown to be superior to exercise in postsurgical knee patients, whereby it prevents a fall in oxidative enzymes and abates muscular atrophy.[9,13,27] Recent studies have shown that in a group of normal subjects with induced nonweight bearing, the quadriceps had one-half the atrophy of the exercise group.[10]

Comparative studies of electrical stimulation and exercise on the quadriceps of normal subjects showed that both methods were capable of achieving comparable increases in muscle strength[9,17,18,21] and that the combination of exercise and electrical stimulation in the quadriceps muscles was no more effective than exercise alone.[6,17] Exercise has been found to be superior to stimulation in terms of producing an increase in muscle power.[13] Furthermore, electrical stimulation has also been shown to have little effect on isokinetic strength.[7,25]

The use of electrical stimulation in the lower back has been used predominantly as a pain reduction modality.[22,26] Electrical stimulation used to improve trunk muscle strength has not been previously reported to our knowledge.

This prospective study was based on the hypothesis that a strong back was associated with a decreased incidence of low-back pain. Therefore, the study was designed to determine whether an exercise or electrical stimulation program was effective in increasing isometric—isokinetic strength and endurance of the trunk musculature. The study was also devised to determine if exercise or electrical stimulation was quantifiably superior in increasing the various trunk strength parameters.

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Table 1. A Summary of Previous Studies Concerning Electrical Stimulation and Quadriceps Strengthening in Normal Subjects

Authors	Body area	Total population and treatment groups	Duration of program and type of exercise	Stimulation parameters		Type of test and results
Currier et al, 1979[6]	Quadriceps muscle, normals	n = 37 E = 11	10 sessions Isometric			Isometric test E, and E and S increased significantly versus C ($P < .05$).
		E + S = 12	Isometric + stimulation 6 sec on, 6 sec off	wave PPS mA	rectangular 25 variable	Comparable increase in strength for E and E and S.
		C = 14	—			
Currier and Mann, 1983[7]	Quadriceps muscle, normals	n = 34 E = 8	15 sessions Isometric			Isometric test E, and E and S increased significantly versus C ($P < .05$).
		S = 8	Stimulation 15 sec on, 50 sec off	wave PPS mA	sine 50/2500 Hz 37-86	Isokinetic test E, S and E and S nonsignificant versus C.
		E + S = 9	Isometric + stimulation 15 sec on, 50 sec off	wave PPS mA	sine 50/2500 Hz 26-86	Comparable increase in strength for E, S and E and S.
		C = 9	—			
Eriksson et al, 1981[10]	Quadriceps muscle normals	n = 17 E = 4	15 sessions Isokinetic	15° per sec		Isokinetic test Comparable and significant increase in strength in all three groups ($P < .05$).
		S = 9	Stimulation 15 sec on, 15 sec off	wave PPs mA	square 1200 Hz 10	
		S = 4	Stimulation 6 sec on, 6 sec off	same as above		
Halbach and Straus, 1980[13]	Quadriceps muscle normals	n = 6	15 sessions			Isokinetic test E-increase in strength, 42%.
		E = 3	Isokinetic 10 repetitions	120° per sec		S-increase in strength, 22%.
		S = 3	Stimulation 10 sec on, 50 sec off	wave PPS mA	 50 Hz 22-27	No statistical tests.
Laughmann et al, 1983[18]	Quadriceps muscle normals	n = 58 E = 19	25 sessions Isometric 10 repetitions			Isometric test E and S increased significantly in strength versus C ($P < .05$).
		S = 19	Stimulation 10 sec on, 15 sec off	wave PPS mA	sine 50/2500 Hz 34-70	Comparable increase in strength for E and S.
		C = 20	—			
McMiken et al, 1983[21]	Quadriceps muscle normals	n = 15 E = 8	12 sessions Isometric 10 repetitions			Isometric test E and S increased significantly in strength ($P < .02$).
		S = 7	Stimulation 10 sec on, 50 sec off	wave PPS mA	square up to 75 Hz	Comparable increase in strength for E and S.

Table 1. A Summary of Previous Studies Concerning Electrical Stimulation and Quadriceps Strengthening in Normal Subjects *(continued)*

Authors	*Body area*	*Total population and treatment groups*	*Duration of program and type of exercise*	*Stimulation parameters*		*Type of test and results*
Owens and Malone 1983[24]	Quadriceps muscle, normals	n = 15	10 sessions			Isometric and isokinetic tests.
		S = 12	Stimulation 10 sec on, 50 sec off	wave PPS mA	sine 2500 Hz 16–82	No significant increase in strength.
		C = 3	—			
Romero et al 1980[25]	Quadriceps muscle, normals	n = 18	10 sessions			Isometric test. S increased significantly in strength verus C (*P* < .05).
		S = 9	Stimulation 4 sec on, 4 sec off	wave PPS mA	Faradic 2000 Hz 50	Isokinetic test. No significant increase in strength for S versus C.
		C = 9	—			

MATERIALS AND METHODS

One hundred seventeen normal women between the ages of 18 and 49 (mean age: 28) participated in this study. None had a recent (>3 months) history of low-back pain. All subjects in this study underwent the physical and clinical examination procedures described in Part 1. All subjects also underwent the test battery described in Part 1. Subjects were randomly assigned to either of two types of electrical stimulation (ES1 and ES2), exercise (E), or to a control group (C). See Table 2. The electrical stimulation groups and the exercise group underwent 20 training sessions (5 days a week for 4 weeks), each of which lasted for 30 minutes. The subjects were allowed to miss 10% of the training sessions before they were excluded from the study. The controls did not receive any intervention.

The electrical stimulation devices used were the Respond TM Quadriflex Model 3109 (Medtronic, Minneapolis, Minnesota) and the Soken (Rehab Medical Specialties, Garland, Texas). These are portable devices. The electrical parameters used for both devices are presented in Figure 1. Electrical stimulation was administered with the subject in the prone position. Electrodes were placed at L2–L4 levels over the erector spinae muscle bulks (Figure 2). The intensity of the electrical stimulation was set at the maximum the subject could tolerate for 20 minutes. Subjects were given additional 5-minute warm-up and cool-down periods at lower intensities. The daily maximum intensity tolerated was recorded for each subject.

The subjects in the exercise group had a warm-up and cool-down period of 5 minutes of stretching, followed by a program of 20 minutes of back exercises. These consisted of prone trunk extension exercises, prone leg lifts, prone arm lifts and a combination of "all fours" arm-and-leg lifts (Figure 3). The amount of exercise repetitions were recorded daily.

After the training period, 99 subjects repeated the test battery in the same order and during the same time of the day as their initial testing (Table 3). The test personnel were not aware of the actual grouping of the subjects.

STATISTICAL ANALYSIS

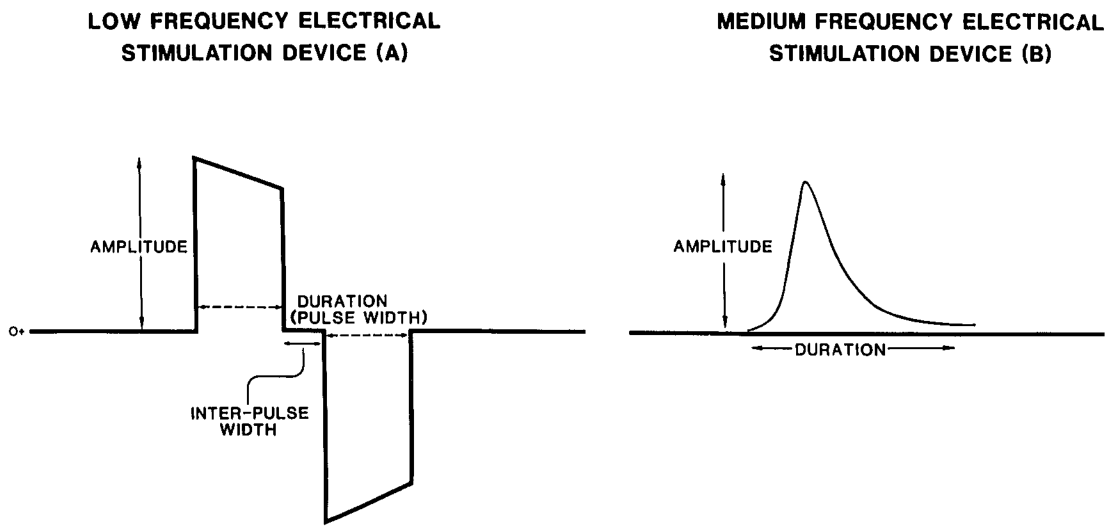
The four groups (ES1, ES2, E, and C) were evaluated for compatibility at $P < .05$ level by a one-way analysis of variance for all parameters studied, including demographic and strength variables. Since strength and endurance parameters after the intervention are a function of the initial strength of the individual (baseline values), the analysis focused on changes in strength and endurance after the intervention. This was done by subtracting the preintervention strength measures from the postintervention strength levels. Mean change was then computed for each of the study groups. Again, a one-way analysis of variance was performed to assess differences among the groups with respect to changes in strength and endurance. In those instances in which a statistical significance was demonstrated, a Student's t test was performed for each of the treatment groups compared with the controls as well as between the three treatment groups. For this study a statistical significance level of $P < .05$ was chosen for the t test.

RESULTS

The results of this study show a consistent pattern. Subjects undergoing electrical stimulation (ES1 and ES2) and the exercise program (E), increased significantly in isokinetic strength ($P < .05$). The subjects undergoing muscle stimulation also increased significantly in endurance ($P < .008$). For the isometric tests, no significant increase in strength occurred. Both the electrical stimulation and exercise groups, however, showed increased strength. The control group showed nonsignificant changes, however, a minor effect could be noted in some parameters in the control group, due probably to a learning process from participating in the test battery. Only selected parameters will be presented in the results; remaining data can be obtained from the authors. The isometric prone and supine tests and the two Natick tests showed no significant increase between the pre- and post-test sessions for the E group and ES groups.

Table 2. Characteristics of Subjects: Mean Values (Standard Deviations) in Age, Height, Weight of Treatment Groups

	Group E (n = 22)	*Group ES1 (n = 30)*	*Group ES2 (n = 29)*	*Group C (n = 18)*
Mean age (years)	27.1 (6.1)	29.5 (6.4)	29.1 (8.2)	30.1 (5.0)
Mean height (m)	1.58 (8.6)	1.59 (14.3)	1.60 (9.3)	1.63 (6.4)
Mean weight (kg)	57.6 (8.1)	57.6 (8.1)	57.8 (7.0)	56.6 (8.6)



	(A)	(B)
1. Amplitude (mA)	0-100	25
2. Voltage (V)	45	0-105
3. Frequency (Hz)	35	300-50
4. Duration (μsec)	300	400-600
5. Interpulse width (μsec)	25	NA
6. Waveform	biphasic, symmetrical, balanced rectangular pulse	monophasic, modified spike wave

Fig 1. Electrical parameters for the Respond (A) and the Soken (B) devices.

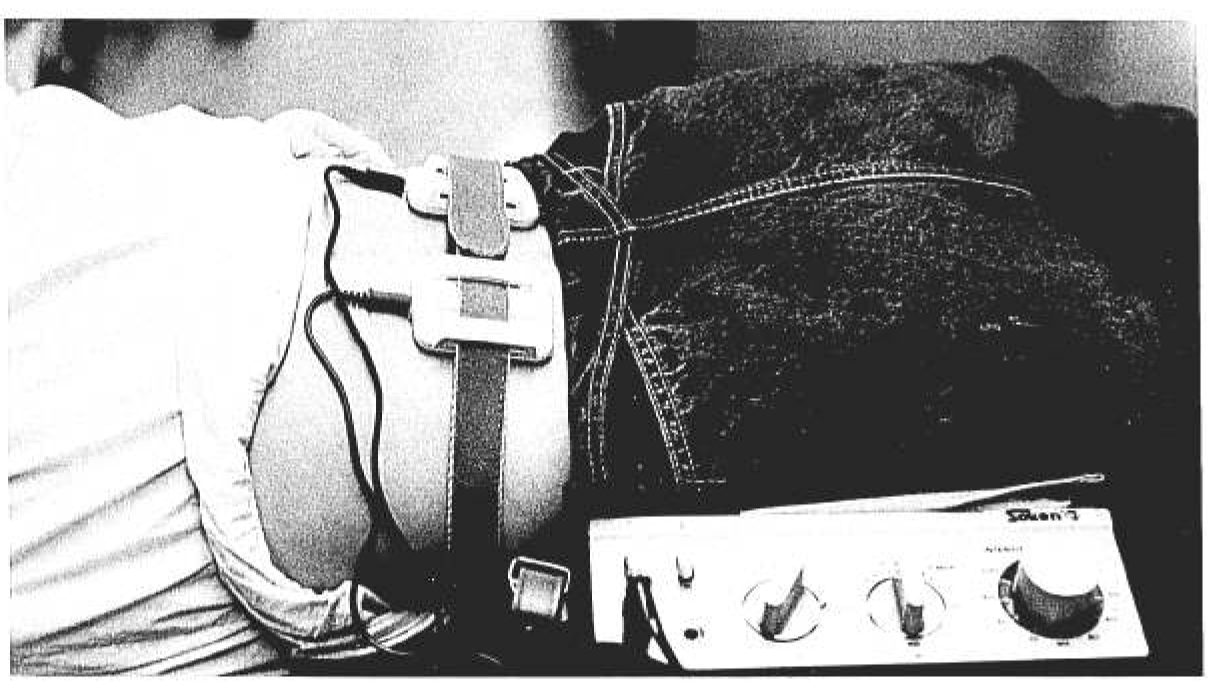


Fig 2. Electrode placement at the L2–L4 levels with the Soken device.

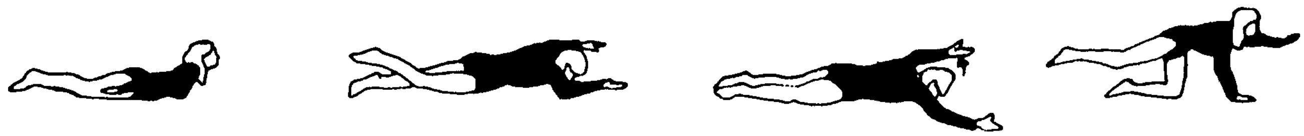


Fig 3. Exercises of the active back strengthening program.

Table 3. Subject Assignments and Compliance

	Group E	*Group ES1*	*Group ES2*	*Group C*
Assigned	31	32	32	22
Completed	22	30	29	18
Drop outs	9	2	3	4
Reasons				
Illness	(1)	(1)	-	-
Back pain	(1)	-	(1)	-
Time	(7)	(1)	(2)	(3)

However, compared with the C group, all subjects receiving either electrical stimulation or exercises showed an increase in strength in extension (Table 4). In the isokinetic tests for flexion and extension at 30° per second and 60° per second, only four parameters of the test battery are provided in Table 5. An analysis of variance of the four groups shows that a statistical significance was reached in all four parameters except for the total energy in flexion at 30° per second and at the average power in extension at 60° per second.

The results for the strength parameters did not change when the values were normalized by dividing the strength parameters with body weight times body height. Table 6 shows the *t* test values

Table 4. Strength Values for Isometric Flexion-Extension and Natick Tests (Mean Values)

Test	*Group E*	*Group ES1*	*Group ES2*	*Group C*	*P value*
Isometric flexion (Nm)	56 (+16)	64 (+6)	82 (−6)	59 (+9)	NS
Isometric extension (Nm)	96 (+18)	98 (+12)	113 (+3)	95 (+9)	NS
Natick peak (N) upright	524 (+60)	476 (+68)	449 (+47)	462 (+23)	NS
Natick peak (N) Flexed back/bent knees	670 (+29)	680 (+21)	624 (+66)	618 (−18)	NS

Values in parentheses ( ) represent amount of change between the post- and pre-tests.
NS = not significant.

Table 5. Analysis of Variance for Selected Isokinetic Flexion/Extension Parameters at 30° and 60° per Second

Parameters	*Group E*	*Group ES1*	*Group ES2*	*Group C*	*P value*
Flexion 30° per sec					
Peak (Nm)	103 (+ 38)	108 (+ 29)	130 (+ 4)	104 (+ 9)	.0001
Total energy (J)	312 (+ 34)	342 (+ 41)	378 (+ 5)	353 (−11)	NS
Peak TAE (J)	81 (+ 47)	84 (+ 31)	126 (−10)	87 (+22)	.002
Average power (W)	29 (+ 8)	31 (+ 6)	35 (+ 3)	32 (− 5)	.002
Extension 30° per sec					
Peak (Nm)	113 (+ 54)	112 (+ 50)	152 (+20)	128 (+13)	.0001
Total energy (J)	363 (+ 53)	351 (+416)	471 (+46)	409 (−28)	.0003
Peak TAE (J)	74 (+ 63)	83 (+ 39)	133 (+ 4)	103 (+ 6)	.004
Average power (W)	44 (+ 11)	45 (+ 13)	45 (+ 7)	37 (− 3)	.0001
Flexion 60° per sec					
Peak (Nm)	99 (+ 31)	99 (+ 35)	124 (+ .6)	116 (+ 4)	.0001
Total energy (J)	315 (+ 13)	366 (+ 68)	346 (+ 6)	334 (−26)	.03
Peak TAE (J)	185 (+132)	84 (+115)	353 (−11)	82 (− 2)	.0001
Average power (W)	52 (+ 7)	52 (+ 13)	62 (+ 2)	65 (− 9)	.001
Extension 60° per sec					
Peak (Nm)	107 (+ 34)	92 (+ 57)	135 (+12)	122 (+ 5)	.0001
Total energy (J)	368 (+ 14)	299 (+144)	407 (+65)	388 (− 4)	.0001
Peak TAE (J)	245 (+125)	238 (+128)	376 (+ 3)	340 (−15)	.0001
Average power (W)	61 (+ 11)	51 (+ 24)	90 (− 7)	69 (− 3)	NS
Sorensen test (sec)	212 (+ 10)	180 (+ 41)	191 (+32)	188 (+ 2)	.04

Values in parentheses ( ) represent amount of change between the post- and pre-tests.
Nm = Newton meters; J = joules; W = watts; S = seconds; NS = not significant.

Table 6. Computed *t*-test Values for the Four Groups

Groups	E vs C	ES1 vs C	E vs ES1	E vs ES2	ES1 vs ES2	C vs ES2
Isokinetic flexion 30° per sec						
Peak	.0004	.008	NS	.0001	.0003	NS
Total energy	.03	.02	NS	NS	.02	NS
Peak TAE	NS	NS	NS	.002	NS	NS
Average power	.005	.017	NS	NS	NS	NS
Isokinetic extension 30° per sec						
Peak	.0008	.001	NS	.0004	.0008	NS
Total energy	.02	.0001	.03	NS	.0001	.03
Peak TAE	.005	.05	NS	.003	.05	NS
Average power	.001	.0001	NS	NS	.008	.05
Isokinetic flexion 60° per sec						
Peak	.003	.0001	NS	.0002	.0001	NS
Total energy	NS	.005	NS	NS	.02	NS
Peak TAE	.0009	.0008	NS	.0001	NS	NS
Average power	.05	.005	NS	NS	.002	NS
Isokinetic extension 60° per sec						
Peak	.007	.0001	.02	.02	.0001	NS
Total energy	NS	.0008	.001	NS	.002	NS
Peak TAE	.002	.0007	NS	.0004	.002	NS
Average power	NS	.0001	.05	NS	.03	NS
Sorensen	NS	.07	.008	.03	NS	.05

NS = not significant.

following the analysis of variance. As can be seen from Table 6, electrical stimulation with low frequency (ESI) and exercises (E) gave a similar significant increase in most measured strength parameters in comparison with the control group (C). These results did not occur for stimulation with medium high frequency. Both electrical stimulation groups (ES1 and ES2) showed a significant increase in extension, 30° per second in total energy compared with both the control groups (C) and the exercise group (E). This shows an increase in endurance for the subjects receiving electrical stimulation. This finding was further confirmed by the Sorensen test results, which showed a significant increase in endurance for the ES groups versus the E group and C group (Table 5). The electromyographic signals collected during the Sorensen test were analyzed in terms of mean power frequency (MPF) and number of zero crossings for the ES1, E, and C groups only. Analysis of variance of the electromyographic data showed no significant difference between the three treatment groups with respect to the changes in the slope and constant values of the linear regression line of MPF and number of zero crossings.

DISCUSSION

Both isometric and isokinetic strength are important in overall muscular conditioning. The specific type of training determines whether idometric or isokinetic strength will be increased. Isometric exercise increases isometric strength whereas dynamic exercise is expected to increase isokinetic strength. With this is mind, the exercise group was expected to increase in isokinetic strength because of the dynamic nature of the exercise training program. In contrast, the electrical stimulation group was expected to increase in isometric strength and endurance of the back muscles. From the results of this study, none of the treatment groups had a statistically significant increase in isometric strength of the back muscles, nor was there a significant change in strength before or after treatment with the Natick tests in any of the groups. This was, however, not surprising because the Natick tests are overall strength tests and not specific tests for the back muscles.

There was a significant ($P < .02$) increase in isokinetic strength in the ES1 and E groups in trunk extension at 30° per second and 60° per second, compared with the ES2 and control groups. The exercise group was expected to have an increase in isokinetic strength, but the increase in the ES1 group is in direct contrast to the results of studies performed with the quadriceps muscles.[7,25] A possible explanation for this increase in isokinetic strength may be ascribed to the parameters used in the ES1 group. Stronger muscle contractions were produced in the ES1 group, causing stimulation of perhaps both the slow- and fast-twitch fibers.[8] The significant increase in holding time for both electrical stimulation groups may further confirm that muscle stimulation with these parameters increases endurance of the back muscles. These findings were, however, not confirmed by a change in slope of the analyzed "fatigue index" of the electromyographic data. It has been well documented that power spectrum of surface electromyography during fatigue shifts from high to low frequency.[2,15,16,19] The mechanism of this phenomenon is unclear. During voluntary sustained isometric contractions, an increase in the low-frequency components and a decrease in high-frequency components of spectral density function have been observed. This shift is mainly caused by a decrease in propagation velocity due to accumulation of nonaerobic metabolites.[19,23] MPF and the number of zero crossings are proportional to the propagation velocity.[12,20] The slope of linear regression line for the MPF and number of zero crossings are quantifiable (fatigue index) and did not significantly change for the erector spinae muscles at the L2–L4 levels in our study before and after training. The large standard deviation found among our subjects may explain the fact that back muscles have a varied distribution of muscle fiber types.[14,18] Another explanation may be the lack of knowledge about the recruitment of the erector spinae muscles during such a long test period (up to 5 minutes). Furthermore, our analysis only took into account the first 72 seconds of the test.

The different results obtained in this study from the previous quadriceps studies may also be due in part to the different type of stimulation devices used, subject populations (all female subjects), types of exercises, methods of testing, and treatment programs.

CONCLUSION

The effect of electrical stimulation on back muscle strength and endurance has not been documented previously to our knowledge. This study suggests that with low-frequency electrical stimulation, isokinetic strength and endurance may be significantly increased. This was not true, however, for medium-frequency stimulation.

Electrical stimulation, a passive modality of muscle strengthening, may be better tolerated than exercise for a patient with acute or subacute low-back pain. Electrical stimulation also has the added advantage of providing an anesthetic effect from the stimulation, which may also decrease pain while treatment is being administered. It must be recognized that selective training with electrical stimulation or exercise, or a combination of both, can be used to obtain optimal clinical results. Electrical stimulation may, therefore, become a valuable treatment modality for patients with acute and subacute back pain before beginning an exercise and conditioning program.

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